# Effects of Field Control of Filler Contents and Compaction on Asphalt Mix Properties

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**The objective of this study is to determine the effects on asphalt mixes of inadequate field supervision over filler content and compaction. Inadequate field control frequently leads to asphalt mixes with more fines in the mix production stage and less compaction than is desirable. An extensive laboratory program was executed in which these effects were studied. Varying the levels of compactive effort and filler content produced appreciable effects on the properties of asphalt mixes, but the effects were not consistent with the degree of variance. Voids are affected more by changes in the filler content than by compactive effort. The variation of modulus of resilience with changes in void content was established and suggests a definite relationship. Finally, a rational mix design procedure is suggested based on the results of the laboratory analysis.**

Pavement structures in Saudi Arabia are beset by a multitude of severe environmental conditions, such as high temperature and humidity. Compounding the environmental factors are problems related to mix design and construction techniques. Due to the nature of fragile aggregates in most areas of the Kingdom, especially in the central and eastern regions, asphalt pavements usually contain larger percentages of fine materials than originally planned. Local aggregates in general expand when soaked, leading to fracture of the aggregate, which means an increase in the fines content of the mix. The resulting increase in fines content is believed to affect field compaction results. One major step in ensuring better performance of roads starts with better understanding of the effects of these mix and field variables.

Kallas et al. (*1*) found that by changing the concentration of filler up to a certain value, stability increases and optimum asphalt content decreases. As filler is added beyond that certain point, however, stability decreases. Tunnicliff (*2*), too, has demonstrated that as filler concentration increases, internal stability increases.

Kallas and Puzinauskas (*3*) found that sensitivity of mixes can be decreased by keeping the ratio of filler to asphalt at a sufficiently low level. This can be achieved either by increasing the asphalt content or by decreasing the filler concentration in the mixture, within limits that allow satisfactory air voids, stabilities, and flow values.

The interaction between compactive effort and filler content is not well established. The precise correlation between binder viscosity and the compactive effort required to densify a paving mixture needs to be found. Some research shows, however, that fillers increase the amount of effort necessary for compacting specimens to the same volume or air void content (*4*). In other research, Bissada (*5*) concluded that resistance to compaction is significantly affected by mix variables such as filler content.

The objectives of this study are as follows:

- To study the effects of field variations in filler content and degree of compaction on Marshall mix design criteria.
- To establish the effect of those variations on mechanistic properties, such as modulus of resilience.
- To suggest a rational mix design procedure that takes into account those effects.

## MATERIAL CHARACTERIZATION

The aggregate used in this research was brought from Al-Mahdiyah, which is approximately 30 km west of Riyadh. This aggregate is widely used in the Riyadh area for asphalt concrete mixes. The other material used, asphalt, was obtained from Petromin Riyadh Refinery.

### Aggregate

Several tests were conducted to characterize the aggregates to ascertain their conformity with both ASTM and AASHTO specifications, as applicable. Table 1 gives the results of quality tests performed on the aggregates.

### Asphalt

The results of quality tests performed on the asphalt from Riyadh Refinery are given in Table 2.

## DESIGN OF EXPERIMENT

The steps outlined in Figure 1 describe the procedure for determining how varying filler content and compactive effort affects the properties and performance of asphalt mixes.

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TABLE 1 RESULTS OF QUALITY TESTS ON AGGREGATES

| Test | Designation of Method | Result | Specification |
|---|---|---|---|
| Sand equivalent (%) | AASHTO T-176 | 59.0 | Min 45 |
| Plasticity index | T-90 | Nonplastic | Max 3 |
| Clay lumps and friable particles (%) | T-112 | 0.00 | Max 1 |
| Los Angeles abrasion (%) | T-96 | | |
| Grade B | | 25.2 | |
| Grade C | | 25.5 | |
| Grade D | | 25.3 | Max 40 |
| Specific gravity of combined aggregate | T-84 | | |
| Bulk specific gravity over dry | T-85 | 2.540 | |
| Apparent specific gravity | | 2.681 | |
| Absorption (%) | | 2.314 | |
| Specific gravity of filler material | C-854 | 2.754 | |
| Crushed aggregate (%) | | | |
| Particles passing No. 4 retained on No. 8 | MOC[a] | 94 | Min 85 |
| Particles retained on No. 4 | MOC[a] | 97 | Min 90 |
| Thin and elongated aggregate (%) | MOR[b] | 2 | Max 10 |
| Soundness of aggregate sodium sulfate (%) | T-104 | | |
| Fine aggregate | | 4.9 | Max 10 |
| Coarse aggregate | | 8.4 | |

[a] Ministry of Communications, Saudi Arabia.
[b] Municipality of Riyadh, Saudi Arabia.

TABLE 2 RESULTS OF QUALITY TESTS ON ASPHALT

| Test | Designation of Method | Result | MOC[a] Specification |
|---|---|---|---|
| Penetration at 25°C, 100 gm, 5 sec | D5-78 | 68.0 | 60–70 |
| Viscosity at 135°C kinematic (Cst) | D2170-81 | 383.0 | |
| Flash point (°C) | ASTM D92-78 | 336.0 | 232.2 min |
| Ductility at 25°C | D13-79 | $100.0^{+}$ | 100.0 min |
| Thin-film oven test | T-179 | | |
| Penetration, percent of original | D5-78 | 60.3 | 52.0 min |
| Percent solubility in organic solvents | D2042-81 | 100.0 | 99.5 min |
| Specific gravity | D70-76 | 1.031 | |

[a] Ministry of Communications, Saudi Arabia.

