On Bituminous Mix Design

Animesh Das[1]

Abstract: Bituminous mix design is a delicate balancing act among the proportions of various aggregate sizes and bitumen content. For a given aggregate gradation, the optimum bitumen content is estimated by satisfying a number of mix design parameters. This article briefly discusses the current approaches in bituminous mix design and singles out the issues involved.

Introduction

Construction of highway involves huge outlay of investment. A precise engineering design may save considerable investment; as well a reliable performance of the in-service highway can be achieved. Two things are of major considerations in this regard – pavement design and the mix design. The present article emphasizes on the mix design considerations.

A good design of bituminous mix is expected to result in a mix which is adequately (i) strong (ii) durable (iii) resistive to fatigue and permanent deformation (iv) environment friendly (v) economical and so on. A mix designer tries to achieve these requirements through a number of tests on the mix with varied proportions and finalizes with the best one. This often involves a balance between mutually conflicting parameters. The present article tries to identify some of the issues involved in this *art* of bituminous mix design and the direction of current research.

Evolution of mix design concepts

During 1900's, the bituminous paving technique was first used on rural roads – so as to handle rapid removal of fine particles in the form of dust, from Water Bound Macadam, which was caused due to rapid growth of automobiles [Roberts et al. 2002]. At initial stage, heavy oils were used as dust palliative. An eye estimation process, called *pat test*, was used to estimate the requisite quantity of the heavy oil in the mix. By this process, the mixture was patted like a pancake shape, and pressed against a brown paper. Depending on the extent of stain it made on the paper, the appropriateness of the quantity was adjudged [Roberts et al. 2002]. The first formal mix design method was Habbard field method, which was originally developed on sand-asphalt mixture. Mixes with large aggregates could not be handled in Hubbard field method. This was one of the limitations of this procedure. Fransis Hveem, a project engineer of California Department of Highways, developed the Hveem stabilometer (1927). Hveem did not have any prior experience on judging the *just right* mix from its colour, and therefore decided to

[1] Assistant Professor, Department of Civil Engineering, IIT Kanpur, 208 016. INDIA, e-mail: adas@iitk.ac.in

measure various mix parameters to find out the optimum quantity of bitumen [Vallerga and Lovering 1985]. Hveem used the surface area calculation concept (which already existed at that time for cement concrete mix design), to estimate the quantity of bitumen required [Hveem 1942]. Moisture susceptibility and sand equivalent tests were added to the Hveem test in 1946 and 1954 respectively [Roberts et al. 2002]. Bruce Marshall developed the Marshall testing machine just before the World War-II. It was adopted in the US Army Corpes of Engineers in 1930's and subsequently modified in 1940's and 50's.

Selection of mix constituents

Binder and aggregates are the two main constituents of bituminous mix. This section discusses some of the issues involved in selection of binder and aggregates.

Binder

Generally binders are selected based on some simple tests and other site-specific requirements. These tests could be different depending of the type of binder *viz.* penetration grade, cutback, emulsion, modified binder etc. For most of these tests, the test conditions are pre-fixed in the specifications.

Temperature is an important parameter which affects the modulus as well as the aging of binder. Superpave specifications [Superpave 1997, 2001] suggest that these acceptability tests are to be carried out at the prevalent field temperatures, not in a laboratory specified temperature. This is an important consideration because, binder from two different sources may show same physical properties at a particular temperature, but their performances may vary drastically at other temperatures. In Superpave specifications, therefore, only the acceptable test values are recommended, and not the test temperatures. The temperature values are found out from the most prevalent maximum and minimum temperatures at the field at a given probability level. Rolling Thin Film Oven Test (RTFO), Pressurized Aging Vessel (PAV), Dynamic Shear Rheometer, Rotational Viscometer, Bending Beam Rheometer, Direct Tension Tester are some of the tests recommended in Superpave binder selection [Superpave 1997, 2001].

Aggregate

Number of tests are recommended in the specifications to judge the properties of the aggregates, e.g. strength, hardness, toughness, durability, angularity, shape factors, clay content, adhesion to binder etc. Angularity ensures adequate shear strength due to aggregate interlocking, and limiting flakiness ensures that aggregates will not break during compaction and handling.

Theoretically, it is difficult [Senov 1987, Aberg 1996] to predict the aggregate volumetric parameters, even the resultant void ratio, when the gradation curve is known. The Fuller's experimental study for minimum void distribution [Fuller and Thompson 1907] still forms the basis of these exercises. Strategic Highway Research Program (SHRP), USA formed a 14 member Expert Task Group for evolution of appropriate aggregate gradation to be used for Superpave. The group, after several rounds of discussions decided to use 0.45 power Fuller's gradation as the reference gradation, with certain restricted zones and control points. The restricted zone and control points are incorporated in order to ensure certain proportion of fines for (i) proper interlocking of aggregates (ii) to avoid the fall in shear strength of mix due to excess of fines and (iii) to maintain requisite Voids in Mineral Aggregates (VMA). These control points and restriction zones are more as guidelines for selecting a gradation than a compulsion to be followed.

