

## IMPROVED INDONESIAN PROCEDURE FOR ASPHALT DESIGN

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**abstract:** In the past Asphaltic Concrete wearing courses on Indonesian roads frequently suffered premature failure by cracking. In contrast Road Asphalt surfacings made to current specifications commonly fail prematurely by plastic deformation. Densification of mix, under heavy traffic, reduces voids in the mix (VIM) to a point where the mortar of bitumen and very fine aggregate begin to carry more of the imposed traffic stresses. Data are presented to confirm that this must be expected if the VIM drop below 3%. A mix procedure is described that supplements Marshall design with compaction to refusal. Mix design criteria are presented to prevent plastic rutting and to optimise mix durability.

### 1. INTRODUCTION

In Indonesia the traditional method of improving an earth track has been 'Telford' type construction. Once traffic levels were high enough to justify further improvement, the Telford was usually overlaid using Penetration Macadam. However, the ride quality was poor which severely limited vehicle speeds and the roads required frequent maintenance.

In the 1970's and early 1980's, a large proportion of Java's busier roads were overlaid with asphaltic concrete (AC). Riding quality was vastly improved but the AC often failed, prematurely, by cracking or ravelling. It was clear that the flexibility and durability of the mixes needed to be improved and new specifications were developed in the early 1980's.

Hot Rolled Sheet (HRS), an adaptation of the Rolled Asphalt used in Britain (BSI, 1985) and South Africa (NITRR, 1978), was introduced (DGH, 1986). Unfortunately, the essential need for this type of mix to have a 'gap grading' was not sufficiently emphasised. Hence, most of the asphalt produced to this specification was really fine AC with a high bitumen content.

A new specification for AC mixes was also introduced (DGH, 1992). It included a requirement for a high minimum binder content to improve mix durability. Subsequently there have been other variations to the specifications, but the requirement for a high bitumen content has remained.

Whilst premature cracking has been largely eliminated, a different type of premature failure through plastic deformation is now prevalent on heavily trafficked roads. This form of failure results in large ruts caused by the flow of the surfacing material towards the edge of the wheel paths. It is potentially more serious than cracking, because the deformed asphalt

can result in earlier development of high roughness and an increased risk of accidents. Also, it is frequently the case that the deformed layer must be removed before a new surfacing is laid.

Unfortunately, none of these earlier designs addressed the fundamental problem; that in order to carry high bitumen contents, the mix must have sufficient Voids In the Mineral Aggregate (VMA), after trafficking, to accommodate the bitumen and allow retention of sufficient Voids In the Mix (VIM) to ensure that the mix will not fail through plastic deformation. Undoubtedly, the problem has been made more severe by an ever increasing severity of traffic loading.

## **2. PROGRESS TOWARDS AN EFFECTIVE METHOD OF ASPHALT DESIGN**

The performance of asphalt surfacings in Indonesia has been the subject of study by the Indonesian Institute of Road Engineering (IRE) and the Transport Research Laboratory (TRL) since 1988.

In 1993 IRE and TRL published reports (TARP, 1993) in which the performance of a wide range of HRS and AC mixes was evaluated. A clear relationship between the loss of VIM and the occurrence of plastic deformation was shown. As a result of this it was suggested that the mix design process should include 'compaction to refusal' to ensure that the VIM could not be reduced to a value below a critical value (TRL, 1993). It will be shown in this paper that this recommendation remains a sound one.

However, without additional care in the design procedure the problem of premature cracking would not necessarily have been avoided. It was important, therefore, to review the modes of failure, which occur in asphalt surfacings in tropical environments so that an appropriate design method could be established.

