CHAPTER 5

ANALYSIS AND DISCUSSION OF RESULTS

5.1 Determination of optimum SEA binder percentage

5.1.1 Effect of increasing percent sulphur in SEA binder percentage on unit weight of mixture

Results obtained are the average value of three separate determination. From Figure 14 it is seen that in general, increasing the percentage of sulphur in the SEA binder results in an increase of unit weight of mixture. This is due to the fact that as the percent of sulphur is increased the weight of SEA binder in the mixture is also increased while its volume remains the same.

5.1.2 Effect of increasing percent sulphur in SEA binder on Marshall sulphur in SEA bindr on stability level

Results of the test are given in Table 29 and plotted in Figures 15 and 16. From Figure 15, it can be seen that for the percent sulphur

Table 29. Effect of percent sulphur on stability (kg)

Range of % SEA binder*	% sulphur by weight				
	20	30	40	50	60
5.45	956	1030	1948	3302	5050
5.65-6.20	961	1083	1814	3363	5229
5.85-6.95	981	1013	1814	2630	3084
6.04-7.72	963	1000	1543	2208	3274

*Note : For actual values of % SEA binder, refer to Tables 19-23

about 30, there is relatively little change in the stability values when compared to those of normal asphalt mixture. However, as the sulphur percentage is increased above this value, the stability values begin to increase significantly and at a rapid rate as illustrated in Figure 16. The increase may be attributed to sulphur recrystallizing at temperature (60°C) much lower than compaction temperature range (121° to 138°C). The recrystallized sulphur gives additional structuring to the mixture. Detailed study on the role of sulphur in SEA payement was conducted by Mcbee et al.[20]

5.1.3 Effect of increasing percent sulphur on air voids

it is clear from Figure 17 that the percent of air voids generally increased with increasing percent of sulphur. This trend was also established by Mcbee.[15, 16] Variation of air voids for the five SEA binder percentages are within the range 3.49 to 8.76 %. This is comparable with the Asphalt Institute[31] Marshall design criteria which set the mimimum and maximum percent air voids at 3 and 5 respectively. . The Thai Department of Highway[29] allows 3 to 5 % air voids for mix used in wearing course and 3 to 7 % for use in binder course. The lower limit of air voids is to ensure that small amount of addition compaction by traffic can take place without flushing, bleeding and loss of stability; while the upper limit is set to ensure that the mix is sufficiently impermeable. From the test results, the lower limit is satisfied. As for the upper limits, although some of the results exceed these values, they may not affect the impermeability of the mix. Tests conducted by Gallaway and Saylack[33] indicate that for a given air void content, the SEA mixture was less permeable than bituminous concrete; for example, it was found that SEA mixes with 16 percent air voids have the same pemeability as bituminous mixes with 6 percent air voids. The phenomenon was explained by Dene, Hammond and McManus[2] who concluded that most of the air voids in SEA mixes appeared to be entrapped by the sulphur causing them to be sealed off from water penetration.

5.1.4 Effect of increasing percent sulphur on level of Voids in Mineral Aggregate (VMA)

Voids in mineral aggregate is the space occupied by the volume of air and volume of net binder. Thus, it exibits an increasing trend with increasing sulphur percentage, same as that of the percent air void. The percent voids in mineral aggregate for each SEA binder percentage generally decrease to a minimum value then increase with increasing binder contents. Variation of VMA values from the tests range from 14.09 to 17.99 percent which is allowable under the Marshall design criteria which require a mimimum VMA of 14 % for nominal maximum aggregate size of 3/4 in. (See Table 10). The Thai Department of Highway specifications set the allowable range at 15 to 20 %

Figure 18 shows results of VMA plotted against percent of binder.

5.1.5 Effect of increasing percent of sulphur on voids filled with binder

The effect is shown in Figure 19. It is seen that for a particular value of binder content the VFB decreases with increasing percentage of sulphur. It varies between 47.48 to 75.23 percent while the DOH specifications set the limits at 65 - 80 % for binder course and 75 - 80 % for wearing course.

5.1.6 Effect of increasing percent of sulphur on flow values

The effect of increasing percent of sulphur on flow values (measured in unit of 0.25mm) is tabulated in Table 30 and shown in Figure 20. The flow shows a decreasing trend with increasing sulphur

Table 30. Effect of percent sulphur on flow (0.25 mm)

Range of % SEA binder*	% sulphur by weight				
	20	30	40	50	60
5.45	23	20	13	10	11
5.65-6.20	23	21	15	11	13
5.85-6.95	25	22	17	11	14
6.04-7.72	26	25	21	12	16

*Note : For actual values of % SEA binder, refer to Tables 19-23

percentage. The initial increase in flow values at lower percent of sulphur, compared to those of the bituminous mixes may be caused by the reduction in viscosity of the binder material caused by the addition of sulphur. As percent of sulphur is increased, the strength of the mix as measured by stability is also increased and the mixture becomes stiffer, hence a reduction in flow values. The Marshall flow varies between the minimum of 10 and the maximum of 26 percent. The allowable range as specified by DOH is between 8 and 18 percent. For a particular percent of sulphur in SEA binder, the flow shows a marginal increase with increasing amount of binder content.