A large number of researches have been reported which have studied performances of various alternative gradations. In India also some studies [Das et al. 2004] have been carried out on various non-standard gradations to see whether the resultant mixes show better performance than the standard mixes.

Role of mix volumetric parameters

Bitumen holds the aggregates in position, and the load is taken by the aggregate mass through the contact points. If all the voids are filled by bitumen, then the load is rather transmitted by hydrostatic pressure through bitumen, and strength of the mix therefore reduces. That is why stability of the mix starts reducing when bitumen content is increased further beyond certain value.

During summer season, bitumen melts and occupies the void space between the aggregates and if void is unavailable, bleeding is caused. Thus, some amount of void is necessary to provide by design in a bituminous mix, even after the final stage of compaction. However excess void will make the mix weak from its elastic modulus and fatigue life considerations. The chances of oxidative hardening of bitumen are more, where, the mix has more voids.

Evaluation and selection of aggregate gradation to achieve minimum VMA is the most difficult and time-consuming step in the mix design process [Anderson and Bahia 1996]. VMA specification has always been a big issue in mix design specifications. The recommendation of minimum VMA is sometimes questioned by the researchers, and is said not to be equitable across different gradations. It is seen that the bitumen film thickness, rather than the VMA, may be related to durability of the mix [Kandhal 1998].

Various mix design approaches

There is no unified approach towards bituminous mix design, rather there are a number of approaches, and each has some merits are demerits. Table-1 summarizes [RILEM 17 1998] some of the important bituminous mix design approaches:

Table-1 Various mix design approaches [RILEM 17 1998]

Mix design method	Description
Recipe method	Recipe based on experience of traditional mixes of known composition. This is experience based approach, which has shown good performance over long period of time, and under given site, traffic and weather conditions.
Empirical mix design method	In empirical mix design method, optimization of several variables are done by mechanical empirical test, taking into account some specifications as limits which evolved through prior experience. Variables considered in this approach may not be used as direct measures of performance.
Analytical method	The analytical method does not consider preparation of any physical specimen. Composition is determined exclusively through analytical computations.
Volumetric method	In volumetric method, proportional volume of air voids, binder and aggregates are analyzed in a mixture, which is compacted in the laboratory by some procedure close to field compaction process.
Performance related approach	In performance related mix design, the specimens that meet volumetric criteria are compacted and tested with simulation and/or fundamental tests to estimate their properties that are related to pavement performance.
Performance based approach	Performance based approach is something which is based on the performance of the complete system. Laboratory instrumentation tends to simplify the situation, yet it is indeed difficult to simulate field conditions. Superpave mix design recommends use of Supepave shear tester, indirect tensile tester for evaluation of laboratory of the bituminous mix. These tests are basically accelerated performance tests of bituminous mixes.

Various countries have adopted various mix design approaches, which have been evolved through individual experiences. Most of the time these do not follow a particular approach as enlisted in Table-1, rather use a combined approach. Some of these mix design approaches followed in various specifications may be summarized in Table-2 [RILEM 17 1998].

Table-2 Mix design approaches adopted in various specifications/ organizations [RILEM 17 1998]

Specification/ organization	Country	Category
NARC'96-I-III	Australia	Recipe/ Volumetric/ Performance related
ASTO/ PANK'95	Finland	Recipe/ Volumetric/ Performance related
AFNOR	France	Recipe/ Volumetric/ Performance related
DIN	Germany	Recipe/ Empirical
CROW	The Netherlands	Volumetric/ Performance related
BS 594 / 598	UK	Recipe/ Empirical
Asphalt Institute	USA	Empirical/ Volumetric
SHRP Superpave	USA	Volumetric/ Performance related / Performance based

Recent trends

As obvious from the above discussion, the recent emphasis on bituminous mix design is on performance related and performance based approaches. The requirement of a good mix design has changed from time to time. Table-3 gives some idea of how the mix design requirements have changed from past to present.

Table-3 Requirements of bituminous mix design

Past	Present
Stability Durability Economy	Stiffness Permanent deformation Fatigue Temperature susceptibility Low temperature cracking Moisture susceptibility Freeze-thaw Permeability Economical Environment friendly Workability Economy

Some of the above requirements are sometimes mutually conflicting. For, example, the higher is the bitumen content, the better is the fatigue life, provided all the other parameters are kept unchanged. But with the increase of bitumen content, the resistance to rutting may decrease. Increase in bitumen content not accompanied by adequate amount of air voids will result in the fall of stability of the mix, the chances of bleeding will increase. The only way to increase bitumen content keeping sufficient air voids (VA) is by maximizing VMA and suitably gradation can be designed.

