NATIONAL TRANPORT RESEARCH CENTRE

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RUT RESISTANT MIX DESIGN

NTRC - 218

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EXECUTIVE SUMMARY

The rutting is one of the major causes of failure of flexible pavements in Pakistan. The overloaded trucks traveling at crawling speed with over-inflated tyres seriously damage the pavements when the bitumen becomes softer at ambient temperature in excess of 40 oC. The development of a rut resistant mix design is, therefore, an urgent requirement.

None of the commonly used mix design specifications are entirely satisfactory. The Marshall Method of Mix Design has been widely used which is based on determination of optimum binder content in the mix based on stability, flow, air voids, specific gravity and density. However, research carried out at University of Nottingham has suggested that Marshall test is a poor measure of resistance to permanent deformation. Their research has indicated that at least 3% voids in the mix after compaction to 'Refusal Density' would perform better under heavy traffic loads as compared to the mixes designed under Marshall compaction criteria. The objective of achieving 3% air voids could best be obtained by altering aggregate type, shape and gradation.

The present study has been carried out in the laboratory using local lime stone material from Margalla quarry. Coarse aggregate were used ranging between 2mm to 20 mm. Below 2mm was considered as fine aggregate and Lawrencepur sand consisting 15 - 30% by weight was used for this purpose. The material was oven dried.

Three blends of coarse aggregates were derived by varying gradation of aggregates. The aggregate blends were compacted in 6" diameter mold using vibratory compactor for one minute. The highest density of aggregate mix was achieved with 20% sand and 80% coarse aggregates. The blend is somewhat coarser than the traditionally used having 30 - 40% fines.

Standard Marshall test was run to determine the optimum binder content. Volumetric analysis at optimum binder content revealed that the voids in the mix were 6%. The mix was then subjected to refusal density test, with vibratory compactor operating at frequency of 20 to 50 Hz in a specially designed mould of 6" diameter. Volumetric analysis of the refusal density specimen revealed that an average of 3.15% voids were retained in the mix. The binder content was 4.5 per cent.

Since a rut resistance mix design has been developed in the laboratory, it is recommended that a test section be constructed by NTRC and the mix design procedure be disseminated to all the highway authorities with the recommendation that similar test sections be laid independently in their respective jurisdiction to verify the viability of the mix in the field. The test sections should be monitored jointly by a team of NTRC and respective highway officials for long term performance.

1: INTRODUCTION

None of the commonly used bituminous mix design specifications are entirely satisfactory. An entirely adequate design specification would provide a test procedure that would enable the designer to assess alternative sources of aggregate, alternative gradations of any given aggregate and alternative binder and filler contents and types. It would give the designer a data set from which a quantitative comparison of the resultant mixes could be made. And make it possible for him to determine which mix is best for deformation resistance and which for durability (oxidation and cracking resistance).

We do not have sufficient understanding of the behavior of asphaltic mixes to be entirely sure of the answers to those questions even after performing a battery of research tests. Certainly, there is no design specification that can satisfy these requirements.

The USA has currently spent billions of dollars in Strategic Highway Research Program (SHRP) designed to close the gaps in our understanding. A consequence of SHRP and related research is the developing ability to specify bituminous mixes in terms of mechanical properties which relate to the performance.

Although the Marshall test is very widely used for mix design, the research carried out at the University of Nottingham [1], suggests that the Marshall test is a poor measure of resistance to permanent deformation and may not be able to rank mixes in order of their deformation resistance. Similarly, the people from the University of Nottingham have insisted on the importance of voids in mix (VIM). Cooper, K.E. Brown, SF and Preston [2], have mentioned that voids in mix (VIM) has the greatest effect on the performance of designed mix against the rut formation. The above facts lead to the requirement of developments of producing a new and practical method for mix design.

2: THE PROBLEM

At low temperatures the deformation resistance of asphaltic highway material is dependent upon two factors:

i) The viscous resistance of the bitumen, and

ii) The internal friction arising from the mechanical interlock of the aggregate particles.

At the high temperatures as occurring in pavements in Pakistan, the bitumen is above its softening point and offers little resistance to deformation. Many premature rutting problems have resulted from use of mixes with binder contents that are too high, resulting in compaction under very heavy traffic loading to a state where air voids become dangerously low (less than 1%) and shear resistance declines sharply. This arises because the compaction effort on site applied to a confined layer of material is more effective than that which occurs in the standard 100 mm diameter mold subjected to a Marshall hammer.