5.2 Influence of compaction temperature on mix properties

5.2.1 Influence of compaction temperature on stability

The temperature-sensibivity study was made to establish the workability of the mixtures with increasing percent sulphur in the

SEA binders. Tests were conducted for different percentages of SEA binder at levels of binder content that yielded maximum stability values as had been determined previously. Results of tests are given in Tables 24 to 28 of chapter 4 and illustrated in Figure 21. From the figure it appears that SEA mixtures containing less than 40 percent by weight of sulphur in the binder are only marginally sensitive to compaction temperature and can be prepared and placed on roadways with essentially the same mixing plants and paving equipment and at the same temperatures as those used for conventional paving, i.e between 107°C (225°F) and 135°C (275°F) for DOH construction procedures. For percent of sulphur greater than 40, the mixture are temperature sensitive and require final compaction above 130 . Similar observations were also made by Mcbee.[15] It should be mentioned that in the present study, at 60 percent sulphur content or SEA binder percentage of 60-40, segregation of aggregate was observed. As a result, the stability for samples using SEA binder percentage of 60-40 decreases slightly as shown in Figure 21.

5.2.2 Influence of compaction temperature on unit weight

The investigation was carried out for the SEA binder percentage of 40-60 which appears to be the optimum binder percentage. Test results are given in Table 26 of chapter 4 and depicted in Figure 22. It is clear from the figure that the unit weight of mixture is temperature sensitive. A significant gain in unit weight can be achieved at compaction temperature above 130°C. The results, in generally agree with work carried out by Mcbee and others[16] which showed a decrease in air voids content as compaction temperature is increased.

5.3 Summary of laboratory investigations

From the test results the optimum SEA binder percentage may be determined by, first finding the optimum values of SEA binder content, in terms of percent by weight of aggregate. These were obtained by averaging the values of binder contents at maximum unit weight and maximum stability for each of the SEA binder percentages. The next step is to compare the characteristics of mixtures at the computed optimum binder contents with those from the Marshall design criteria as given in Tables 9 and 10 in chapter 2. A summary of the comparison is shown in Table 31.

Table 31. Optimum values of binder content and some of their corresponding properties.

Ps-Pa	Optimum binder content %	Some Properties at the optimum binder contents				
		stability (kg)	% Air voids	flow (0.25mm)	% VMA	% VFB
20-80	5.81	980	5.50	24.6	16.3	66.1
30-70	5.78	1080	4.95	20.9	15.2	67.0
40-60	5.89	2070	5.15	14.5	15.1	65.5
50-50	6.24	3240	6.10	12.5	15.8	62.0
60-40	6.42	5080	6.51	11.1	15.9	59.0
Marshall design Criteria		Min.680	3-5	8-16	Min.14	65-80*

* THAI DEPARTMENT OF HIGHWAYS SPECIFICATION

From the table above it is seen that the SEA binder percentage of 40-60 i.e, 40 percent of sulphur by weight and 60 percent of asphalt gives acceptable results except for the percent air voids of 5.15 which is slightly greater than the limit set by the criteria. However, the percent air voids can be reduced by compacting at a slightly higher temperature as mentioned earlier, to bring it within the specified limit. Taking into consideration, the influence of compaction temperature on stability of mixtures, it appears that the 40-60 SEA binder percentage is the optimum value.