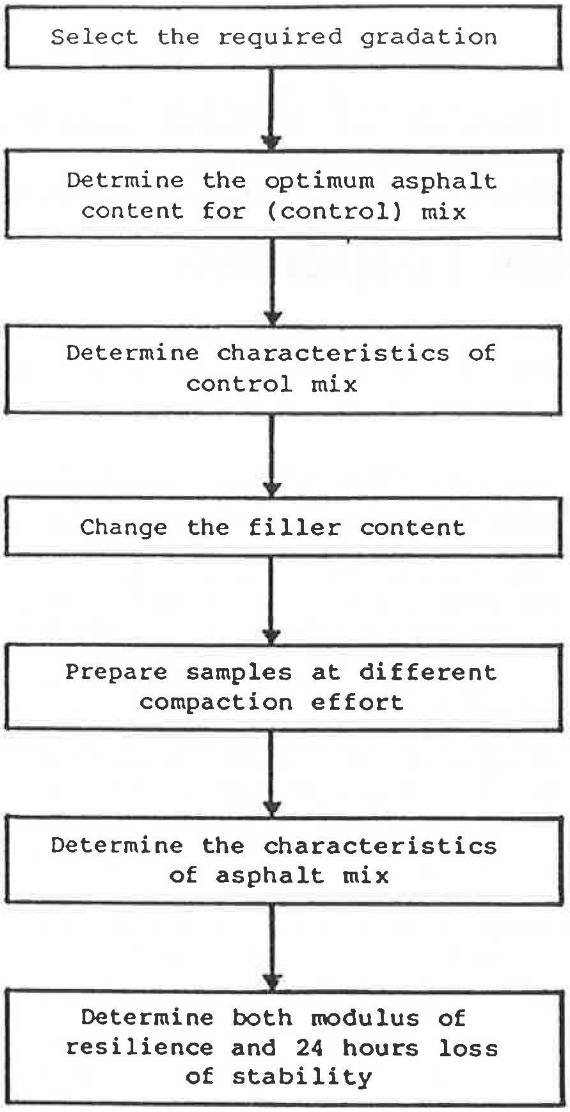

**FIGURE 1 Steps for determining sensitivity of asphalt mixes to changes in filler content and compactive effort.**

The initial design set 4.8 percent as the optimum asphalt content, with 7 percent filler content. (In this study, filler is defined as limestone dust passing the No. 200 sieve.) Mixes were then prepared with filler contents ranging between 0 and 12 percent, which represents the usual range of filler content in locally produced asphalt mixes. The change in the filler content from the optimum mix prepared with 7 percent filler was offset by proportionally decreasing or increasing the other aggregates. The asphalt content was not changed because the optimum asphalt content is dictated by the design; it is the amount of filler that varies, for the reasons explained earlier.

Table 3 shows the gradation of mixes used for various filler contents. These mixes were all prepared using 75 blows. In order to assess the effect of compactive effort, the procedure was repeated, but this time the mixes were prepared using between 30 and 90 blows. All mixes were prepared at a mixing temperature of 300°F and a compaction temperature of 280°F. Figure 2 gives the matrix of tests performed.

## EFFECTS OF CONSTRUCTION VARIATION ON MARSHALL MIX DESIGN CRITERIA

Several tests were conducted to determine the effect of construction variations represented by changes in both filler content and compactive effort on mix design variables. The aim of the tests was to find possible combinations of variations that could satisfy design requirements.

TABLE 3 AGGREGATE GRADATIONS USED FOR VARIOUS FILLER CONTENTS

| | Percent Passing | | | |
|---|---|---|---|---|
| Sieve No. | JMF for 0.0% Filler | JMF for 3.0% Filler | JMF for 7.0% Filler | JMF for 12.0% Filler |
| ¾ | 100.0 | 100.0 | 100.0 | 100.0 |
| ½ | 89.2 | 89.6 | 90.0 | 90.5 |
| ⅜ | 79.5 | 80.2 | 81.0 | 82.0 |
| 4 | 56.9 | 58.3 | 60.0 | 62.1 |
| 10 | 34.9 | 36.9 | 39.5 | 42.7 |
| 40 | 15.0 | 17.6 | 21.6 | 25.2 |
| 80 | 7.5 | 10.3 | 14.0 | 18.6 |
| 200 | 0.0 | 3.0 | 7.0 | 12.0 |

| No. of blows | % of filler content | | | |
|---|---|---|---|---|
| | 0 | 3 | 7 | 12 |
| 30 | X | X | X | X |
| 45 | X | X | X | X |
| 60 | X | X | X | X |
| 75 | X | X | X | X |
| 90 | X | X | X | X |

(X) Four samples were prepared for each cell

**FIGURE 2 Matrix of tests for determining effects of filler contents and compactive efforts.**

### Effect on Mix Stability

Figure 3 shows Marshall stability values for varying filler contents and at various compactive efforts. At the lowest compactive effort (30 blows), stability increases almost linearly with the increase in the percentage of filler used. However, for compactive efforts of 45 and 60 blows, stability increases up to a point as the filler increases, and then decreases. At higher compactive efforts (75 blows and above), stability generally continues to increase with the increase in the filler content of the mix.

As the filler-to-asphalt ratio increases, the viscosity of the mortar also increases, requiring more compaction energy to produce a uniformly compacted mix. At a very high compactive effort, the increased viscosity's resistance to compaction can be overcome. At lesser compactive effort, a mix with a high filler-to-asphalt ratio cannot be densely compacted and it will consequently possess a lower stability value.