3: OBJECTIVES

This report presents the detail application of a mix design procedure first tried by people at "Road Research Center", Kuwait . The aim was to study the new mix design method in detail and to propose its applicability for actual field testing. The method has been applied in the laboratories at NTRC by using local materials and interpreted with the benefit of local experience for adoption in the country.

4: THE DESIGN PROCESS

The stages in the design process are:

i) Choice of the optimum grading of the Coarse Aggregate.
ii) Choice of the optimum Fine Aggregate Content.
iii) Determination of Specific gravity of aggregates.
iv) Choice of the optimum bitumen content & volumetric analysis.
iv) Percentage Refusal Density test & volumetric analysis.

4.1 **Optimizing the Grading of the Coarse Aggregate:** Local lime stone material from Margalla quarry was used. Various fractions required for the mix were dried, sieved and stored separately. For the sake of this study, two assumptions have been made:

a) Maximum size of the Coarse aggregate is 20mm;
b) Division between Coarse and Fine aggregate is 2.0 mm

The grading of the coarse aggregate is expressed by general equation given below:

% passing sieve diameter 'd' = 100x(d-2 .0)/(20-2.0))^ n

where 'n' can be varied to alter the shape of the grading curve. Some examples of the effect of 'n' are tabulated below:

Table - 1 Coarse Aggregate Grading Selection

Coarse Aggregate Grading						
Sieve Diameter	100 *((d-2.0) / (20 - 2.0)) ^ n where n = 0.5 - 1.0					
Mm	0.5	0.6	0.7	0.8	0.9	1.0
20.0	100	100	100	100	100	100
16.0	88	86	84	82	80	78
9.5	65	59	54	50	45	42
5.0	41	34	29	24	20	17
2.0	0	0	0	0	0	0

Samples of coarse aggregate fractions are combined to make up the grading shown above. Each sample of 5500 gms consisting of above grading is compacted in a 6 inches diameter mold under the action of the vibrating hammer for one minute duration. The density of each sample is measured. The optimum coarse aggregate grading is defined as that which gives the maximum density. On the basis of above trials the blend of coarse aggregates with n = 1 has been selected for further testing and its composition is mentioned below:

Table - 2 Final Blend of Coarse Aggregates

Size of Aggregate in mm	Mass Retain (%)
20.0 - 16.0	22
16.0 - 9.50	36
9.50 - 5.0	25
5.0 - 2.0	17
Total	100

4.2 **Determination of Optimum Fine Aggregate**: Samples of coarse aggregate has been made up to the now established optimum grading and various proportions of sand by weight of coarse aggregates (5500 gms) have been mixed into them. Trial proportion of sand from Lawrancepur quarry has been added between 15% & 30% of the weight of coarse aggregate. Again the aggregate blends were compacted in 6 inch mold using the vibratory compactor for one minute and at each percentage of sand the density of mix was noted. The highest density of compacted aggregate mix has been achieved at 25 %. of sand by weight of coarse aggregate. The final blend of aggregates selected for Specific gravity determination is shown below:

Table - 3 Final Blend of Aggregates

Size of Aggregate in	Mass Retain (%)
20.0 – 16.0	18
16.0 – 9.50	29
9.50 - 5.0	20
5.0: - 2.0	13
# 40	20
Total	100

The blend is comprised of 80% coarse and 20 % fine aggregates, which is somewhat coarser than those use traditionally with n = 0.45.

4.3 Determination of Specific Gravity of Aggregates & Bitumen:

Relative densities and water absorption of different sizes of aggregate were found by using wire bucket, jar or pycnometer as per ASTM specifications. All sizes of coarse aggregates were lime stone from Margalla quarry. Table - 4 below show the results:

Table - 4 RELATIVE SPECIFIC GRAVITY & WATER ABSORPTION OF AGGREGATES

AGGREGATE SIZE	MASS (gms)				BULK	S.S.D	APPARENT	ABSORPTION	APPARATUS
	A	B	C	D	D/A-(B-C)	A/A-(B-C)	D/D-(B-C)	100(A-D)/D	
20.0 - 16.0 mm	3697.0	0.0	0.0	3675.0	2.67	2.68	2.71	0.60	Bucket
16.0 - 9.5 mm	3488.0	0.0	0.0	3457.0	2.65	2.67	2.71	0.90	Bucket
9.5 - 5.0 mm	503.2	954.8	640.4	500.0	2.65	2.66	2.69	0.65	JAR
5.0 - 2.0 mm	503.5	982.6	667.8	500.0	2.65	2.67	2.70	0.69	JAR
Pass # 40	508.0	947.5	641.8	500.0	2.47	2.51	2.57	1.60	PYCNOMETER

