The Difficult Nature of Minimum VMA:
A Historical Perspective

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INTRODUCTION

Several researchers have recently discussed problems with Superpave volumetric mix design. Anderson and Bahia believe that evaluating and selecting the aggregate gradation to achieve minimum voids in the mineral aggregate (VMA) is the most difficult and time-consuming step in the mix design process (*1*). Hinrichsen and Heggen feel that the minimum VMA requirements are too restrictive and rule out economical mixes with acceptable performance properties (*2*). Kandhal, Foo, and Mallick suggest that some of the problems in meeting the minimum VMA requirements may be caused by the increased compactive effort of the Superpave gyratory compactor (*3*). Some of these researchers recommend that the average asphalt film thickness be considered in the Superpave volumetric mix design (*2*-*4*).

At first glance, these "new" problems may appear to result from the implementation of Superpave, e.g., the new gyratory compactor or the restricted zone, etc. A look through the asphalt literature, however, reveals that asphalt technologists have debated related issues since the early days of asphalt paving. VMA has been associated with mix durability since the early part of this century, yet only 40 years ago was it recognized as a critical mix design parameter, principally through the efforts of Dr. Norman W. McLeod. Today, in the Superpave volumetric mix design process it indirectly defines what is an acceptable aggregate gradation.

The intent of this paper is to examine if specifying a minimum VMA requirement is the best approach to getting to a rational or economical mix design. To accomplish this, it is necessary to review the role of VMA in mix design, understand how it has evolved since the early days of asphalt paving, and examine some alternatives to the VMA criterion.

EARLY MIX DESIGN

Early mix designers recognized the role played by VMA in durable mixes. Hudson and Davis, in reviewing early mix design, cite F. J. Warren's 1901 application for a patent on bituminous concrete, which emphasized the importance of minimizing voids in the mineral aggregate as much as possible to insure proper gradation and sufficient stability (*5*). The upper limit on VMA was 15 percent. Clifford Richardson in "The Modern Asphalt Pavement" published in 1907 recognized the role of aggregate surface area, showing that the increased surface area in a fine mix would allow the presence of a larger quantity of bitumen than a coarse mixture (*6*). Hudson and Davis suggest the ideas of Warren and Richardson led to two different approaches to mix design:

1. *Design the mix to get maximum density or minimum VMA achievable. Typically, the designers combined VMA, air voids, and experience to determine the best asphalt content.*
2. *Determine the asphalt content based upon the computed surface area of the aggregates and an optimum film thickness. These designers combined air voids, the product of surface area and optimum film thickness, and experience to determine the best asphalt content.*

Because both approaches relied heavily on experience, the resulting mixes were typically quite similar. Usually, the aggregate gradations were specified by gradation envelopes, by locally available materials, or by theoretically "idealized" gradations.

The Hubbard-Field mix design, used primarily for the design of sheet asphalt mixes with 100 percent passing the 4.75 mm sieve, is an example of the first approach. The optimum asphalt content was selected based on air voids and maximum stability, which generally occurred at the minimum percentage of aggregate voids (*7*). Sometimes the percentage of aggregate voids was used to compare different mix designs or to adjust the mix gradation to achieve desired air voids.

The Hveem mix design method is an example of the second type of approach. Hveem (1940) suggested that "*there was little evidence to show that the voids ratio can be dependably utilized in the design of mixtures*" and "*that neither the amount of binder required nor the important properties can be confidently predicted from a knowledge of the void volume alone*" (*8*). However, he clearly recognized the importance of mix volumetrics, stating in 1942 *"Regardless of other considerations, the volume of asphalt must be maintained safely below the volume of voids in the aggregate"* (*9*).

The 'early' Marshall mix design approach did not have a VMA requirement. Marshall himself believed "*no limits can be established for VMA, for universal application, because of the versatile application of bituminous materials to many types and gradations of aggregate*"(*10*). McFadden and Ricketts (1948) presented the Corps of Engineers (COE) version of the Marshall method for design and field control of paving which used five parameters in determining the design asphalt content:

1. A minimum stability of 500 lbs.,
2. A maximum flow of 20,
3. Air voids between 3 and 5 percent,
4. A VFA of 75-85 percent, and
5. Unit weight.

The peak values of all parameters except flow were averaged to determine the design asphalt content (*11*).

THE SHIFT TOWARDS A MINIMUM VMA REQUIREMENT (1955-62)

McLeod (1955) presented his initial analysis on "*the voids properties of compacted paving mixtures*", in which he laid out the basic principles of a minimum VMA requirement (*12*). His argument did not explicitly mention durability; he was concerned that specifications with requirements on both air voids and VFA were too restrictive at higher asphalt contents. He showed for absorptive aggregates that computed VMA and VFA would be wrong unless the bulk specific gravity was used in the calculations.