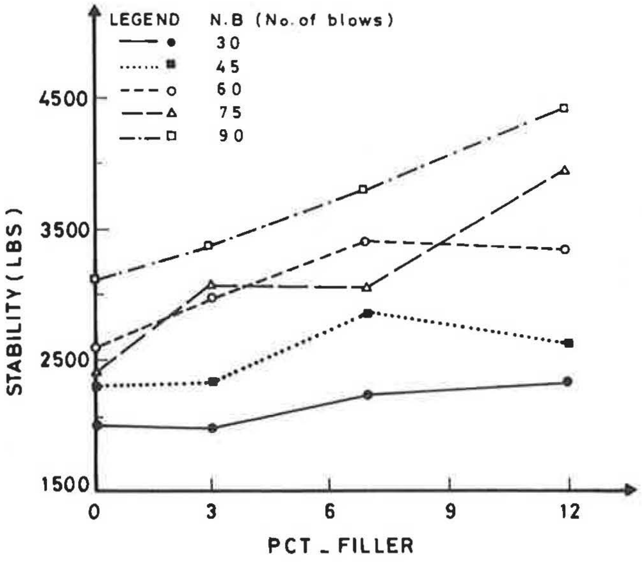

**FIGURE 3 Effect of percentage of filler in the mix on Marshall stability.**

### Effect on Mix Voids

Changing both the filler content and the compactive effort affects the amount of air voids in the asphalt mix. As Figure 4 indicates, air voids in the mix are more sensitive to changes in the percentage of filler at higher compactive efforts (60 blows and above). It also appears that, for all compactive levels, raising the percentage of filler content yields a smaller percentage of air voids up to an optimum percentage of filler. Filler contents higher than this optimum tend to lead to an increased percentage of air voids as the mix becomes more resistant to compaction.

It is important to establish how air voids in the mix affect other mix properties such as bulk specific gravity and stability.

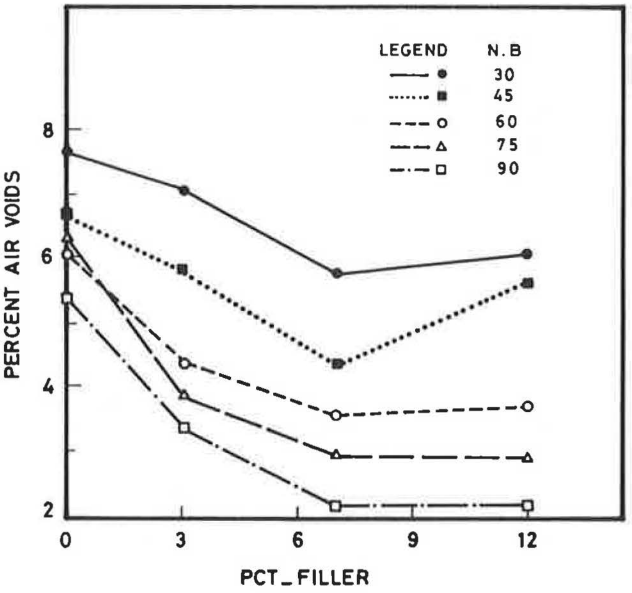

**FIGURE 4 Effect of increasing percentage of filler on air voids for various compactive efforts.**

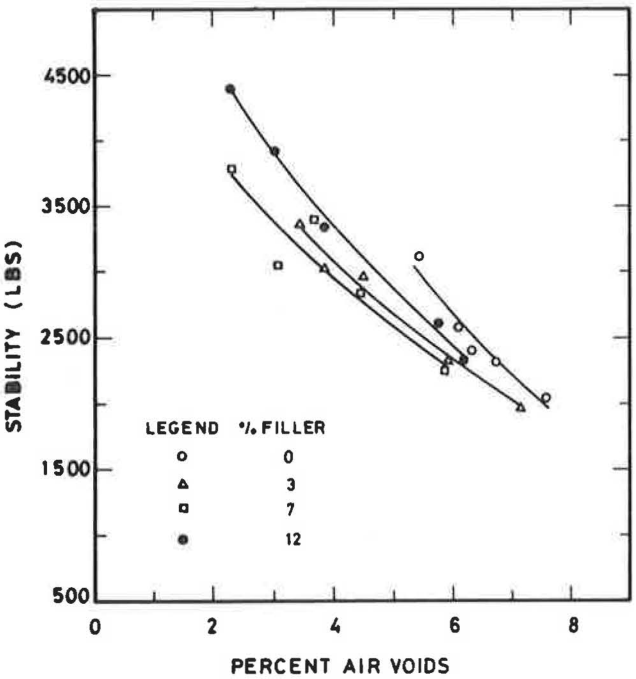

**FIGURE 5 Variation in mix stability with air voids for various filler contents.**

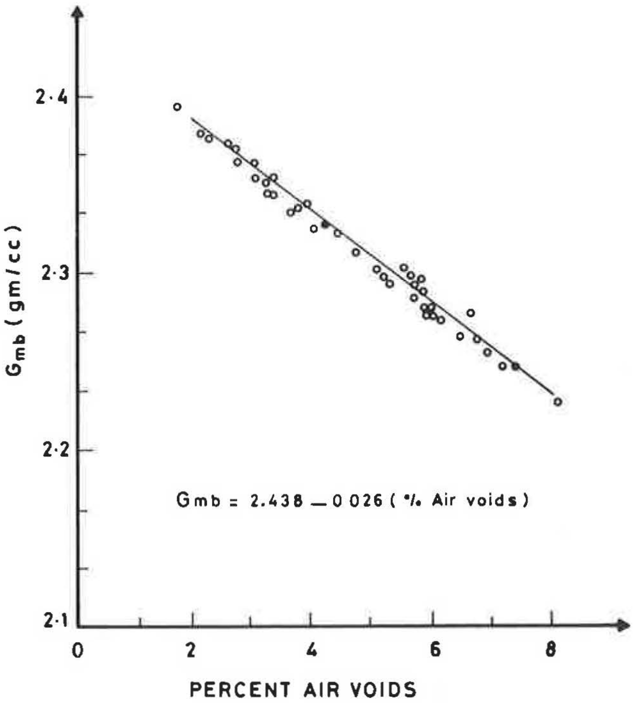

**FIGURE 6 Relationship between mix air voids and bulk specific gravity.**

The voids for each test, which corresponded to either a specified filler content or the compactive effort, were therefore plotted against the resulting Marshall stability and specific gravity; the results are shown in Figures 5 and 6, respectively.