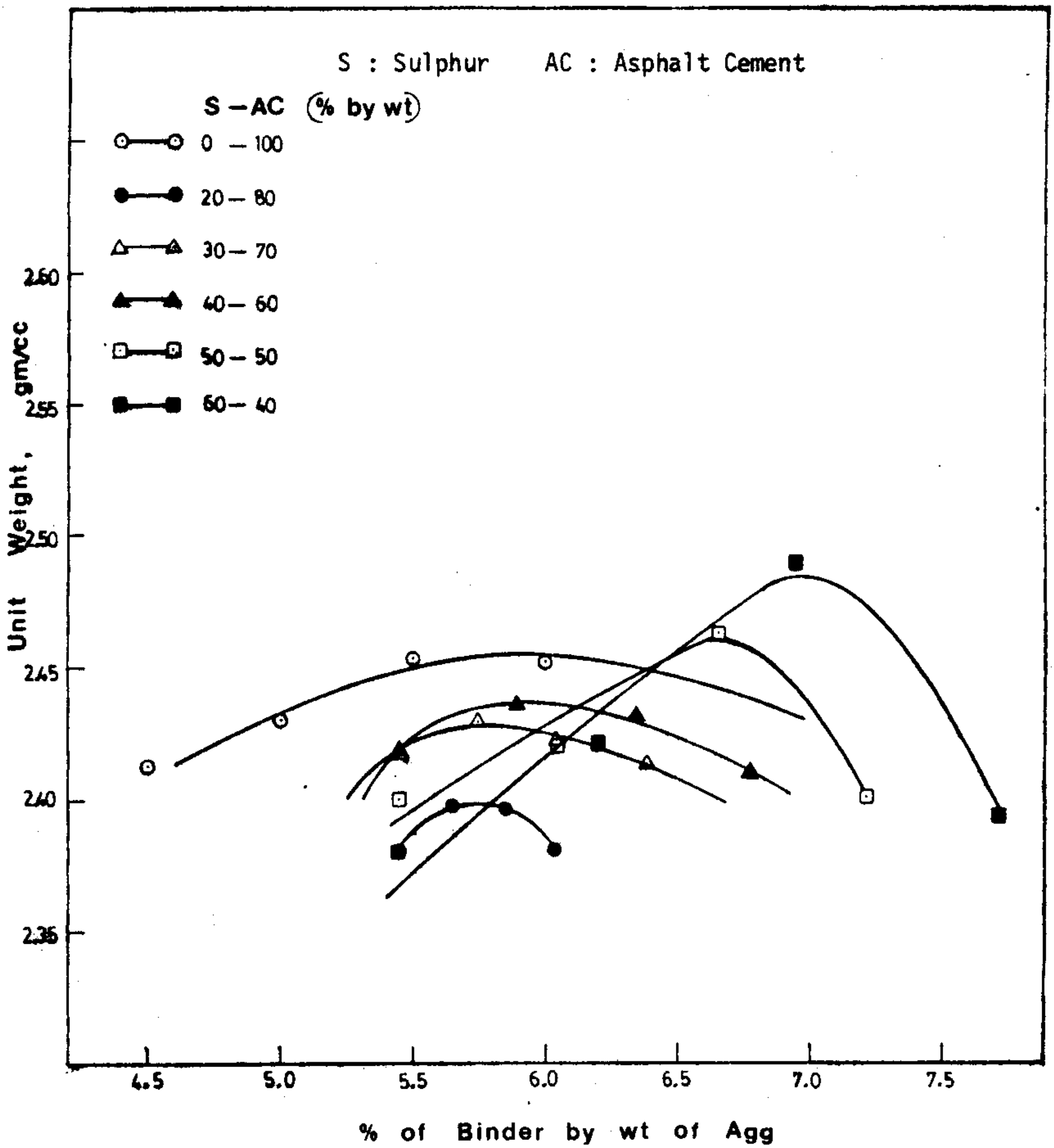

FIGURE 14. EFFECT OF PERCENT SULPHUR ON UNIT WEIGHT

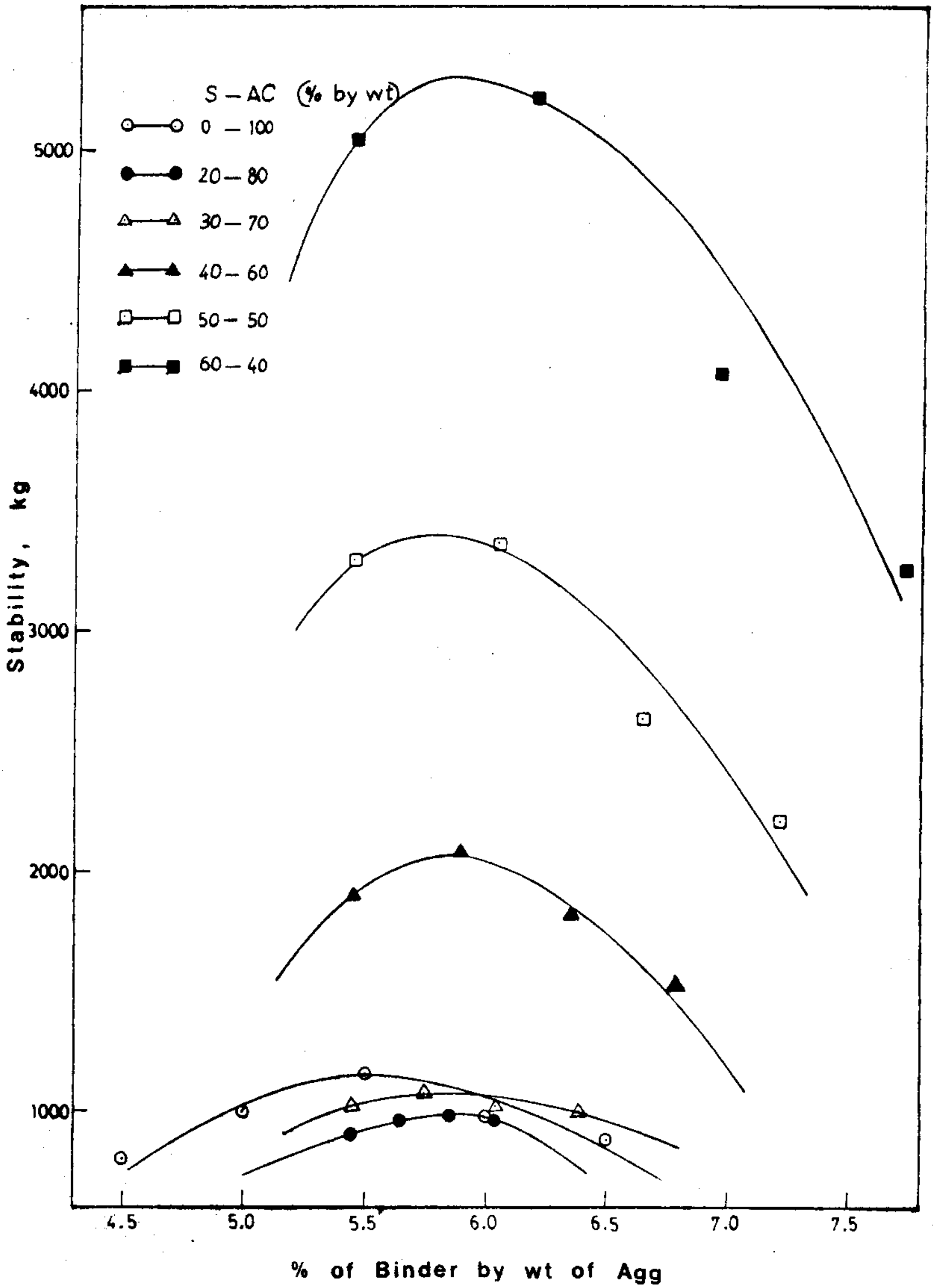