In 1956, McLeod presented a modified Marshall mix design methodology, which listed a minimum VMA requirement of 15 percent (*13*). He showed graphically (See Figure 1) that a VFA range of 65-80 percent was unachievable for mixes with asphalt contents above 10.5 percent by weight (approximately 20 percent by volume). He provided similar design charts that covered the range of aggregate specific gravity from 2.00 up to 3.00 and asphalt specific gravity from 0.95 up to 1.11, in all cases the minimum asphalt content required would be at least 4 percent by aggregate weight, plus any absorbed asphalt. At a typical aggregate specific gravity G_{sb} = 2.65 and asphalt specific gravity of 1.01 McLeod's design charts specify a minimum asphalt content of 4.5 percent. McLeod believed that the physical test limits would broaden the range of acceptable aggregates, lower the cost of bituminous paving mixtures and provide satisfactory paving mixtures with respect to stability, voids, durability, etc.

In 1957, Lefebvre re-emphasized the importance of minimum VMA (*14*). Aware of the difficulty of achieving 15 percent voids in the mineral aggregate and 3-5 percent air voids, he investigated the influence of the principal fractions of the mineral aggregate; coarse aggregate, fine aggregate, fine sand, and mineral filler on the performance of the paving mixture. He found that the fine aggregates were the most critical component, controlling the VMA and contributing to stability. His recommendations included using a moderately high percentage of fine aggregate containing a small percentage of fine sand. The fine aggregate should be angular, with rough surface texture, and suitably graded. The coarse aggregates, while good for stability, are bad for VMA particularly if mineral filler is present. Mineral filler was not recommended, because it fills voids and takes the place of bitumen, and may be detrimental to durability. It is worth noting that Lefebvre states that he conducted the investigations that led to the minimum VMA requirements, but does not reference them or present any data.

Campen, et al. (1957) stressed that a satisfactory mixture is one where the aggregate contains enough voids to permit the addition of sufficient asphalt to provide comparatively thick films without filling all the voids in the aggregate (*15*). They showed data suggesting that engineers typically use a high coarse aggregate content to control the voids.

McLeod (1957) again stated his case for using the bulk specific gravity and effective asphalt content for volumetric analysis of the mixture (*16*). He concluded that if the compacted paving mixture was restricted to 3-5 percent air voids, requiring a minimum VMA (15 percent) was less restrictive than requiring a VFA range of 75-85 percent. More importantly, he suggested that the VFA requirement would allow a pavement to be constructed with 3.76 percent asphalt, which he felt was too low for durability. The minimum VMA requirement would ensure at least 4.5 percent asphalt and provide adequate durability. McLeod observed that Canadian aggregates typically were too densely graded to provide the required VMA. He summarized the principal factors influencing VMA as follows:

1. For any given particle size, the Fuller or Weymouth curve should produce maximum density.
2. Moving off the maximum density curve (To either side!) should provide less density and more VMA.
3. Using slightly more (or less) fine aggregate should open space between the coarser particles resulting in higher VMA.
4. Using appreciably less fine aggregate will result in an “open graded” mixture with relatively high VMA.
5. If the quantity of fine material ranges from slightly less to appreciably more than the Fuller curve, the VMA in the resulting dense graded mixture will increase steadily (slowly) but so will the required asphalt content such that the air voids will still be in the range of 3-5 percent.
6. Choosing to add or reduce fine aggregate depends on (1) required pavement surface texture, (2) whether or not the resulting pavement would be durable enough for local climate and traffic conditions, and (3) relative cost of coarse and fine aggregates.
7. Adding mineral filler can drastically reduce VMA. Hence reducing mineral filler can rapidly increase VMA.

McLeod (1959) again stated his case for using VMA and air voids requirements in designing pavement mixtures (*17*). In place of his previously held requirements of 15 percent minimum VMA, he related minimum VMA to nominal maximum particle size. Figure 2 shows McLeod’s suggested relationship. He warned that the minimum VMA requirements were subject to modification as further experience and additional test data were accumulated.

Campen, et al. (1959) emphasized that asphalt film thickness, not VMA was essential to mixture durability (*18*). VMA is independent of the surface area of the aggregate. They presented data showing that two aggregate blends could have identical VMA and one could have twice the surface area and film thickness as the other. At the same time, they found that the surface area did not indicate the asphalt content required for minimum VMA. Increased surface area requires more asphalt, but there is no direct proportional relationship. They prescribed film thicknesses in the range of 6-8 microns as producing the most desirable paving mixtures.

VMA: 1962 - SUPERPAVE

The Asphalt Institute incorporated a new density-voids analysis, which accounted for asphalt absorption, into the Marshall mix design method in its 1962 MS-2 (*7*). VFA, previously a Marshall method design parameter in previous editions, is not mentioned. No rationale for dropping VFA is presented. McLeod wrote the appendix presenting the inclusion of a minimum VMA requirement into the mix design process.

Hudson and Davis (1965) described an arithmetical method for computing VMA from the aggregate gradation (*5*). Using factors for the ratio of percent passing one sieve divided by the percent passing the next smaller sieve. Their procedure differentiated between rounded and angular aggregate. They felt VMA depended on the following conditions:

1. Particle arrangement or degree of compaction,
2. Relationship between sizes of aggregate particles, in particular the ratio between percents passing adjacent sieves,
3. The range of size between fine and coarse materials, and
4. Aggregate shape.

They believed that their arithmetic method of computing VMA would allow the mix designer to estimate design asphalt content, if McLeod's chart (Figure 1) was used.