Figure 5 shows that for all mixes, with different filler contents, stability decreases as the percentage of air voids increases. The effect of filler content is more pronounced at lower air voids (that is, at higher compactive efforts). Also notable is that for a selected stability value, e.g., 3,000 lb, an increase in filler content from 0 to 7 percent is associated with a reduction in air voids from about 5.5 percent to about 3.9 percent. However, any further increase in filler content results in higher air voids (about 4.8 percent) at the selected stability value. This can be explained by the sharp increase in the viscosity of the filler/asphalt mortar when the filler content exceeds 7 percent (filler-to-asphalt ratio of 1.46), which was found with a sliding plate microviscometer to vary as follows:

| *Filler-to-Asphalt Ratio* | *Absolute Viscosity at 25°C (poises × $10^6$)* |
|---|---|
| 0.00 | 1.31 |
| 0.63 | 2.98 |
| 1.46 | 10.32 |
| 2.50 | 26.21 |

The increase in stability caused by the sharp increase in the stiffness of the mortar apparently more than counteracts the reduction in stability associated with the increase in air voids resulting from higher resistance to compaction.

Similarly, Figure 6 shows that the bulk specific gravity of these mixes decreases when air voids increase, no matter what causes the void increase. The maximum theoretical specific gravity corresponding to a voidless mix is 2.438.

### Effects on Other Mix Properties

The effects of compactive effort and percentage of filler on other mix design properties (voids in the mineral aggregate (VMA), voids filled with bitumen (VFB), and flow) are shown in Figure 7. The variation in VMA is, as expected, similar to that shown earlier in Figure 4 for air voids because asphalt cement content was the same for all mixes.

The percentage of VFB, which is used as a mix design criterion in Saudi Arabia, was calculated as follows:

$$VFB\ (\%) = \frac{VMA - \text{air voids}}{VMA} \times 100$$

Figure 7(b) shows VFB variation with changes in percentage of filler and compactive effort.

Figure 7(c) shows that reduction in filler content beyond 7 percent—the level at which optimum asphalt content was determined—results in a larger decrease in flow than when filler content rises above the 7 percent value. However, the relationship between the rate of reduction in flow and the compactive effort cannot be well defined. In general, test results were erratic and the precise effect of both variables on flow could not be established.

### Effect on Loss of Marshall Stability

The effect of field control procedures on loss of Marshall stability holds pronounced local interest because existing asphalt pavements exhibit poor water resistance. Figure 8 shows the percent loss of Marshall stability after specimens were soaked

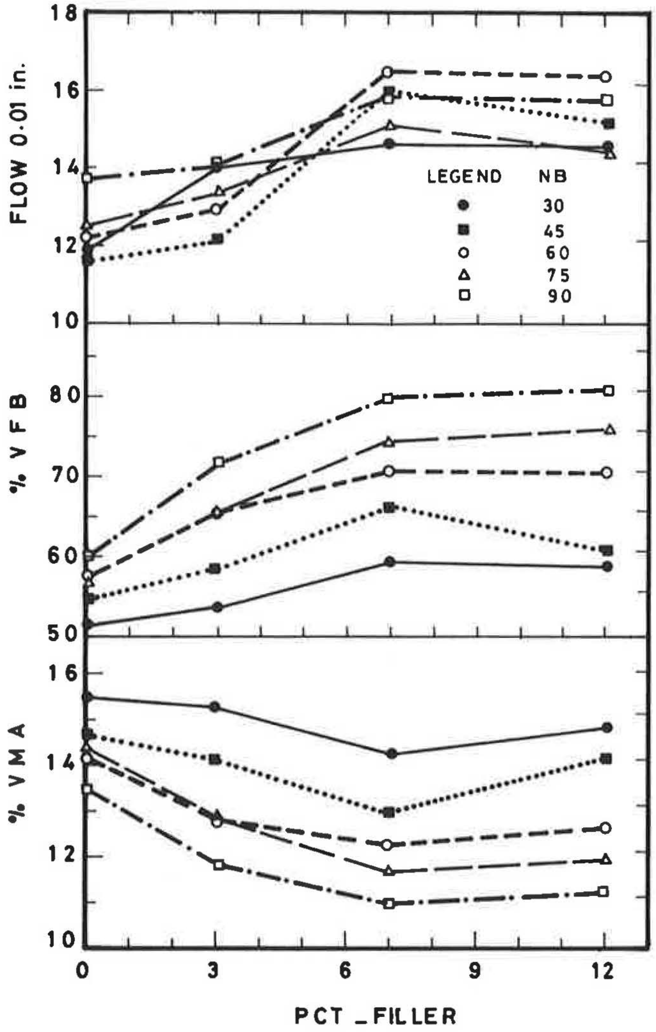

**FIGURE 7 Effect of percentage of filler on percent VMA, percent VFB, and flow for various compactive efforts.**

in water for 24 hr at 60°C. Varying filler content affects the percent loss of Marshall stability according to the compactive effort applied. At lower compactive efforts (30, 45, and 60 blows), any increase in filler content (within the range studied) causes a reduction in the percent loss of Marshall stability. The rate of the reduction decreases with the increase in filler content. At higher compactive efforts (75 and 90 blows), however, percent loss of Marshall stability decreases only until the optimum filler content (i.e., 7 percent) is reached.