A = Mass of Saturated Surface Dried Aggregate
B = Mass of Jar + Aggregate + Water
C = Mass of Jar + Water
D = Mass of Oven Dried Aggregate

Relative density of bitumen was obtained from Shell handbook wherein it is quoted as 1.02 to 1.03 for the 70 dmm of penetration grade bitumen. Effective relative density of individual size of aggregate was taken as average of saturated surface dry and apparent relative densities. The bulk and effective relative densities of the combined aggregates were calculated by using the percentage by weight of each size to work out the weighted averages. Using these densities, the bitumen absorption was worked out by the formula:

$$Pba = \{ 100 * [Gse - Gsb] / [Gse * Gsb] \} * Gb$$

Where Pba is the bitumen absorption (by weight of aggregate), Gse is effective relative specific gravity and Gsb is effective bulk specific gravity of the combined aggregates, Gb is the specific gravity of bitumen.

Table - 5 EFFECTIVE RELATIVE SPECIFIC GRAVITY OF AGGREGATES & BITUMEN ABSORPTION

SIZE OF AGGREGATE	MASS RETAIN (%)	BULK SP.GRVTY	S.S.D SP.GRVTY	APPARENT SP.GRVTY	AVERAGE	EFFECTIVE BULK SP.GRVTY	EFFECTIVE RELATIVE SP.GRVTY	BITUMEN ABSORPTION (%)
20.0 - 16.0 mm	18	2.67	2.68	2.71	2.687	2.615	2.646	0.45
16.0 - 9.5 mm	29	2.65	2.67	2.71	2.679			
9.5 - 5.0 mm	20	2.65	2.66	2.69	2.670			
5.0 - 2.0 mm	13	2.65	2.67	2.70	2.675			
Pass # 40	20	2.47	2.51	2.57	2.520			

4.4 **Determination of Binder Content & Volumetric Analysis**: The binder used in the mix design was 70 - 80 penetration grade bitumen from Attock Refinery which had penetration of 72 dmm and softening of 50 oC with penetration Index of +1. Asphalt samples have been made containing the chosen aggregate grading and 3.5, 4.0 , 4.5 & 5% of the bitumen by the weight of mix. The mix has been compacted by the Marshall's hammer by applying 75 blows at each side on the resulted specimens. Percentage volume of aggregate in Marshall specimens were determined by using the Effective Bulk relative specific gravity of the combined aggregate and that of the Marshall specimen by Archimides principal. Table-6 presents the densities of compacted mix at different bitumen contents. While Table-7 show volumetric analysis.

Table - 6 COMPACTED DENSITY OF MARSHALL SPECIMENS

Bitumen (%) By Weight of Mix	Specimen NO	Weight of Specimen in air (gms)	Weight of Specimen in Water (gms)	Volume of Specimen (cc)	Compacted Mix Density (gms/cc)	Average Compacted Mix Density (gms/cc)
3.5	1	1330	745	585	2.274	
	2	1330	740	590	2.254	
	3	1328	742	586	2.266	2.265
4.0	4	1305	732	573	2.277	
	5	1306	731	575	2.271	
	6	1310	735	575	2.278	2.276
4.5	7	1325	751	574	2.308	
	8	1333	758	575	2.318	
	9	1341	764	577	2.324	2.317
5.0	10	1351	762	589	2.294	
	11	1311	738	573	2.288	
	12	1352	758	594	2.276	2.286

Table - 7 VOIDS ANALYSIS OF MARSHALL SPECIMENS

Bitumen (%) By Weight of Mix	Specimen NO.	CDM (gms/cc)	Average CDM (gms/cc)	CDMA (gms/cc)	Average CDMA (gms/cc)	Average MIX SGM Theory	VIM Theory	VMA Theory
3.5	1	2.274		2.194				
	2	2.254		2.175				
	3	2.266	2.265	2.187	2.185	2.508	9.71	17.41
4.0	4	2.277		2.186				
	5	2.271		2.180				
	6	2.278	2.276	2.187	2.184	2.490	8.61	17.45
4.5	7	2.308		2.204				
	8	2.318		2.214				
	9	2.324	2.317	2.219	2.212	2.472	6.27	16.39
5.0	10	2.294		2.179				
	11	2.288		2.174				
	12	2.276	2.286	2.162	2.172	2.454	6.83	17.93