McLeod (1971) discussed the trend of modifying paving mixtures with rubber or asbestos to increase durability and proposed the alternative approach of using conventional asphalt binder but requiring the higher 2-3 percent higher than normal VMA values shown in Figure 2 (*19*). He demonstrated that the VMA value of a dense graded paving mixture essentially controls the quantity of asphalt that can be incorporated into the mixture. Also, he argued that VMA should be determined through measurements of compacted mixtures; it cannot be determined from aggregate test properties alone. He offered several methods to increase VMA; most importantly using crushed angular aggregates.

Field (1978) presented the results of a study investigating the minimum VMA criterion, the accuracy of the test, and examining alternative approaches (*20*). He pointed out that the Ontario Ministry of Transportation and Communications (MTC) had supplied acceptable mixes that did not meet the required minimum VMA. The MTC was changing its requirements to those shown in Table 1, where it must be noted that the maximum size is the same as the Superpave nominal maximum size. At the time, the MTC was adjusting The Asphalt Institute's standard VMA requirements as follows:

1. For aggregates near the borderline acceptable VMA, if the percent passing #4 sieve was increased by 5 percent, the required VMA increased by 0.5 percent.
2. For aggregates of good VMA with desirable mix characteristics – cohesion, stability, and coatability, the if the passing #4 sieve was increased by 5 percent, the required VMA increased by 0.8 percent.

3. The minimum VMA should correspond to a minimum air voids content, e.g., if VMA of 15 percent is required for air voids of 5 percent, then if design air voids are decreased, the minimum VMA should decrease correspondingly.

Field discussed four alternative approaches to using minimum VMA in getting mix durability:

1. A VFA requirement,
2. The surface area method,
3. The centrifuge kerosene equivalent (CKE) test, and
4. Visual observation of coatability.

A VFA requirement of 75-85 percent was ruled out because it would allow mixes with very low VMA and very low asphalt contents to be used. The surface area method provided mixes with average design asphalt contents 1.2 percent lower than those obtained using the VMA criterion. So, despite good laboratory test properties (excepting low VMA!) and no construction or performance problems, because of conceptual problems the method was deemed unacceptable.

The CKE approach was found unsatisfactory because it is "lengthy, tedious, subject to many errors, and not realistic." Using visual observation for coatability was deemed acceptable based on past projects where it had been used. The criteria involved making sure (1) the loose mix was moderately rich with respect to asphalt, (2) the compacted test specimen was moderately rich to rich in appearance, and (3) the aggregate particles were well coated with asphalt. He concluded that the minimum VMA requirement based on bulk specific gravity was the best method of establishing proper asphalt content for durability. Field also recommended follow up performance studies be conducted on pavements with VMA and void contents below the design criteria to provide the necessary experience and confidence.

Kandhal (1985) reported there were still problems with the VMA criterion (*21*):

The VMA is considered to be the most important mix design parameter which affects the durability of the asphaltic concrete mix. High VMA values allow enough asphalt to be incorporated into the mix to obtain maximum durability without the mix flushing. Additionally, such mixes have the following advantages compared to low VMA mixes:

1. *Lower stiffness modulus at low temperatures. This is helpful in minimizing the severity of thermal and reflection cracking.*
2. *Lower susceptibility to variations in asphalt and fines content during production. Such variations can cause the mix to be too brittle or too rich.*

Unfortunately, only 16 of 38 states using the Marshall method specify a minimum VMA. Of these 16 states, only seven use the effective asphalt content (total asphalt minus the asphalt absorbed by the aggregate) to calculate the realistic VMA value, as recommended by the Asphalt Institute. If the effective asphalt content is not used, the calculated VMA values are not reliable especially when the mix contains an absorptive aggregate.

Foster (1986) reviewed the use of voids in mix design and specifications (*22*). While acknowledging McLeod's explanation of VMA as providing "the desirable conditions for a good asphalt pavement" he questioned the minimum requirement of 15 percent VMA. He reviewed McLeod's 1956, 1957, and 1959 papers and Lefebvre's 1957 paper and pointed out that none report actual pavement VMA or performance data in support of the recommended criteria. Foster reported that as of 1985 seventeen states were using VMA in their mix designs. He compared pavement performance data from several projects and his data is presented graphically in Figures 3 and 4.

Figure 3 presents graphically the volumetric mix data from traffic tests that the U.S. Army Corps of Engineers used to develop their Marshall design criteria. The nominal maximum size was (primarily) 19.0 mm (¾ in.). The data clearly show the importance of the 3-5 percent air voids criterion. For VFA, a criterion of 68-77 percent (approximately) will result in satisfactory pavements. The VMA criterion shows that a minimum of 14 percent is necessary to distinguish the ‘almost plastic’ pavements, but does not break out the ‘almost brittle’ pavements.

Figure 4 presents graphically the volumetric mix data from 18 experimental overlays on Nebraska highways from 1961-1972. The rings differentiate the different mix types; nominal maximum size was (primarily) 19.0 mm (¾ in.). The data clearly show that a VFA criterion of 68-83 percent (approximately) will result in fair or good pavements. The VMA criterion is ineffective at distinguishing pavement performance in this data. Interestingly, Foster also had film thickness information for these projects that also did not correlate well with performance.