## EFFECTS OF CONSTRUCTION VARIABLES ON MECHANISTIC PROPERTIES

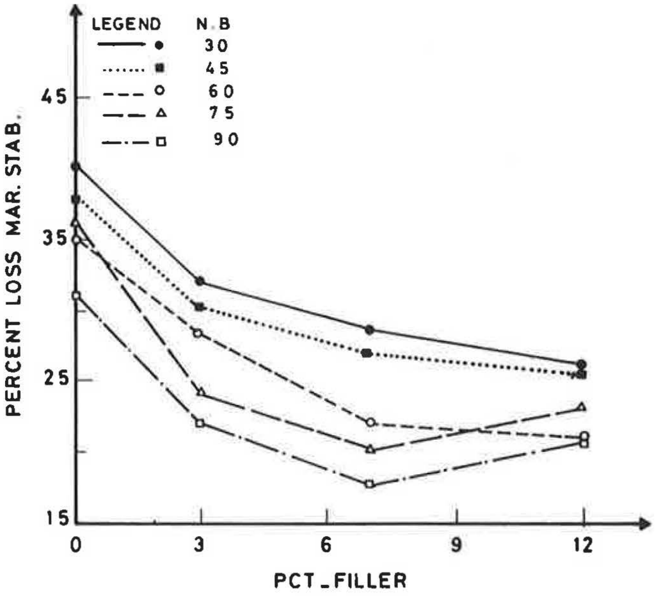

**FIGURE 8 Effect of increasing percentage of filler content on loss of Marshall stability for various compactive efforts.**

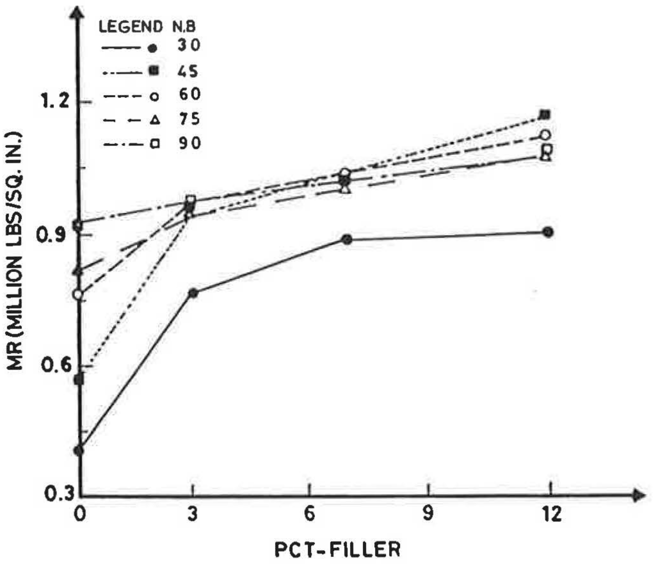

**FIGURE 9 Effect of increasing percentage of filler content on modulus of resilience for various compactive efforts.**

In order to study the effects of field control on the mechanistic response of the mix [i.e., the modulus of resilience ($M_R$)], tests were carried out on samples prepared according to the matrix in Figure 2. As Figure 9 shows, test results indicate that $M_R$ values are not sensitive to variations in filler content at high compactive efforts (60, 75, and 90 blows). The results also indicate that the reduction in $M_R$ values resulting from a drop in filler content can be offset by increasing the compactive effort.

The effect of air voids in the mix on the $M_R$ was also established. Figure 10 shows test results, which indicate that $M_R$ drops drastically at air void contents around 6–8 percent. Test results also indicate that, for mixes with 3 percent or more filler content, the reduction in air voids achieved by higher compactive efforts has relatively little effect on $M_R$ values where the variation of $M_R$ values is within 10–20 percent for the different levels of compactive effort used. For mixes with 0 percent filler content, however, the variation in $M_R$ values is greater (above 50 percent), pointing to the sensitivity of