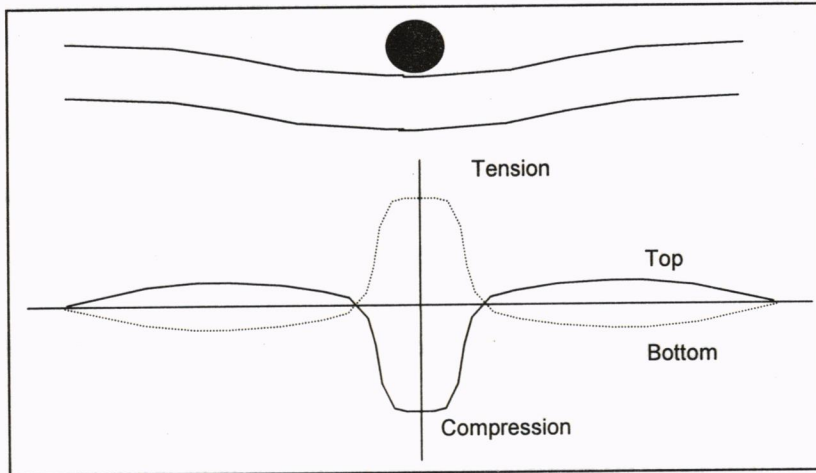
### **2.1 Cracking in Asphalt Surfacings**

Cracks are caused by tensile stresses or strains which can be caused by traffic loading, environmental effects or a combination of the two. The largest tensile strains, caused by flexure of the road, occur at or near to the bottom of an asphalt layer. These strains are illustrated in Figure 1. Smaller but significant tensile strains also occur at the top of the asphalt; in front, behind and to the side of the loading wheel as the pavement deflects transiently. In addition, traction, braking and steering forces can also induce tensile strains at the surface. Diurnal and seasonal changes in temperature also induce tensile strains in the asphalt surface. These are less significant in Indonesia than in countries further from the tropics.

Classic fatigue theory assumes that cracks will start at the bottom of the asphalt layer, where the largest flexural strains occur. However, cores taken from cracked road surfaces have shown that the vast majority of cracks start at the top of the asphalt. This mode of failure has been observed in many other countries (Rolt et al, 1986) (Smith et al 1990) (Hizam et al 1992 and 1995). It has been shown that severe hardening of the bitumen in the surface of the asphalt can cause the development of a steep bitumen viscosity gradient in the top ten



millimetres of the layer. This can result in the viscosity of the bitumen in the top 1-mm being several hundred times greater than that in the body of the layer. In effect a brittle 'skin' is formed which can be very susceptible to cracking under tensile strains. Although this phenomenon is more severe in hot and dry climates it is nonetheless an important potential mode of failure in Indonesia.



**Figure 1**  
**Structural Strains in a Road Pavement**

The bitumen hardening is a function of the loss of volatile oils by evaporation, by absorption into any porous aggregates which may be present and by oxidation which is accelerated by ultra violet light. All these will harden the top few microns of any exposed bitumen.

## 2.2 The Cause of Plastic Deformation in Asphalt

Studies in several countries have shown that when the VIM in an asphalt surfacing is reduced to less than 3 per cent by secondary compaction under traffic, there is a very high risk of failure by plastic deformation (Smith H.R. et al). Studies have confirmed that this also applies to roads in Indonesia.

In order to resist plastic deformation, asphalt mixes depend mainly on internal friction between the aggregate particles. When VIM is reduced to a low value, stresses are progressively transferred to the bitumen which then forces the aggregate apart and allows the material to deform plastically (Cooper et al, 1985).

## 2.3 The Conflict in Asphalt Mix Design

AC and HRS mixes must have sufficient bitumen to ensure good durability. They must also retain sufficient VIM after trafficking to resist plastic deformation. If the VMA in an asphalt layer is too low there will be insufficient room to satisfy both of these requirements. An essential part of the asphalt design process is to ensure that the volumetric design of the mix

is correct. Performance testing to ensure that a mix will behave as desired under heavy traffic is then the second requirement (Asphalt Institute, 1994) (Cominski, Superpave<sup>TM</sup>, 1996).

The type of mix will have an important effect upon the design emphasis, for instance:

- (i) The properties of open graded mixes, in which the air voids are interconnected, are likely to be more durable if the Bitumen Film Thickness (BFT) is optimised to resist oxidation by air, which may enter the mix.
- (ii) Mixes in which the air voids are not interconnected will benefit from a balanced volumetric design in which case the VFB will probably be the best indicator of their durability and resistance to cracking.
- (iii) A characteristic of gap graded mixes (HRS) is that air voids usually become interconnected at a higher value of VIM than is the case for continuously graded (AC) mixes. This makes HRS mixes much less sensitive to small compositional errors.