Huber and Heiman (1987) examined 9 test sites in Saskatchewan to see if mix design characteristics differentiated pavements that performed well from those that rutted badly (*23*). For the mix characteristics examined, they found the threshold values listed in Table 2. If 4 percent air voids are taken as a design target, then their VMA and VFA criteria limit possible designs to a single point (Air Voids = 4%, VMA =13.5%, and VFA =70%). Interestingly enough, they concluded that asphalt content and voids filled with asphalt were the most basic parameters that effect rutting, with VFA including the effects of both air voids and VMA.

McLeod (1987) re-emphasized his earlier arguments for using VMA in mix design (*24*). Aware of Huber and Heiman’s findings, he acknowledges that there is apparent justification for using air voids and VFA as design criteria. However, using an air voids and VFA criteria of 75-85 percent would not be a practical specification for production. He further argues against placing requirements on all three volumetric parameters, air voids, VMA, and VFA, showing that they overlap. As a practical matter, he suggests, the only reasonable criteria is to use the minimum VMA based on nominal maximum particle size and air voids requirement. He mentions that in Ontario during the OPEC oil crisis of 1973, the VMA requirements were significantly reduced as a cost saving measure, but quickly halted due to an epidemic of poor pavements and raveling problems.

Huber and Shuler (1990) in looking for a new performance based mix design cite the development of the VMA criterion as an example of a new test or specification developed to predict or explain observed behavior that could not be explained with historical tests *(25)*. However, they designate VMA as a surrogate property, meaning that it is not a fundamental property. VMA is used in volumetric design and also in field verification. The volumetric design would be similar to the existing Marshall design and the field verification would involve testing to ensure uniformity of production.

Huber and Shuler (1991) focused on the relationship between VMA and the maximum density line (MDL) *(26)*. They concluded that the MDL needed to run from the origin to the 100 percent passing maximum sieve size. They tried to relate distance from the MDL to VMA but could find no general rule to ensure minimum VMA, because of the influence of aggregate angularity and surface texture on VMA. They also recommended against comparing gradations with large differences in material passing the #200 sieve.

VMA IN THE ERA OF SUPERPAVE

Cominsky, Leahy, and Harrigan (1994) present and discuss the Superpave Level 1 mix design that was developed during the Strategic Highway Research Program (SHRP) *(27)*. Based on the recommendations of a panel of experts using the Delphi method, the VMA requirements were absorbed into Superpave. The panel's final rating of the various aggregate and asphalt-aggregate mixture characteristics for inclusion into the specification is shown in Table 3. As can be seen, the panel strongly recommended air voids and VMA but was essentially neutral on VFA, dust/asphalt ratio, and film thickness.

The Asphalt Institute (1994) re-introduced a VFA criterion into Marshall mix design, changed the design air voids to 4 percent, and added a table of VMA requirements depending on air voids and nominal maximum aggregate size *(28)*. The stated purpose of the VFA criterion was to limit the maximum values of VMA and asphalt content.

Aschenbrenner and MacKean (1994) examined 101 mix designs to determine which maximum density line (MDL) worked best for predicting VMA, achieving the best correlation with the Superpave definition *(29)*. They report that in 1993, the first year the Colorado Department of Transportation specified a minimum VMA, the average mix design asphalt content increased 0.46 percent. Also, they examined 24 laboratory mixes to study the effects of four variables on VMA:

1. Gradation,
2. Percent passing 75 μm sieve,
3. Size distribution passing 75 μm sieve, and
4. The fine aggregate angularity.

They found that gradation played a role in influencing VMA, but got such poor correlation that VMA could not effectively be predicted from gradation. The percent passing the 75 μm sieve has a significant effect on VMA, particularly for gradations on the fine side of the MDL. Lower percent passing 75 μm sieve increased VMA, higher reduced VMA. They recommended that the fine aggregate be kept well off the MDL. Their results examining size distribution passing the 75 μm sieve were inconclusive. They found aggregate angularity to substantially affect the VMA, with crushed aggregates providing more VMA and rounded aggregates less. The fine aggregate angularity was more influential for coarse mixes or mixes following the MDL than for mixes on the fine side of the MDL.

Kandhal and Chakraborty (1996) set out to reexamine the rationale behind the minimum VMA requirements currently being used and to establish an optimum film thickness for mix durability *(4)*. Like Foster, they could not find any significant rational data correlating pavement performance with the currently specified minimum VMA values for HMA mix design. They tested mixtures with six effective asphalt thicknesses, aged both short and long term, and they tested specimens for resilient modulus and tensile strength. They also tested the recovered binder for penetration, viscosity, complex modulus, and phase angle. In their studies they found that asphalt film thickness correlated well with resilient modulus, and they recommended an average film thickness of 9-10 microns for specimens compacted at 8 percent air voids. Interestingly enough, a 9 micron film thickness at 4 percent air voids would require a minimum VMA of 15.6 percent, 1.6 percent higher than Superpave specification.

Hinrichsen and Heggen (1996) also proposed using average film thickness in mix design *(2)*. They provided equations, which used the aggregate gradation and volumetric properties to determine the proper VMA for each mix design uniquely. To do this, they took the standard film thickness equation, assumed a standard film thickness, and back-calculated the amount of asphalt required providing this film thickness. Using volumetric relations, they computed the minimum VMA allowable with this asphalt content and a target air voids. They provided information that showed that mixes based on minimum VMA, were not always the best in terms of performance and economics. They questioned the use of "rigid" minimum VMA specifications, showing that there is considerable variability in the tests performed to determine VMA, resulting in a standard deviation of 1.3 percent for VMA.