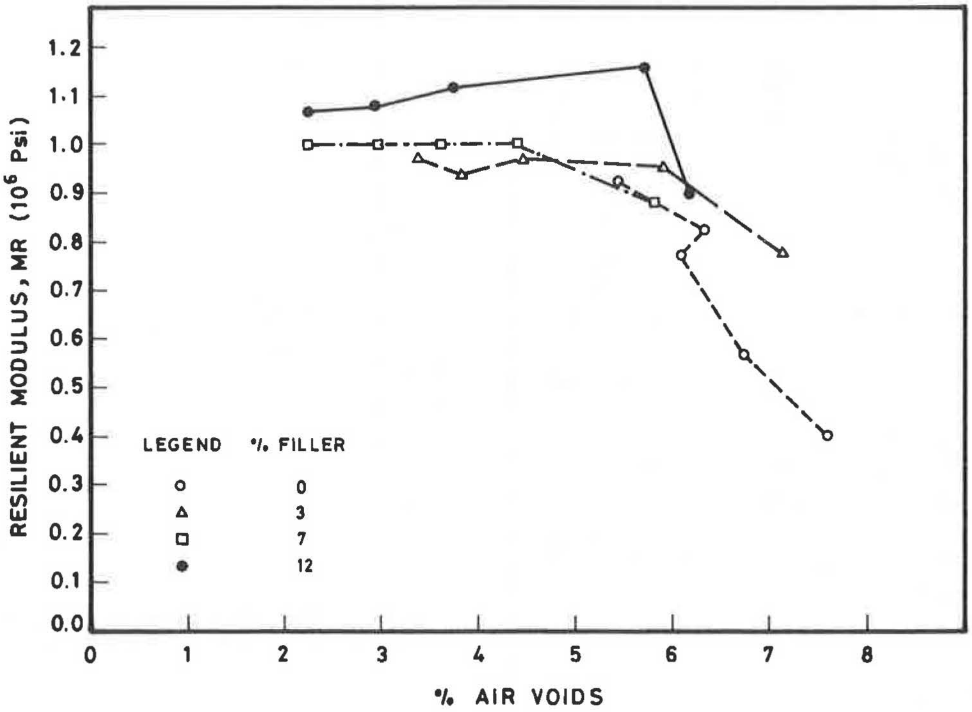

FIGURE 10 Variation of resilient modulus with air voids for various filler contents.

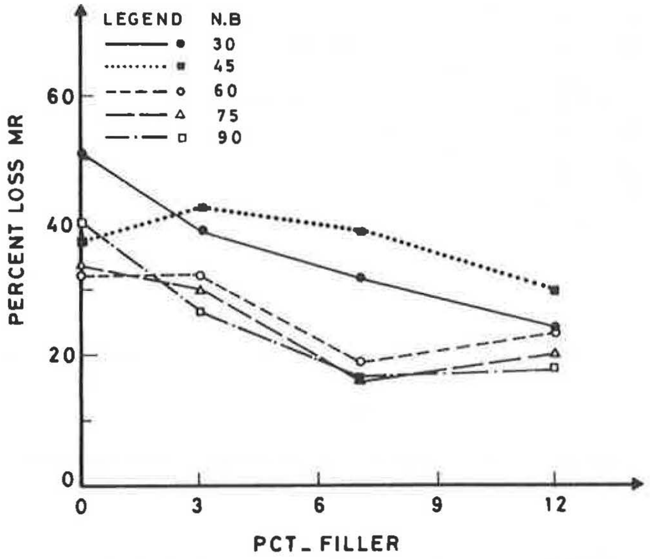

FIGURE 11 Effect of increasing percentage of filler content on $M_R$ loss for various compactive efforts.

the mixes to air void variation. Because mixes with low filler content are associated with high air voids, it is especially important that the compactive effort for such mixes be strictly controlled.

The effect of variations in filler content and compactive effort on the moisture susceptibility of the mixes was also evaluated using the $M_R$ test. Specimens were immersed in water for 24 hr at 60°C and $M_R$ values for those specimens were then determined at 25°C. The percentage loss of $M_R$ caused by immersion was established; test results are in Figure 11. The percentage loss in $M_R$ values generally decreases as the percentage of filler in the mix increases. When filler content is increased above 7 percent, resistance to moisture damage is improved only for mixes with lower compactive efforts (30 and 45 blows), probably because these mixes have high air void values.

## RATIONAL MIX DESIGN

The aim of the proposed mix design is to determine optimum asphalt content of the mix by taking into account the effects of filler content and compactive effort in the process. In addition, more criteria are specified in order to arrive at the optimum asphalt content. Table 4 shows the properties and values that went into this analysis. Besides the criteria in Table 4, a minimum VMA value of 14 percent was selected based on an aggregate nominal maximum particle size of ¾ in.

The mix design draws on the various relationships estab-

TABLE 4 SPECIFICATIONS FOR DETERMINING THE OPTIMUM ASPHALT CONTENT

| Mix Property | Specification |
|---|---|
| Stability (lb) | Min 1,550 |
| Flow (0.01 in.) | 9.4–15.7 |
| Percent loss of stability | Max 25 |
| Percent air voids (AV) | 3–5 |
| Percent voids filled with bitumen (VFB) | 70–80 |

NOTE: Based on specifications for the Ministry of Communications, Saudi Arabia.