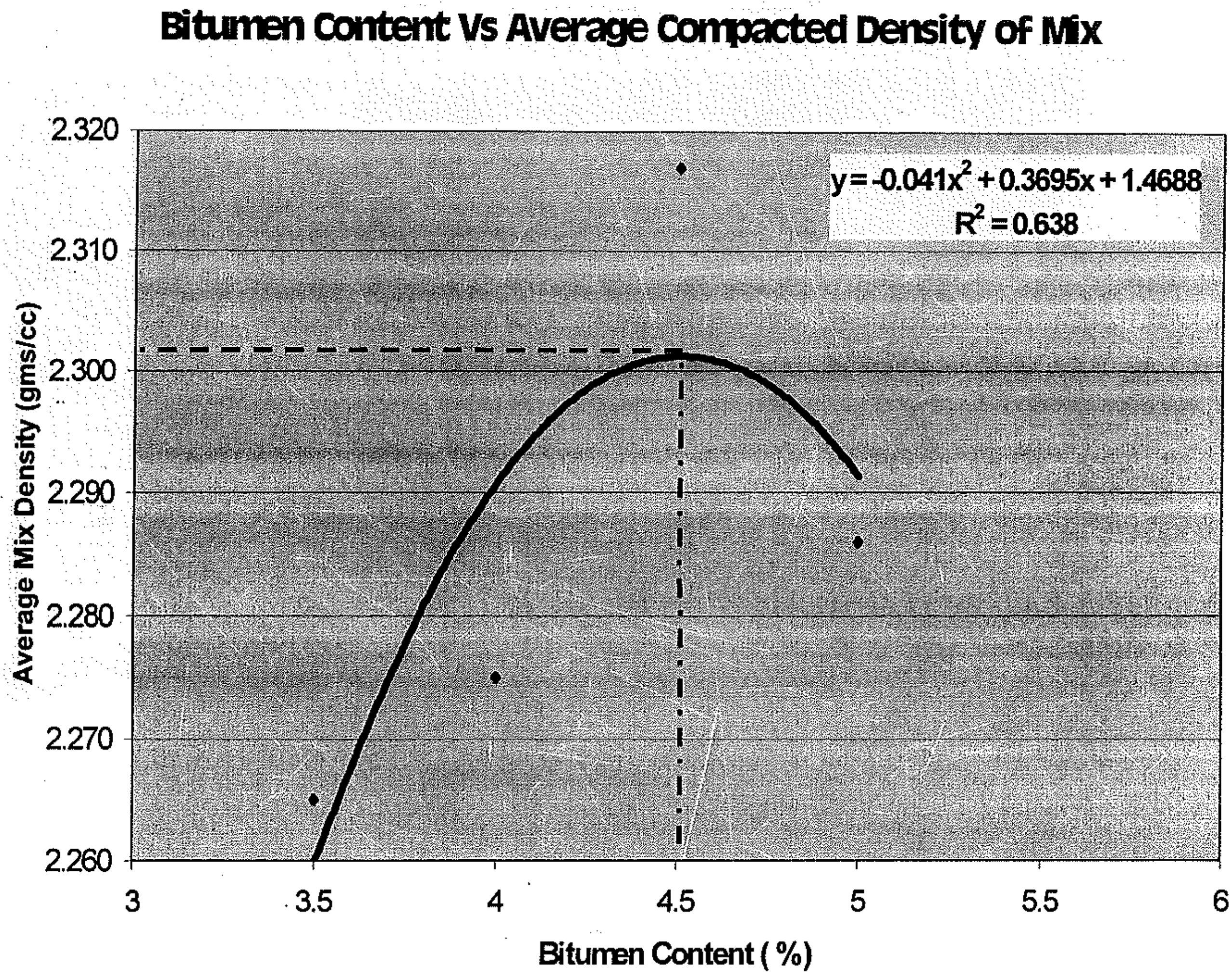
Percentage (effective) volume of bitumen was also determined in the same way by using the effective bitumen content which is the total bitumen content less bitumen absorption. Net air voids (VIM) thus worked out after finding the percentage (effective) volume of bitumen and percentage of aggregate in the Marshall specimen.