### 3. PERFORMANCE EVIDENCE FROM INDONESIA AND ELSEWHERE

#### 3.1 Early Studies in Indonesia

Statistical studies of the probability of failure by cracking or by plastic deformation (Dardak et al, 1992) emphasised the importance of retaining in situ VIM of at least 3 per cent, particularly for heavy (> 1 micron equivalent standard axles per year) channelised traffic moving at limited speeds (average of 60 kph).

Results summarised in Table 1 show that:

- (i) Asphalt with retained VIM less than 3 percent is five times more likely to fail by plastic deformation than asphalt with retained VIM greater than 3 percent.
- (ii) Asphalt with retained VIM in excess of 9 percent is five times more likely to fail by cracking than asphalt with VIM between 3 and 6 percent.

**Table 1. Percentage of Types of Surfacing Failure after Five Years of Heavy Traffic**

Range of VIM (%)	<3	3-6	6-9	9-12	>12
Test points with plastic deformation (%)	25	5	0	0	0
Test points with surface cracking (%)	0	10	20	50	100

The most consistently satisfactory mixes were those:

- (i) whose combined aggregate grading had a distinct 'gap' between 0.6 and 2.36 mm, as described in the BS 594 Specification for Rolled Asphalt (BSI, 1985 and 1992),
- (ii) which had a BFT of at least 5 microns.

### 3.2 Extended Studies in Indonesia

A summary of mean in situ properties of asphalts mix laid on four roads in Java is given in Table 2.

**Table 2. In Situ Properties of Asphalt Mixes**

Location and Material	Age (years)	Traffic	BFT (microns)	VFB after Trafficking (%)	VIM after Trafficking (%)	Performance
Cirebon-Losari Northern corridor HRS	10	Very heavy	7.2	80	3.2	No cracking No plastic deformation
Cirebon-Kuningan HRS	10	Heavy	6.5	73	4.9	Some cracking No plastic deformation
Kopo-Rancabali Called HRS but not gap-graded	6	Moderate	7.4	64	6.3	Little cracking No plastic deformation
Banjar-Pangandaran AC	15	Light to Moderate	5.9	71	48	Badly cracked In places No plastic deformation

Note: Core drill samples used to measured VFB and the extracted aggregate used to determine BFT.

It was suggested in Section 2.3 that gap graded HRS mixes would perform well if the retained VIM after trafficking was 3 per cent or more and that VFB was as high as possible. It can be seen from Table 2 that no plastic deformation occurred on those sections of the Cirebon-Kuningan or Cirebon-Losari roads that retained 3% VIM under heavy and very heavy traffic. A high VFB of 80 per cent and a BFT of 7.2 microns has ensured that the mix on Cirebon-Losari was also resistant to cracking. On the Cirebon-Kuningan road both the VFB and BFT were lower at 73 per cent and 6.5 microns respectively and some cracking had developed.

For AC mixes it was suggested that mixes which retained 3 per cent VIM and had a high BFT would give the best performance. It can be seen from Table 2 that on the Kopo-Rancabali and Banjar-Pangandaran roads the AC's retained VIM in excess of 3 per cent and no plastic deformation occurred. Less cracking has occurred on the Kopo-Rancabali road where the BFT was 7.4 microns and VFB was only 64 per cent than on the Banjar-Pangandaran road where the BFT was only 5.9 microns and VFB was 71 per cent. This suggests that BFT has been the more important parameter in relation to the onset of cracking.

### 3.3 Studies in Other Countries

The results of studies into plastic deformation in three countries have been reported by TRL (Smith and Jones, 1997), which showed that the risk of plastic deformation increased dramatically when the in situ VIM decreased to less than 3 per cent.

The Asphalt Institute (1994) also warns that VIM must not be allowed to decrease to less than 3 per cent and recommends that the target VIM after trafficking should be  $4 \pm 0.5$  per



cent. In addition it is pointed out that the VIM at construction may have to be as high as 8 per cent to ensure that adequate VIM is retained after secondary compaction under traffic. Unfortunately, at this level of VIM, bitumen hardening is quite rapid and this is likely to continue in areas of the road surface which are outside the wheel paths and therefore not subject to additional compaction. There would, therefore, be areas of the surfacing with different levels of densities and different degrees of bitumen hardening and different susceptibilities to cracking.