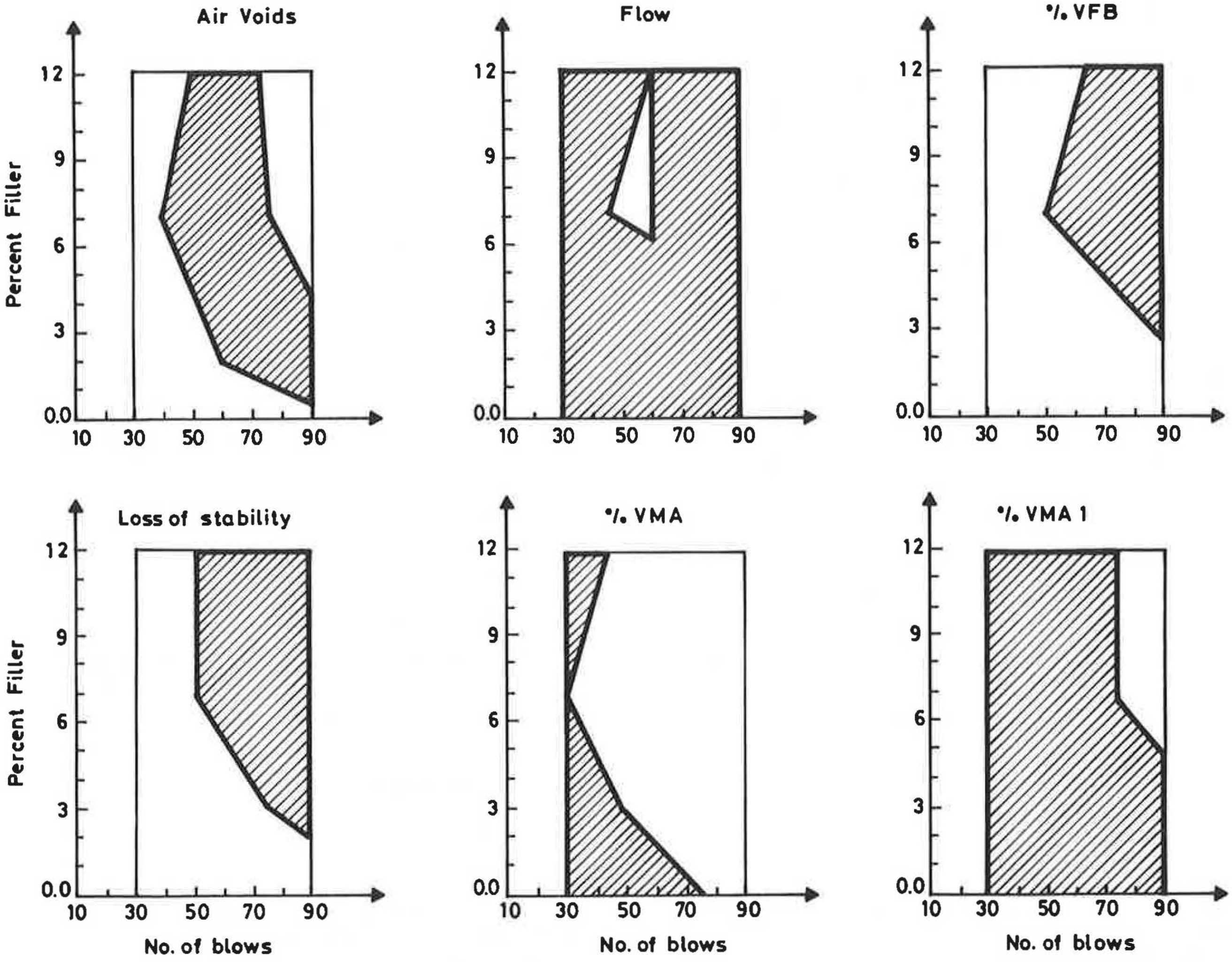

FIGURE 12 Ranges of compactive effort and filler contents that satisfy mix design criteria.

lished earlier between mix properties and changes in both percentage of filler used and the number of compaction blows administered. For each variable at the specified limit, the ranges for number of compaction blows and percentage of filler contents that satisfy these limits were established; the results are shown in Figure 12. For example, the dashed range for percent-VFB was set by interpolating the possible combinations of filler content and compactive effort (see Figure 7-b) that render VFB values between 70 and 80 percent (as specified in Table 4). The plot for flow contains within it an area of unacceptable combinations of compactive effort and filler content, probably because the test results for flow, as shown in Figure 7, were so erratic. Stability is not addressed at all in Figure 12 since it is satisfied for all mixes.

The overall results of the analysis are shown in Figure 13. The range of allowable filler content and compactive efforts should satisfy all the criteria established in Table 4. Ideally, a "common" block would satisfy all criteria simultaneously, yet obviously there is no "zero" common block in this case; no mix satisfies all requirements.

One important reason is that all void criteria cannot simultaneously be met. Figure 14 illustrates the theoretical relationship for voids while the dashed area indicates the range that satisfies the requirements of Table 4 for voids (air voids and VFB). If the VMA requirement is also introduced, it is obvious that the size of the dashed area will decrease as the minimum VMA required increases. For the type of aggregate used in this study, an acceptable range of compactive efforts and filler contents that could satisfy all three void criteria simultaneously could not be found.

To address that problem, a new set of voids in mineral aggregates (hereafter VMA1) was established, based on the apparent specific gravity (2.681) rather than on the bulk specific gravity of the aggregates (2.540). Using apparent specific gravity allowed an increase in the calculated VMA; consequently, an acceptable range could be set for filler content and compactive effort that satisfy mix-design requirements (see Figure 15). The range of acceptable filler content is between 3 and 12 percent if the compactive effort used to produce the mix ranges between about 60 and 90 blows. This range indicates that the mix is more sensitive to variations in compactive effort than to variations in filler content.

Figure 15 also shows that if the filler content of the mix exceeds the design value (7 percent), strict control on com-

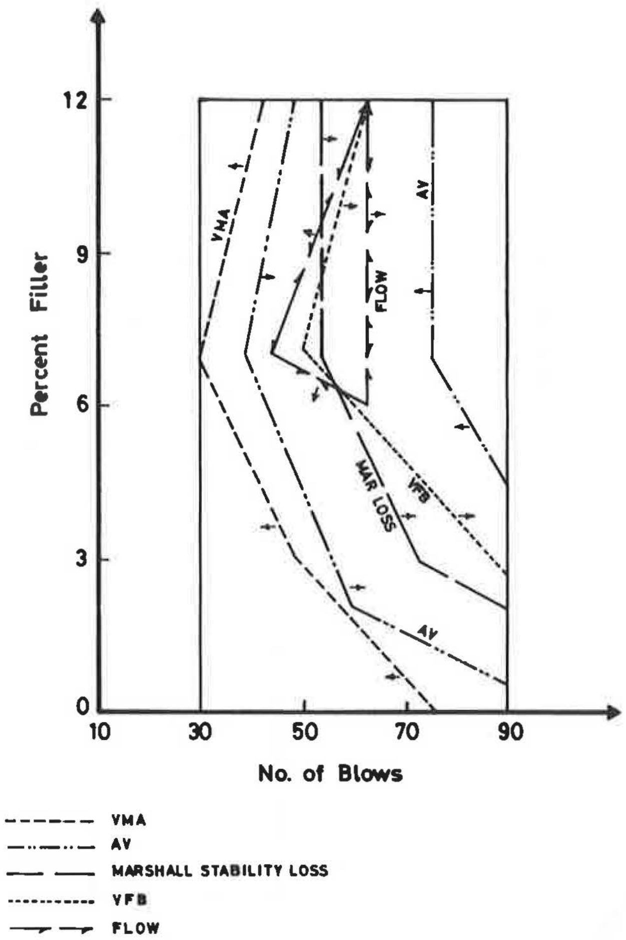

FIGURE 13 "Zero" common block boundary of compactive effort and filler content that satisfies mix variables (VMA based on bulk specific gravity of aggregate).