FIGURE 15. EFFECT OF PERCENT SULPHUR ON MARSHALL STABILITY

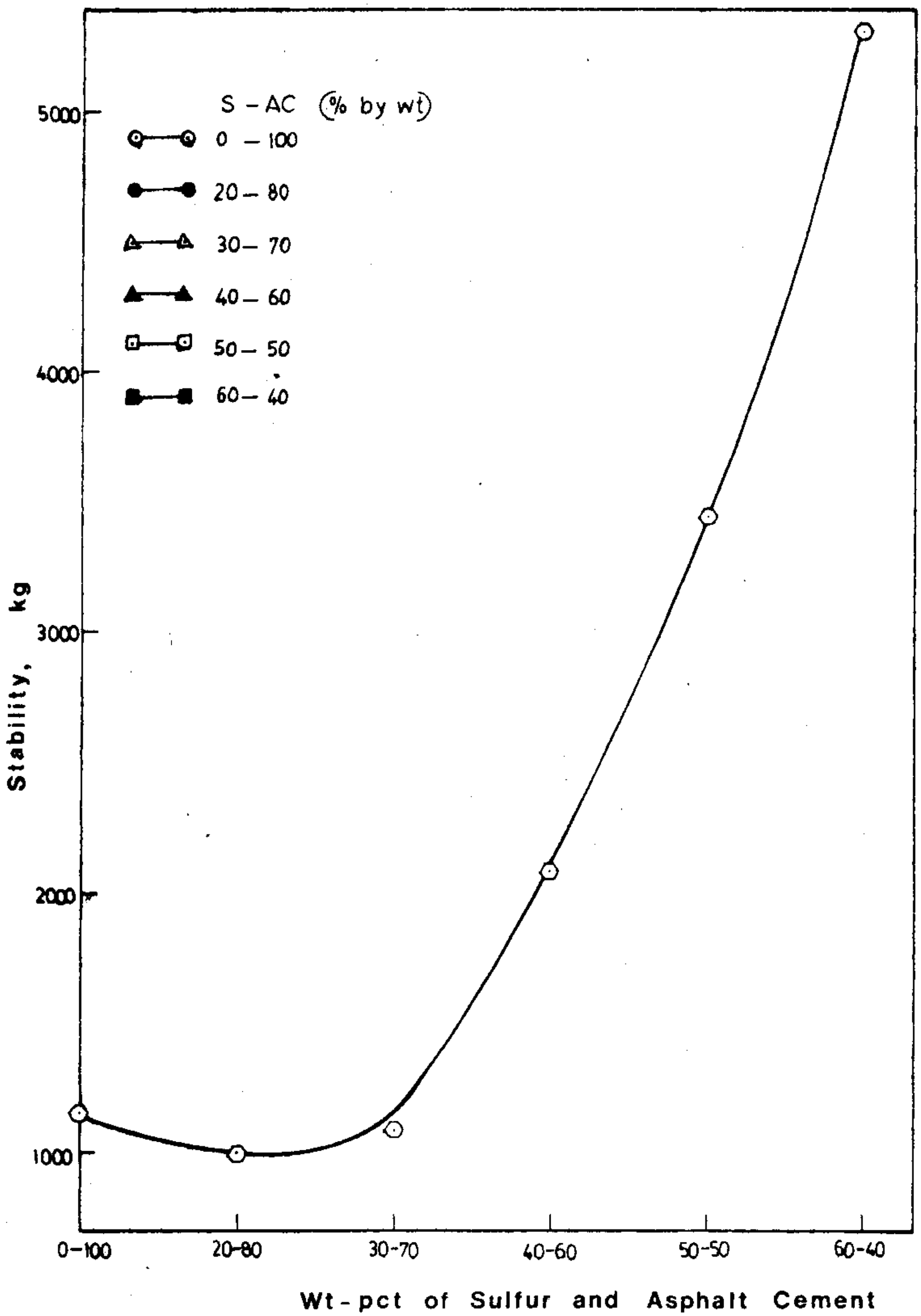

FIGURE 16. EFFECT OF