#### **4. DEVELOPMENT OF A NEW ASPHALT DESIGN PROCEDURE**

##### **4.1 Methods of Compacting Asphalt Mixes to Refusal Density**

Clearly there are currently some major difficulties in using the Marshall test procedure to design asphalt surfacings for heavily trafficked roads. The procedure assumes that 75 blow compaction produces a very similar density to that which will occur in the road after several years under heavy traffic. This is not very often the case and secondary compaction under traffic is frequently underestimated. The universal use of 75 blow compaction produces an arbitrary density which may or may not be correct in order to produce an effective design by the Marshall method the designer must know the eventual density in the road and the number of blows to use for compaction.

It is recommended that compaction to refusal density is introduced to provide a reference density, which can be used to ensure that a mix can be designed so that VIM cannot be reduced to less than 3 per cent under even the heaviest traffic.

There are two simple and inexpensive methods by which 'refusal density' can be achieved. One method uses an electric vibrating hammer (BS: 598 Part 104, 1989), which uses a 102 mm diameter foot to compact samples in a 152 mm diameter split mould. The other method is an extension of the Marshall compaction in which samples are subjected to 400 or more blows per face instead of 75. Use of these test methods is described in Overseas Road Note 31 (TRL, 1993).

Tests have been carried out on asphalts recovered from heavily trafficked project roads where the material was either failing or close to failing through plastic deformation. Samples were compacted to refusal by the two methods and the densities obtained were compared to the in situ densities. The results are summarised in Table 3.

The densities achieved in the refusal tests are nearly 2 per cent higher than the density of cores taken from the wheel paths on West Java's Northern Corridor, which is possibly the most heavily trafficked road in Indonesia. This confirms that the two test methods produce true 'refusal' densities. The difference of 0.0015 between the individual mean values and the grand mean of 2.419 is very much smaller than the standard deviation for each of the two test methods. Hence, the methods may be regarded as being interchangeable and effective.

**Table 3. Comparison of In Situ and Refusal Densities**

Location	In situ density (core drill samples) (Mg/m <sup>3</sup> )	Laboratory Refusal Densities (Mg/m <sup>3</sup> )	
		Vibrating Hammer	Extended Marshall Test (400 blows)
West Java	Mean = 2.376	Mean = 2.421	Mean = 2.418
(Northern corridor)	Std = 0.037	Std = 0.025	Std = 0.020

It is worth noting, however, that compaction by vibrating hammer is a very much quicker operation than the 400 blow Marshall compaction. It is also less sensitive to small fluctuations in mix temperature or to layer thickness. Moreover, it compacts more by kneading the mix and reorientating aggregate particles and less by crushing them than 400 blow Marshall compaction.

#### 4.2 The Mix Design Procedure

The suggested design procedure is recommended for HRS mixes. Asphaltic concrete wearing courses present particular problems in design and these will be discussed in Section 4.3 below.

There are two stages in the design procedure:

- (i) Selection of suitable aggregates that have a satisfactory gradation.
- (ii) Design tests to confirm that a viable mix can be produced. If not, the design process must be repeated with a new aggregate grading. In some cases it may be necessary to introduce a new source of material.

Marshall tests using 75 blow compaction are carried out and values of VMA, VFB, stability, flow and Quotient are determined. The binder content which gives 6 per cent VIM is determined and samples are made at this bitumen content and at 0.5 per cent higher and lower than this value for refusal compaction. These results may indicate that additional samples are needed to cover the required range of VIM values. Compaction to refusal can be done by extended Marshall compaction or by vibrating hammer.

The results obtained are compared with the specified requirements given in Tables 4, 5 and 6.

**Table 4. Strength and Flexibility Criteria for HRS Mixes**

Marshall Properties		
Stability (kg)	Max.	800
	Min.	-
Flow (mm)	Max.	-
	Min.	2.5
Quotient (kg/mm)	Max.	200
	Min.	500