Table - 8 AIR VOIDS IN MIX BY CONSIDERING BITUMEN ABSORPTION

BITUMEN CONTENT (%) BY WEIGHT OF MIX	EFFECTIVE BITUMEN CONTENT (%)	SPECIMEN NO.	CDM (gms/cc)	Average CDM (gms/cc)	VOLUME OF BITUMEN (%)	VOLUME OF AGGREGATE (%)	AIR VOIDS IN MIX (%)
3.5	3.05	1	2.274		6.71	82.59	10.70
		2	2.254				
		3	2.266	2.265			
4.0	3.55	4	2.277		7.84	82.56	9.61
		5	2.271				
		6	2.278	2.275			
4.5	4.05	7	2.308		9.11	83.61	7.28
		8	2.318				
		9	2.324	2.317			
5.0	4.55	10	2.294		10.10	82.07	7.83
		11	2.288				
		12		2.286			

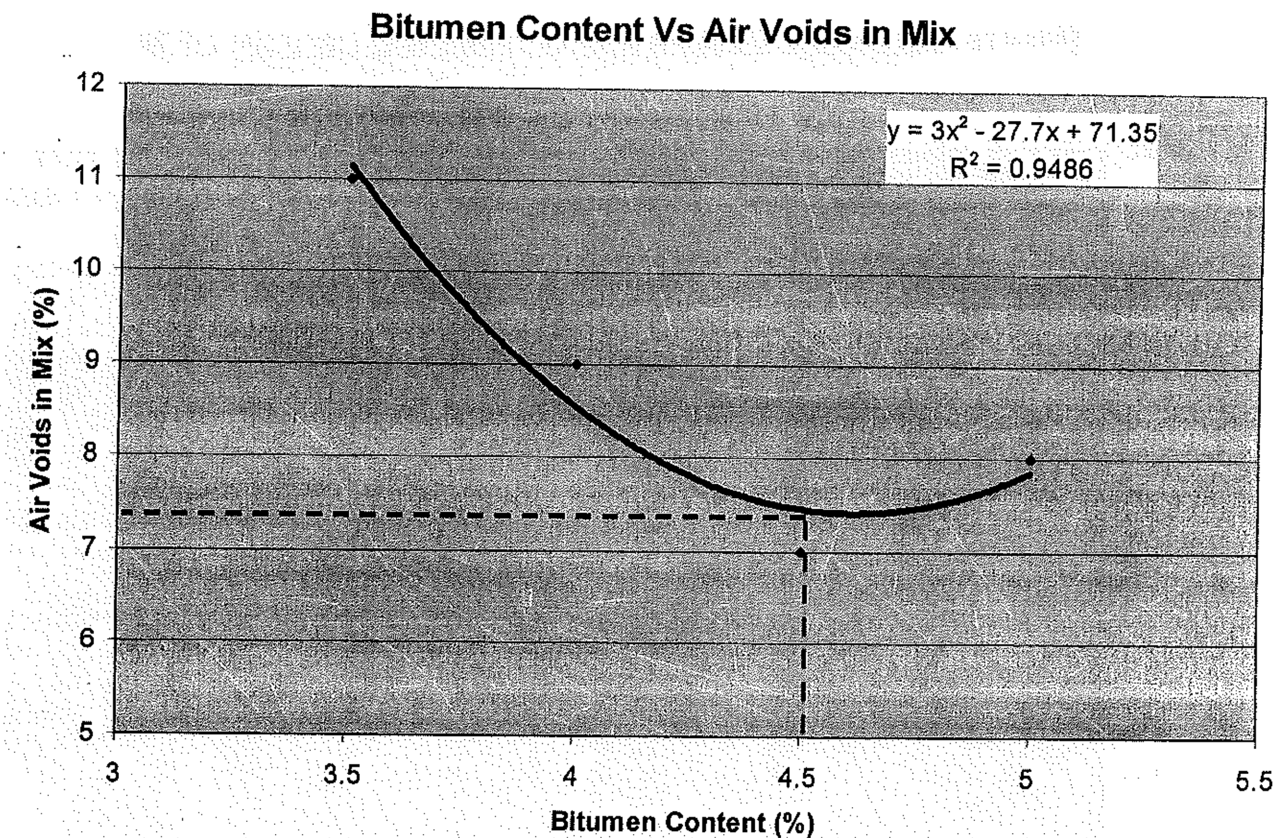
A graph has been plotted between the bitumen content by weight of mix and the compacted density at Figure -1. The binder content resulted the highest compacted density would be chosen further analysis.

Figure -1



Similarly a graph is prepared between the bitumen content and the Air Voids in mix at Figure - 2.

Figure - 2



On the basis of above analysis the optimum bitumen content by percentage of the mix weight selected is 4.5 %. At the optimum binder content, the mix has achieved the maximum compacted density equal to 2.302 gms/cc. Similarly the air voids in the mix (by considering the bitumen absorption) has achieved a value of 7.5 %, which is acceptable as per the MS-2 recommendations.