PERCENT SULPHUR ON MAXIMUM STABILITY VALUES

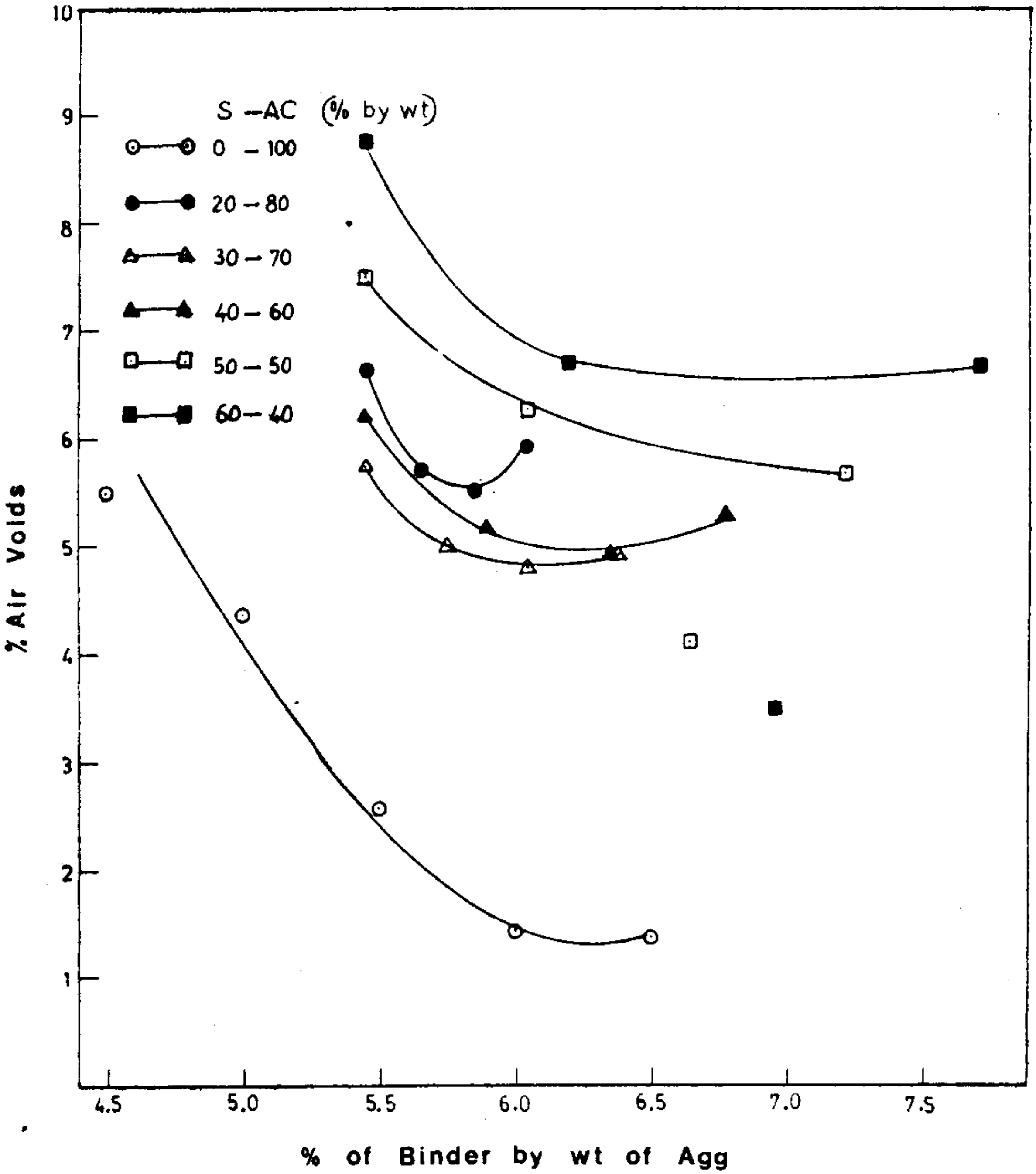

FIGURE 17. EFFECT OF PERCENT SULPHUR ON PERCENT AIR VOIDS