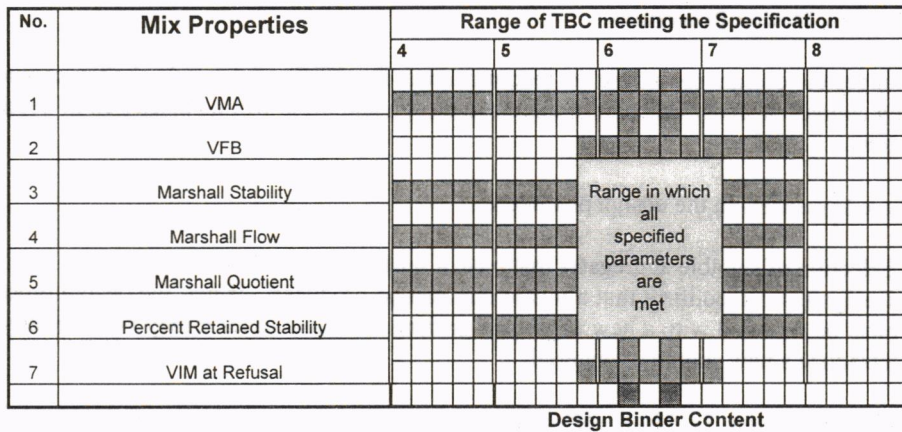
**Table 5. Durability criteria for HRS Wearing Course and Base Course Mixes**

Design Life Traffic (ESA)	Mix Property after 75 Blows Marshall Compaction	
	All Traffic	Minimum VMA (per cent)
> 1,000,000	Minimum VFB (per cent)	65
500,000-1,000,000		68
< 500,000		75

**Table 6. Criteria for HRS for Resistance to Plastic Flow**

Design Life Traffic (ESA)	VIM at Refusal Density (per cent)	
	Minimum VIM	Maximum VIM
> 1,000,000	3	5
500,000-1,000,000	2	4
< 500,000	1	3

A convenient way to present the data is to plot the range of bitumen contents for which each of the criteria is satisfied, as illustrated in Figure 2.



**Figure 2. Example Mix Design Bar Chart**

The design bitumen content will be within the range for which all the design parameters are satisfied, but the VIM at refusal density and the VFB are the primary parameters. It is recommended that the mix should be designed so that the range of satisfactory bitumen contents should be at least 1 per cent, with the central value as the median value for VIM at refusal density.

The mean density achieved at the time of construction should be 95 per cent of refusal density, with no values less than 93 per cent of refusal density. It is important to attain high densities but the mix composition, particularly the bitumen content, must not be arbitrarily increased in order to obtain satisfactory densities.

**4.3 Design of AC Mixes**

In principle the criteria given above for HRS mixes could be applied to the design of AC mixes. Unfortunately AC wearing courses tend to be very dense materials in which the



VMA is too low to meet the refusal VIM design criteria for very heavy traffic. The easiest way to increase VIM is to use a coarser aggregate grading and it is likely that gradings for basecourse or road base materials will satisfy the requirements.

As stated earlier a characteristic of HRS mixes is that air voids usually become interconnected at a higher value of VIM than is the case for AC wearing course mixes. For these latter types of mix a major difficulty can arise because the VIM at the time of construction can be very high.

An example of the relationship between VIM criteria, density at refusal compaction and VIM at the time of construction is given in Table 7.

**Table 7. An Example of the Expected VIM in an AC Immediately After Construction**

Refusal Density (mg/m <sup>3</sup> )	VIM at Refusal Density (per cent)	Condition of AC Immediately After Construction	
		Density (per cent of refusal density)	VIM (per cent)
2.42	3	95	7.9
	5		9.7

Such a mix will be resistant to deformation, which is the primary requirement, but the durability of the mix will be dependant on the rates at which secondary compaction and bitumen hardening occur, factors which may vary from contract to contract.

It is in this context that TRL currently recommend that when AC or DBM base courses are used as road surfacings they should receive a surface dressing soon after construction to reduce the likelihood of durability problems arising from a high initial VIM.

An alternative type of mix, which will conform to the new mix design is a Stone Mastic Asphalt (SMA). This mix has a reduced fine aggregate content and smaller maximum stone size. It is capable of carrying a thicker binder film and may therefore satisfy the requirements of resistance to cracking and plastic deformation.

## 5. FURTHER RESEARCH AND VALIDATION

Whilst the recommended criteria for HRS mixes can be expected to produce effective wearing courses further work is being done to refine the suggested limits and to test the sensitivity of performance in the road to changes in mix composition and other parameters.

It is important that the proposed HRS and AC/SMA mixes are used on a large scale so that any problems in their application can be identified. It will be essential to ensure that, under contract conditions, sufficiently high levels of quality control and laboratory testing can be achieved.

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