4.5 **Percentage Refusal Density test & volumetric analysis**: The binder content corresponding to 7.5 percent VIM in the Marshall test has been noted which is 4.5 % in our case and the percentage refusal density test has applied for further analysis. For this purpose an especially design mold of 6 inches diameter and a vibratory hammer is used. Figure - 3 shows the equipment. The electric vibrating hammer should have a power consumption of 750 watts or more and operate at a frequency of 20 to 50 Hz. Two tamping feet are used, one with a diameter of 102 mm and other 146 mm. Samples should be mixed so that they can be compacted immediately afterwards at an initial temperature of 140 ± 5 oC for 80/100 penetration grade bitumen or 145±5 o C of 60/70 penetration grade bitumen.

Figure - 3

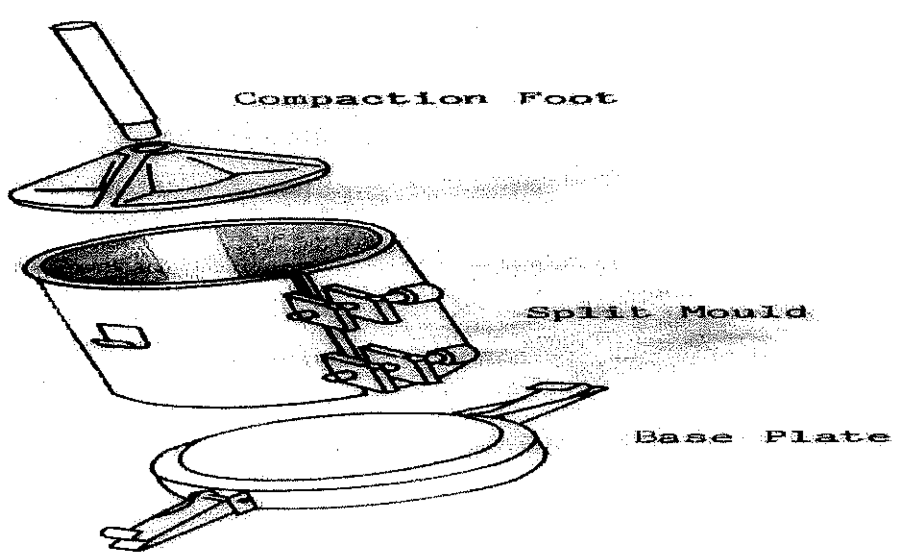


Table - 9 & 10 show the voids analysis of the specimens compacted at the refusal density.

Table - 9 VOIDS ANALYSIS OF REFUSAL SPECIMENS

BITUMEN CONTENT (%)	SPECIMEN NO.	CDM (gms/cc)	AVERAGE CDM (gms/cc)	CDMA (gms/cc)	AVERAGE CDMA (gms/cc)	MIX SGM THEORY	VIM THEORY	VMA
4.5	1	2.395		2.287				
	2	2.399		2.291				
	3	2.410	2.401	2.302	2.293	2.472	2.84	13.33

Table - 10 AIR VOIDS IN MIX BY CONSIDERING BITUMEN ABSORPTION & COMPACTED TO REFUSAL

BITUMEN (%)BY WEIGHT OF MIX	EFFECTIVE BITUMEN CONTENT (%)	SPECIMEN NO.	CDM (gms/cc)	AVERAGE CDM (gms/cc)	VOLUME OF BITUMEN (%)	VOLUME OF AGGREGATE (%)	AIR VOIDS IN MIX (%)	VOIDS FILL WITH BITUMEN (%)
4.5	4.05	1	2.395		9.44	86.67	3.89	73
		2	2.399					
		3	2.410	2.401				

The method assures that the Voids in Mix (VIM) at refusal density should be equal to 3%. In this way, the present study of improvement of mix to overcome rutting problem is based on selection of mix ingredients materials i.e. coarse and fine aggregate and mixing and compacting them to such an extent that after refusal, the voids in mix (VIM) are 3% and voids filled with bitumen (VFB) are not more than 80% of voids in mineral aggregates (VMA). The whole theme is that mixes draws its strength from within its constituent's selection in an engineered manner.

5: CONCLUSION AND RECOMMENDATIONS

This mix design exercise, carried out using a limestone aggregate and asphalt cement from Attock Refinery, suggested that, for these components, an coarse aggregate gradation based on a curve with n=1 exponent and with 25% sand by weight of coarse aggregate and a bitumen content of 4.5%, would give satisfactory end product if adequate compacted. The mix assures air voids of 3% at the refusal. Observing the results obtained from the exercise, it is recommended that the mix should actually be applied on road section and monitoring its long term performance under traffic should be carried in order to cope the problem of pre-mature failure of pavement due to rutting in the country.