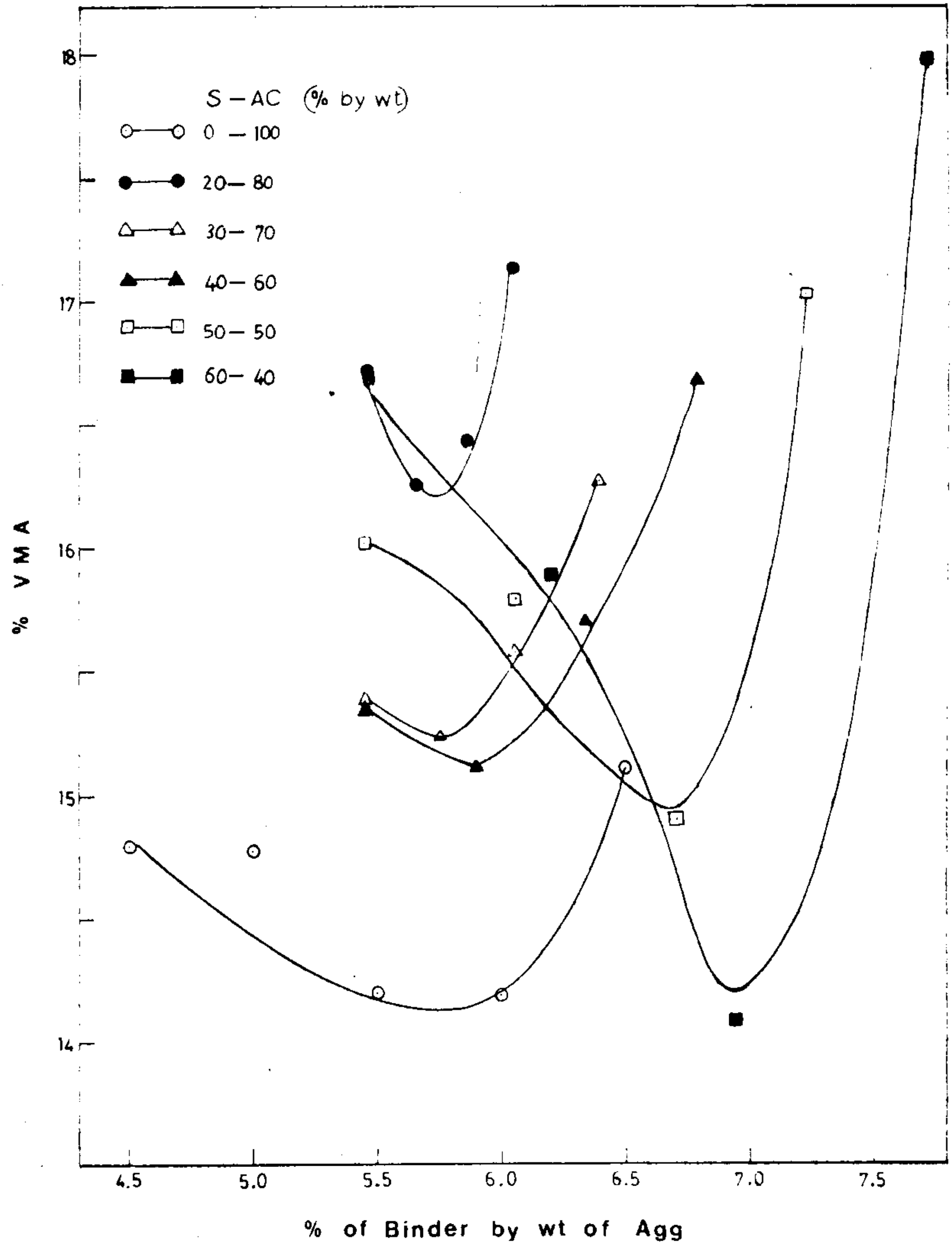

FIGURE 18. EFFECT OF PERCENT SULPHUR ON PERCENT VMA

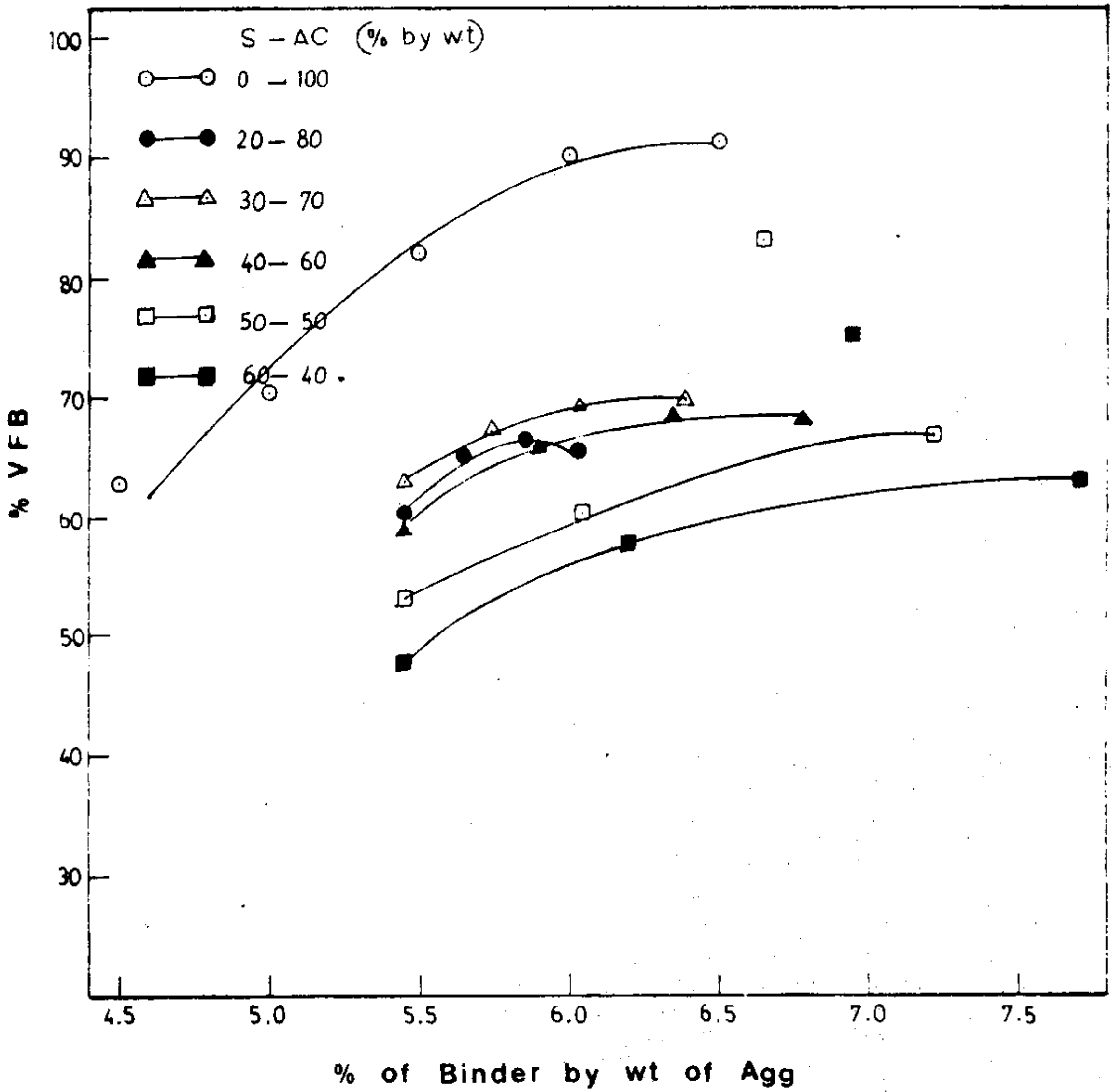