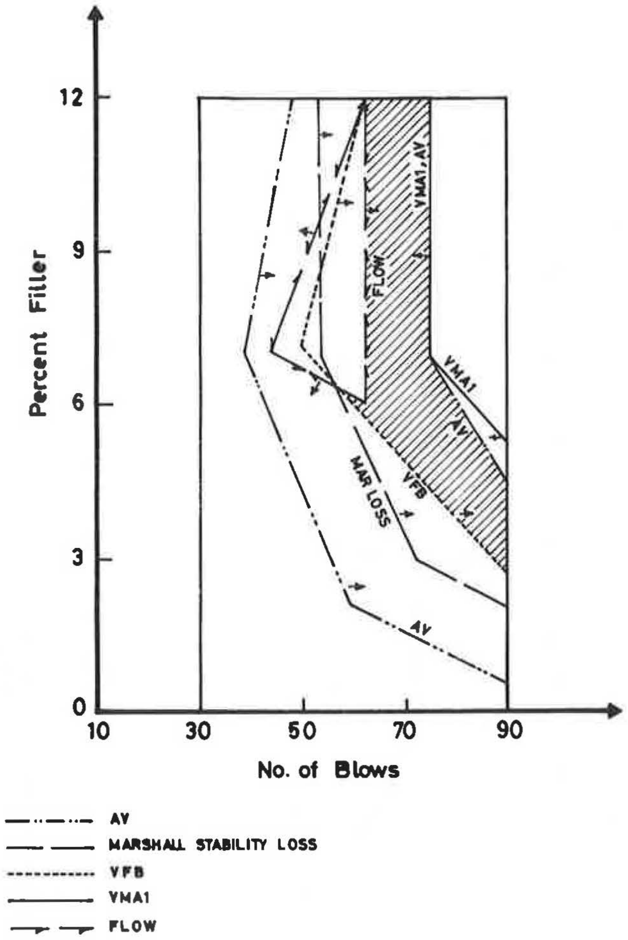

FIGURE 15 "Common Block" boundary of compactive effort and filler content "dashed area" that satisfies mix variables (VMA based on apparent specific gravity of aggregate).

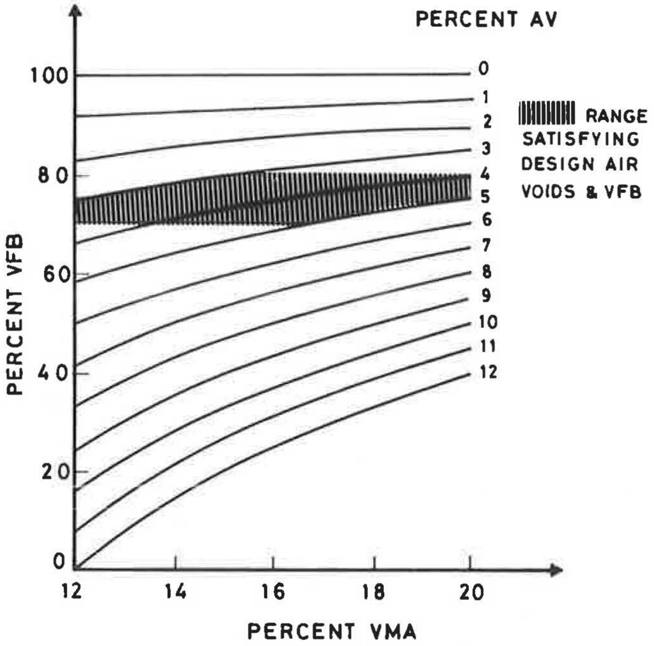

FIGURE 14 Theoretical relationship between VFB and VMA for various air voids.

paction must be applied to ensure that the mix will satisfy design criteria. On the other hand, overcompacting this mix above 100 percent (corresponding to 75 blows) will produce unacceptably low air voids. Nevertheless, air voids could be satisfactory at the high compactive effort if filler content is reduced beyond the design value.

## SUMMARY AND CONCLUSIONS

The results of this study have demonstrated that the effect of field control on properties of mix design is appreciable. Most important is the effect on mix voids which, in turn, directly affects the $M_R$ of the mix and the water-resistance of asphalt mixes. Incorporation of the effects of field variables in a rational mix design procedure was illustrated, and the difficulty of simultaneously satisfying all void criteria was apparent. Nonetheless, the field compaction and filler contents can vary in the field and still produce acceptable mixes.

The results of the study provide the basis for setting better specifications on both degree of compaction and percentage of filler contents. Please note, however, that the results of this study are based on only one type of aggregate and filler.

The conclusions of this study can be summarized as follows:

- The degree of compaction and filler content can vary and still produce acceptable mixes, which points up the need for setting specifications on both degree of compaction and percentage of filler content.
- Within the range of filler contents studied, mix design criteria are more sensitive to decreasing the filler content than to increasing it above the design value.
- The effect of decreasing air voids on modulus of resilience is more pronounced at high air voids (above 6 percent), whereas the effect of decreasing air voids on Marshall stability is more pronounced at lower air voids.

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