5.1 **Construction of Test Sections:** The final gradation of the mix designed in the present study comprises of 80% coarse materials and 20% final which is relatively coarser than the traditionally used gradation comprising of 60 - 70% coarse and 30 - 40% fines. It is expected that the mix designed in NTRC laboratories would provide resistance against rutting. Therefore, it is recommended that test sections of appropriate length be laid by different road building agencies such as NHA, CDA and Provincial C&W Departments using the rut resistance mix and its long term performance be monitored.

5.2 **Refusal Density Design Procedure:** The study in NTRC laboratories has been carried out using the latest design approach namely: "Refusal Design Procedure" which is based on the British Standard Test Procedure namely; BS598 Part 104 (1989). The method is appropriate for sites, which are subject to severe loading. The research has shown that it is desirable to retain a minimum of Voids in Mix of 3% in order to minimize the risk of plastic deformation. The details of Refusal Density Design Procedure are given at Appendix-A.

5.3 **Effect of Vibratory Compaction on Particles Orientation:** With a view to evaluate the effect of vibratory compaction on particle orientation and carrying out extraction/gradation test on the samples prepared with the vibratory compaction has checked for breaking of edges. There was no significant difference observed in gradation of particles compacted under normal compacted efforts as compared to the vibratory compaction. Similarly, there was no significant effect observed of breaking of edges of aggregate particles under vibratory compaction. However, when test section would be laid the actual performance of the mix and its constituent materials such as aggregate particles and the effect of trafficking on them would be observed/tested in the field as well as in the laboratory for establishing a realistic affect of such factors.

5.4 **Wheel Tracking Test on Rut Resistance Mix:** In order to test the mix developed in the laboratory using Wheel Tracking Machine, it is recommended to run a separate experiment. Two different test samples would be prepared one with the conventional gradation and determining the optimum binder content with the Marshall Method of Mix Design and the second sample with the mix procedure developed under the study. The samples are proposed to test under Wheel Tracking Machine for determining rutting potential. This experiment would further explain the characteristics of the mix designed in the present study.

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Appendix-A

REFUSAL DENSITY DESIGN

1 : Introduction

Some authorities have adopted a procedure of extended Marshall compaction to design asphalt, which will retain required minimum voids in the mix (VIM), after secondary compaction by traffic. An alternative method based on an extended form of the compaction procedure used in the Percentage Refusal Density (PRD) Test (BS 598 Part 104 (1989)) uses a vibrating hammer for compaction. These methods are appropriate for sites which are subject to severe loading where research shows that it is desirable to retain a minimum VIM of three per cent to minimise the risk of failure by plastic deformation. Neither method exactly reproduces the mode of compaction which occurs under heavy traffic but the latter procedure is both quicker and more representative. There are no national or international standards for these procedures and therefore they are both likely to be subject to further development.

2 : Extended Marshall Compaction

For severe sites, the base-course specifications, BC1 and BC2, given in Table 8.4 and Table 8.7 are likely to be the most appropriate. The normal Marshall design procedure using 75 blows on each face should be compacted first to provide an indication that Marshall design parameters will be met.

The binder content corresponding to 6 per cent VIM obtained in the Marshall test should be noted and additional test samples prepared at each of three binder contents, namely the binder content corresponding to 6 per cent VIM and also binder contents which are 0.5 per cent above and 0.5 per cent below this value. These samples must be compacted to refusal.

The number of blows required to produce a refusal condition will vary from one mix to another. It is preferable to conduct a trial using the lowest binder content and to compact using an increasing number of blows, say 200, 300, 400, etc until no further increase in density occurs. Usually 500 blows on each face is found to be sufficient.

By plotting a graph of VIM at the refusal density against binder content the design binder content which corresponds to VIM of 3 per cent can be determined. This value should be obtained by interpolation, not by upwards or downwards, as appropriate, to permit this.

3 : Extended Vibrating Hammer Compaction

3.1 **Laboratory Design Procedure:** In the vibrating hammer method the samples are compacted in 152-153 mm diameter moulds to a thickness approximately the same as will be laid on the road. The BS 598 compaction procedure for the PRD test is repeated for as many cycles as are necessary to achieve an 'absolute' refusal density. The electric vibrating hammer should have a power consumption of 750 watts or more and operate at a frequency of 20 to 50 Hz. Two tamping feet are used, one with a diameter of 102 mm and the other of 146 mm. Samples should be mixed so that they can be compacted immediately afterwards at an initial temperature of 140 $\pm$ 5 C for 80/100 penetration grade bitumen or 145 $\pm$ 5 C for 60/70 penetration grade bitumen.