Anderson and Bahia (1997) found achieving VMA the most difficult and time consuming step in Superpave volumetric mix design *(1)*. They analyzed 128 trial gradations from 32 mix designs performed by The Asphalt Institute from 1992-96 to determine if they could make any recommendations towards selecting an aggregate gradation. Their analysis agreed with prior researchers that VMA is dependent on more than just aggregate gradation. They found that current methods for increasing VMA were not absolutely effective. Their best recommendation to meet VMA requirements was to develop an S-shaped gradation curve ($r^2 = 0.58$) or to use the sum of the distances from the MDL ($r^2 < 0.20$) to meet the VMA requirements.

Kandhal, Foo, and Mallick (1998) assumed asphalt mix durability was dependent on film thickness *(3)*. Based on average film thickness, they found the current minimum VMA requirements inadequate for ensuring mix durability. They concluded that it penalized coarse graded mixes with low VMA but adequate film thickness. They recommended dropping the minimum VMA requirement in place of a minimum average film thickness of 8 microns. While they could not find the background research data on which The Asphalt Institute surface area factors are based, they felt they should still be used.

SUMMARY/RECOMMENDATIONS

The role of VMA in mix design has changed dramatically since the early days of mix design. Some early mix designers sought to minimize VMA to for stability. Others chose to require a minimum film thickness for durability. Prior to the mid-1950's, VMA was mainly a peripheral mix parameter and not emphasized. The Corps of Engineers had a requirement on VFA, not VMA in their recommended Marshall mix design. Over the period from 1955 –1962, Norman McLeod argued the need for a minimum VMA criterion in several papers, but neglected to provide supporting data. The Asphalt Institute adopted McLeod's suggested VMA requirement in the 1962 mix design guidelines. With the implementation of Superpave, there has been a renewed awareness of the difficulties in meeting minimum VMA requirements. Several researchers are recommending use of a minimum film thickness requirement, in place of VMA.

McLeod, in introducing the relationship between minimum VMA and nominal maximum size suggested that the VMA requirement "*is subject to change as further experience and additional test data are accumulated*" *(19)*. In the 40-plus years that minimum VMA has been a design criterion, mix design has gone through some major changes, and as evidenced by some of the recent papers discussed above, still evolving. Based on the literature review above the following recommendations are made:

1. The minimum VMA requirements need to be validated against pavement performance. This includes the effects of particle shape, surface texture, and gradation.
2. Given the precision of the tests used to determine VMA, rigid enforcement of a minimum VMA criterion should be discouraged.
3. The minimum average film thickness also needs to verified and related to field performance. The surface area factors and shape constants dating back to the 1940s need to be examined using modern technology.

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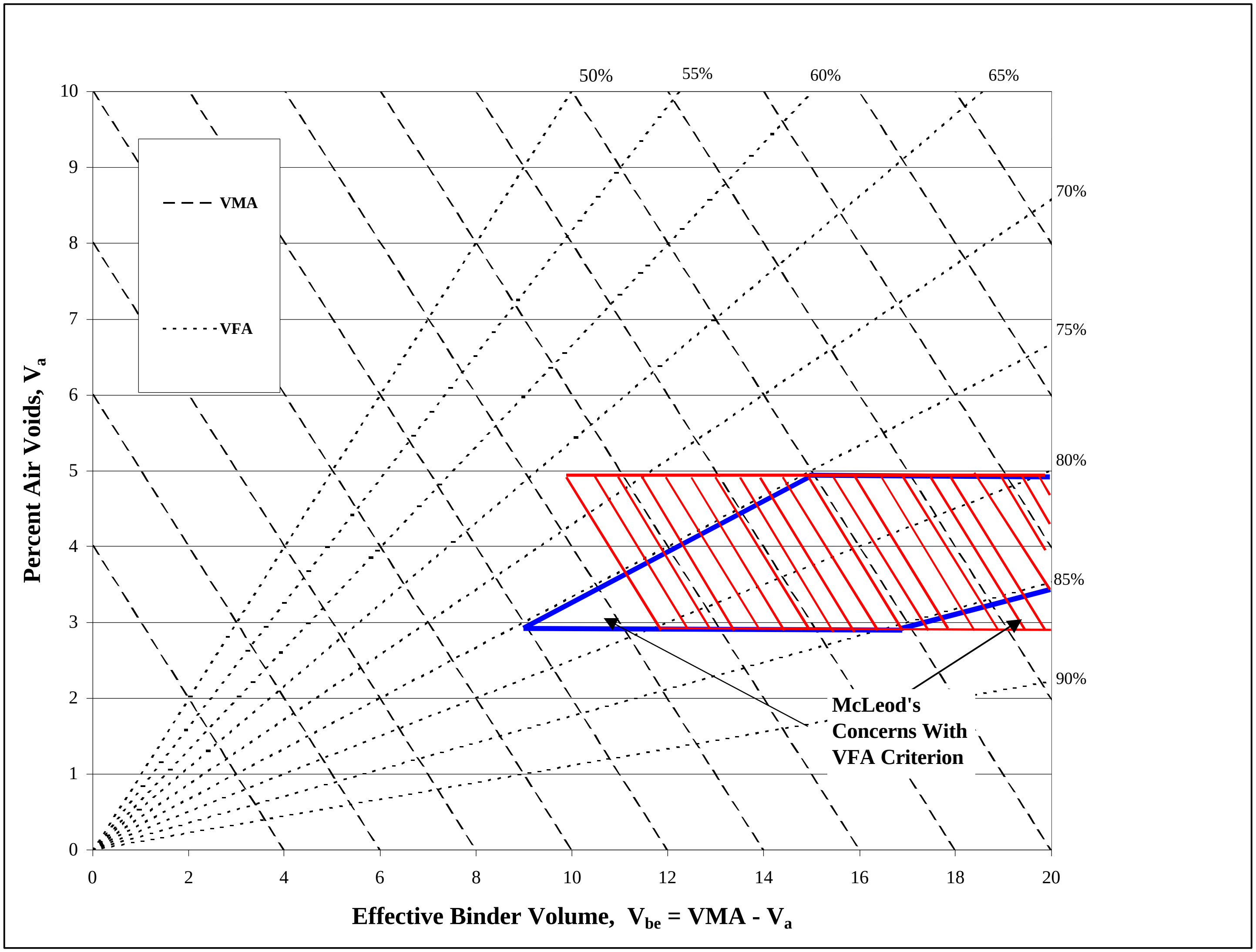