FIGURE 19. EFFECT OF PERCENT SULPHUR ON VFB

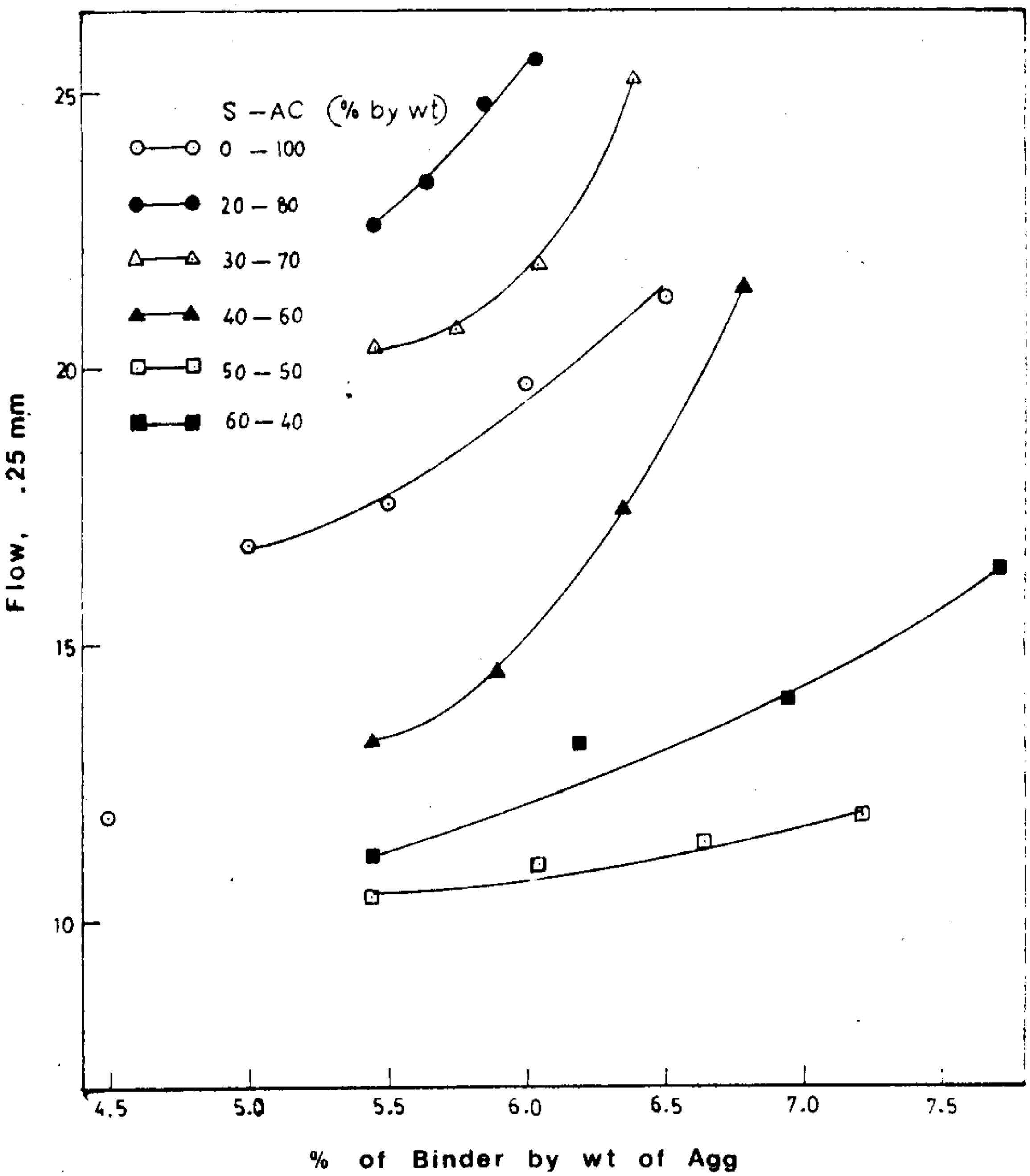

FIGURE 20. EFFECT OF