The moulds and tamping feet must be pre-heated in an oven before starting the test. If the mould is of sufficient depth, a close fitting steel disk can be used as a spacer. After pre-heating, this will assist in maintaining the sample at the required temperature. Cooling of the sample by as much as 15 to 20 C during compaction should not prevent achievement of the correct refusal density. The small tamping foot is used of most of the compaction sequence. The hammer must be held firmly in a vertical position and moved from position to position in the prescribed order, i.e. using the points of a compass. To identify the position, the order should be N,S,W,E,NW,SE,SW,NE or equivalent. At each point, compaction should continue for between 2 and 10 seconds, the limiting factor being that material should not be allowed to 'push up' around the compaction foot. The compaction sequence is continued until a total of 2 minutes $\pm$ 5 seconds of compaction time has been reached. The large tamping foot is then used to smooth the surface of the sample.

A spare base-plate, previously heated in the oven, is placed on top of the mould, which is then turned over. The sample is driven to the new base plate with the hammer and large tamping foot. The compaction sequence is then repeated. It may be possible to use the heated steel disc, or a spare disc, for alternate compaction cycles to maintain the mix temperature. The free base plate and disc should be returned to the oven between compaction cycles.

This is the standard PRD compaction procedure but to ensure that the refusal density is reached, it may be necessary to repeat this procedure two or three times for the initial tests. It is suggested that trial mixes with a bitumen content which corresponds to approximately 6 per cent VIM in the Marshall test, are used to

i) Determine the mass of material required to give a compacted thickness of approximately the same thickness as for the layer on the road

ii) Determine the number of compaction cycles, which will ensure that absolute refusal density, is achieved.

After these tests have been completed, samples are made with bitumen contents starting at the Marshall optimum and decreasing in 0.5 per cent steps until the bitumen content at which 3 per cent voids is retained at absolute refusal density can be determined.

3.2 Transfer of laboratory design to compaction trials: After the standard PRD compaction cycles, test samples of base-course or roadbase which have been compacted from the loose state can be expected to have densities between 1.5 and 3 per cent lower than of the same material compacted in the road but cored out and subjected to the PRD test. This is an indication of the effect of the different compaction regime and is caused by a different resultant orientation of particles. The differences between the densities for laboratory and field samples after refusal compaction should be measured to confirm whether this difference occurs.

A minimum of three trial lengths should be constructed with bitumen contents at the laboratory optimum for refusal density (3 per cent VIM) and at 0.5 per cent above and 0.5 per cent below the optimum. These trials should be used to

i) Determine the rolling pattern required to obtain a satisfactory density

ii) Establish that the mix has satisfactory workability to allow a minimum of 93 per cent of PRD (standard compaction (BS598:1989)) to be achieved after rolling

iii) Obtain cores so that the maximum binder content which allows at least 3 pr cent VIM to be retained at refusal density can be confirmed.

For a given aggregate and grading, cores cut from the compacted layer can be expected to give a constant value of voids in the mineral aggregate (VMA) at the refusal density, irrespective of bitumen content. This will allow a suitable binder content to be chosen to give a minimum of 3 per cent VIM at refusal density.

A minimum of 93 per cent and a mean value of 95 per cent of the standard PRD density is recommended as the specification for or density on completion of compaction of the layer. From these trials and the results of laboratory tests, it is then possible to establish a job mix formula. This initial procedure is time consuming, but is justified by the long term savings in extended pavement service life that can be obtained. After this initial work, subsequent compliance testing based on analysis of mix composition and refusal density should be quick, especially if field compaction can be monitored with a nuclear density gauge.

It is essential to provide a surface dressing for the type of base-course mixes which are best suited to these severe conditions. This protects the mix from severe age hardening during the period when secondary compaction occurs in the wheelpaths, and also protects those areas which will not be trafficked and are likely to retain air voids above 5 per cent.

4 : Possible Problems with the Test Procedures

Multi-blow Marshall compaction and vibratory compaction may cause breakdown of aggregate particles. If this occurs to a significant extent then the test is unlikely to be valid.

Because of the time taken to complete the Marshall procedure, considerable care must be taken to prevent excessive cooling of the sample during compaction.

It is important to note that the different particle orientation produced by these compaction methods, in comparison with that produced by roller compaction, limits the use of samples prepared in these tests to that of determining VIM at refusal. It would be unwise to use samples prepared in this way of fatigue or creep tests.