Figure 1. McLeod's Concern with VFA Criterion.

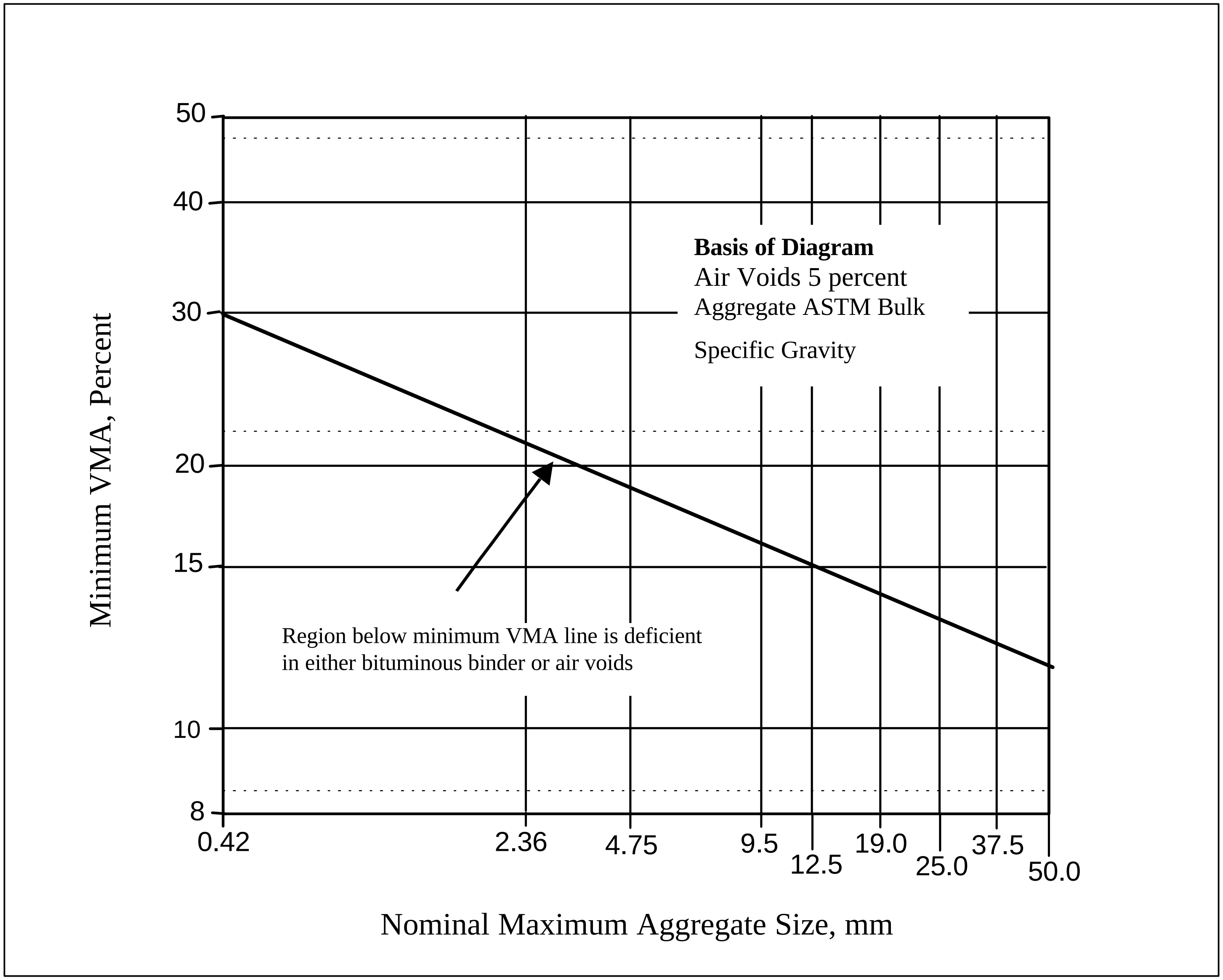

Figure 2. McLeod's Relationship between Minimum VMA and Nominal Maximum Aggregate Size.