Heavy duty bituminous pavements are composed of bituminous binder course and wearing course, for example, Dense Bituminous Macadam (DBM) and BC [MORT&H 2001], as per Indian specification. Same grades of bitumen are generally used for construction of these layers. Generally same grades of bitumen are used for construction of these layers. Stiffer grade of bitumen has higher value of stiffness, and it causes lesser stains to the pavement layers and also it is expected to show lesser rutting. On the other hand, higher fatigue life as observed for bituminous mixes with softer grade of bitumen [Das 1998], indicates greater longevity of the pavement against fracture. It can be shown computationally [Das and Pandey 2000, Das 2004] that if a pavement is constructed with softer grade of bitumen at the lower layer, and harder grade at the top layer, the pavement is expected to last longer, than a pavement constructed with same grades for both the layers – this technique is known as rich-bottom pavement construction [Harvey et. al. 1997, Monismith 2001] in other countries.

Discussions

The present article has discussed some of the considerations involved in bituminous mix design. The complex behaviour of bituminous mixes and its relationship with volumetric parameters are not fully understood; as of now, the bituminous mix design largely depends on the laboratory experiments and its performance on the in-service roads is difficult to predict. The Marshall test is a popular mix design approach, possibly due to its simplicity and low cost. The Superpave recommendations have rationalized the concepts of bituminous mix design to a great extent, however, it involves evaluation of mix properties through a number of costly equipment. But, some of the concepts, for example, development of statistical specifications of binder and aggregate, considerations of mix performances with reference to fatigue, rutting and other parameters could be verified before finalizing the mix proportions. It is possibly the need of the day to develop a sequential mix design protocol at various levels of significances. With the development various of special purpose mixes, mixes with modified bitumen, perpetual pavement, rich bottom pavement etc – it is expected that in future days, the mix design and structural pavement design together will develop to be an integrated approach.

References

Aberg, B., (1996). "Void sizes in granular soils", *Journal of Geotechnical Engineering*, ASCE, Vol. 122, No. 3, pp. 236-239.

Anderson, R. M. and Bahia, H. U., (1996). "Evaluation and selection of aggregate gradations for asphalt mixtures using Superpave", *Transportation Research Record*, 1583, TRB, National Research Council, Washington, D. C., pp.75-79.

Das, A., (1998). *Analytical design of bituminous pavements based on field performance*, unpublished PhD thesis, Civil Engg. Dept., IIT, Kharagpur.

Das, A., and Pandey, B. B., (2000). "Economical design of bituminous pavements with two grades of bitumen in the surfacing", *Seminar on Road Financing, Design, Construction and Operation of Highways in 21st Century*, 24th and 25th September, IRC, pp.II-35-II-42.

Das, A., (2004). "Some suggestions to improve the Mechanistic-Empirical bituminous pavement design in Indian context", *Proceedings of 1st International Symposium on Design and Construction of Long Lasting Asphalt Pavements*, June 7-9, Auburn, pp.199-215.

Das, A., Deol, M. S., Ohri, S. and Pandey, B. B., (2004). "Evolution of non-standard bituminous mix – a study on Indian specification", *The International Journal of Pavement Engineering*, Vol 5(1), pp. 39-46.

Fuller, W. B., and Thompson, S. E., (1907). "The laws of proportioning concrete", *Transactions of ASCE*, ASCE, Vol. 59, pp.67-143.

MORT&H Specifications for Roads and Bridge Works, 4th Revision, (2001). Ministry of Surface Road Transport and Highways, Government of India, published by IRC.

Monismith, C. L., Long F. and Harvey, J. T. (2001). “California’s interstate-710 rehabilitation : Mix and structural section designs, construction specifications”, *Journal of the Association of Asphalt Paving Technologists*, Vol.70, pp.762-799.

Harvey, J. T., Deacon, J. A., Taybali, A. A., Leahy, R. B. and Monismith, C. L., (1997). “A reliability based mix design and analysis system for mitigating fatigue distress”, *Proceedings 8th International Conferences on Asphalt Pavements*, Seattle, WA, August, pp.301-324.

Hveem, F. N., (1942). “Use of CKE as applied to determine the required soil content for dense graded bituminous mixtures”, *Journal of Association of Asphalt Paving Technologists*, Vol. 13, pp.9-40.

Kandhal, P. S., Foo, K. Y. and Mallick, R. B., (1998). “Critical review of voids in mineral aggregate requirements in Superpave”, *Transportation Research Record* 1609, Transportation Research Board, National Research Council, Washington, D. C., pp. 21-27.

RILEM Report 17, Bituminous Binders and Mixes, (1998). Editor: L. Francken, E & FN Spon, London.

Roberts, F. L., Mohammad, L. N. and Wang, L. B. (2002). “History of hot mix asphalt mixture design in the United States”, *Journal of Materials in Civil Engineering*, ASCE, pp. 279-293.

Sennov,. V. A., (1987). “Theory of use of granulated materials in road construction”, *Transportation Research Record*, 1119, National Research Council, TRB, Washington, D. C., pp. 1-10.

Superpave Performance Grade Asphalt Binder Specification and Testing, (1997). 2nd Edition, The Asphalt Institute.

Superpave Mix Design, Asphalt Institute, Superpave, Series No. 2, 3rd Edition, 2001.

Vallerga, B. A., and Lovering, W. R., (1985). “Evolution of Hveem stabilometer method of designing asphalt paving mixtures”, *Journal of the Association of Asphalt Paving Technologists*, Vol. 54, pp.243-265.