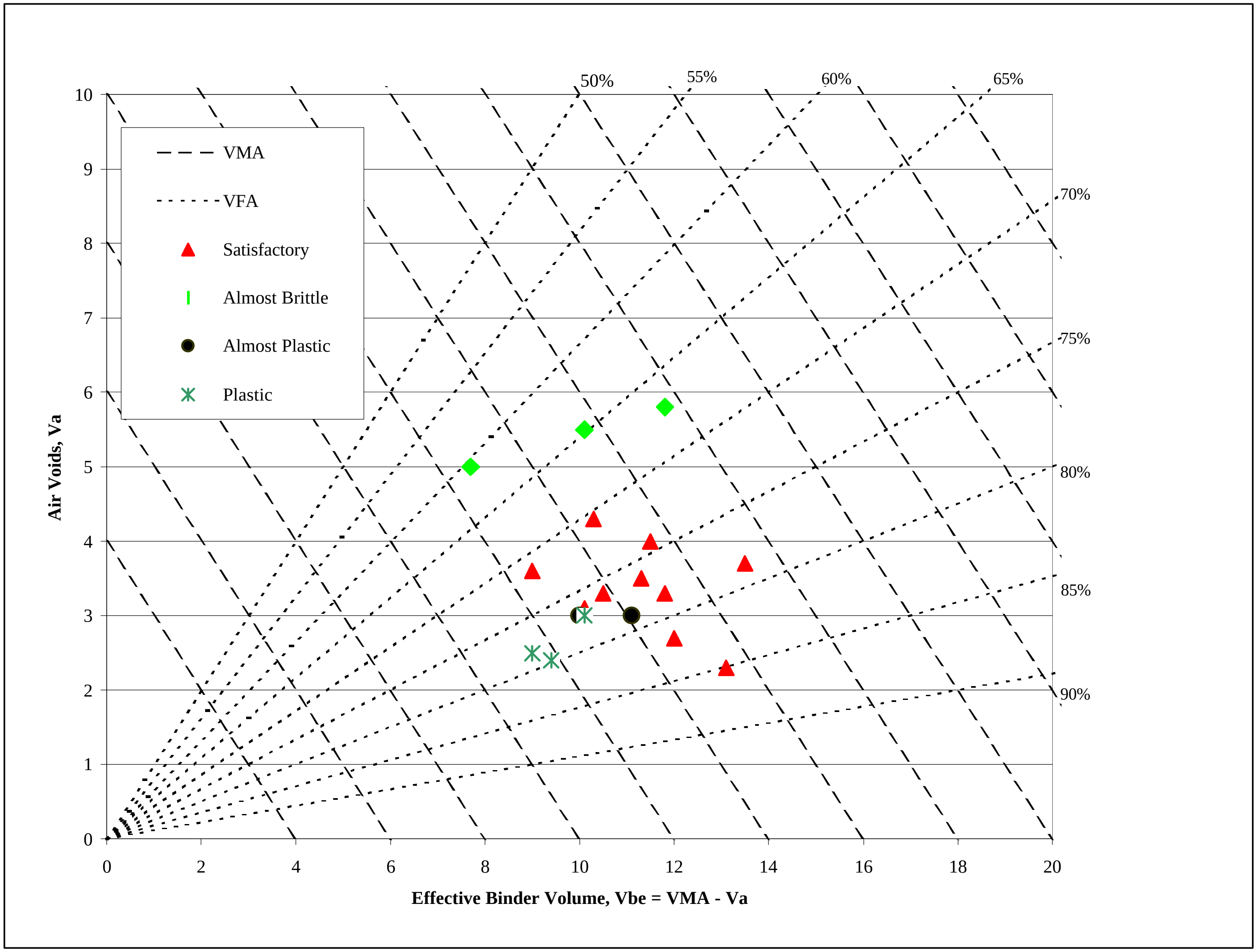

Figure 3. Ineffectiveness of Using VMA to Distinguish Pavement Performance.

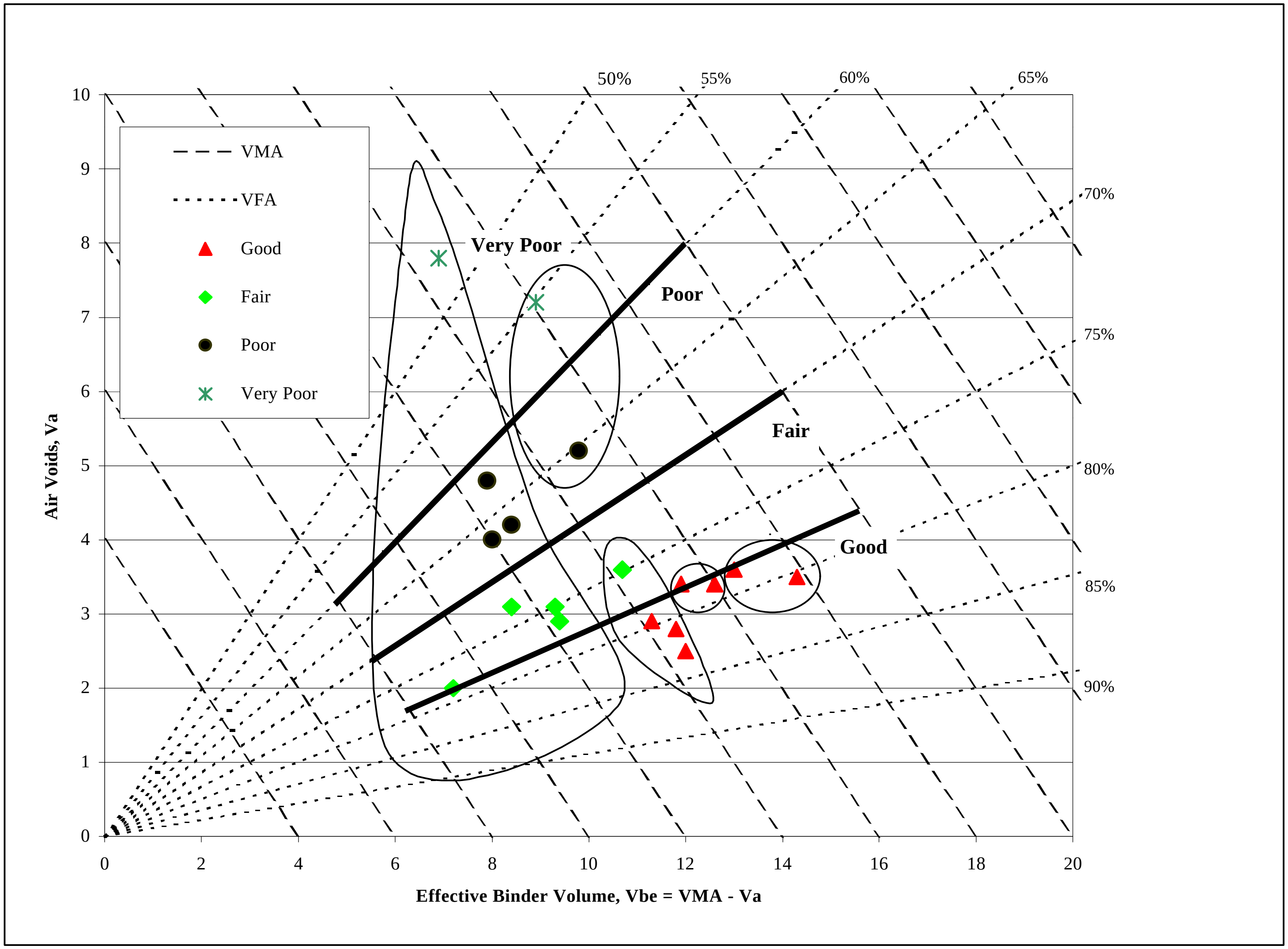

Figure 4. Effectiveness of VFA for Predicting Pavement Performance.

Table 1. Ontario Ministry of Transportation and Communications Modification to VMA Requirements (After 20).

Mix Type	Percent Pass 4.75 mm * (By Mass)	Nominal Maximum Particle Size (mm)						
		2.36	4.75	9.5	13.2	16.0	19.0	26.5
HL-2		21	18.0	16				
HL-1	40				13.5	13.0	12.5	11.5
HL-3	45				14.0	13.5	13.0	12.0
HL-4	50				14.5	14.0	13.5	12.5
HL-5	55				15.0	14.5	14.0	13.0
HL-6	60				15.5	15.0	14.5	13.5
HL-8	65				16.0	15.5	15.0	14.0

Above % V.M.A. is for 3½ % voids
Reduce % V.M.A. by amount of voids set less than 3½ %
Increase % V.M.A. by amount of voids set more than 3½ %

A design mix must have at least a moderate to moderately rich asphalt coating appearance on aggregate particles before compaction.

When the difference between the bulk relative density of the retained 4.75 mm material and the bulk specific gravity of the pass 4.75 mm material is greater than 0.3 then the percent pass 4.75 mm must be on a volume basis.

Table 2. Observed Threshold Values for Mix Design Characteristics (After 23).

PARAMETER	**THRESHOLD VALUE**
Air Voids	4% minimum
Voids in the Mineral Aggregate	13.5% minimum
Asphalt Content	5.1% maximum
Voids Filled with Asphalt	70% maximum
Fractured Faces	60 % minimum
Marshall Stability	-----
Hveem Stability	37% minimum

Table 3. Average Ratings of Asphalt-aggregate Mix Characteristics by SHRP Expert Task Group (After 27).

Characteristic	Rating	Standard Deviation	"Best" Measurement
Air Voids	6.77	0.44	Rice specific gravity
VMA	6.15	0.90	Bulk specific gravity of aggregate
VFA	4.00	1.68	None identified
Dust Asphalt Ratio	4.46	1.85	None identified
Film Thickness	3.31	1.89	MS-2 Procedure

*Scaled ratings:
1 – very strongly disagree
2 – strongly disagree
3 – disagree
4 – Neutral
5 – agree
6 – strongly agree
7 – very strongly agree