PERCENT SULPHUR ON FLOW VALUES

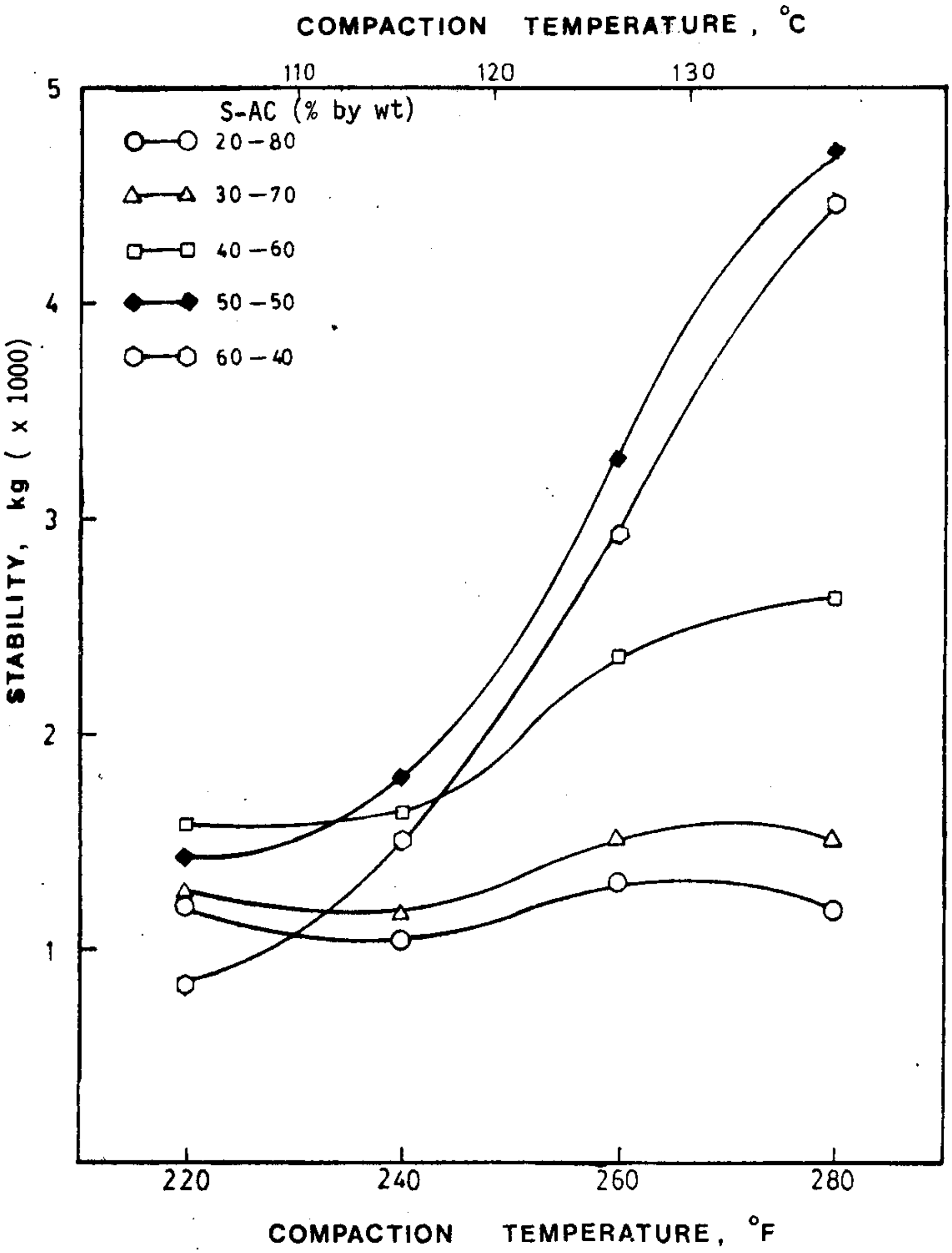

FIGURE 21. EFFECT OF COMPACTION TEMPERATURE ON STABILITY

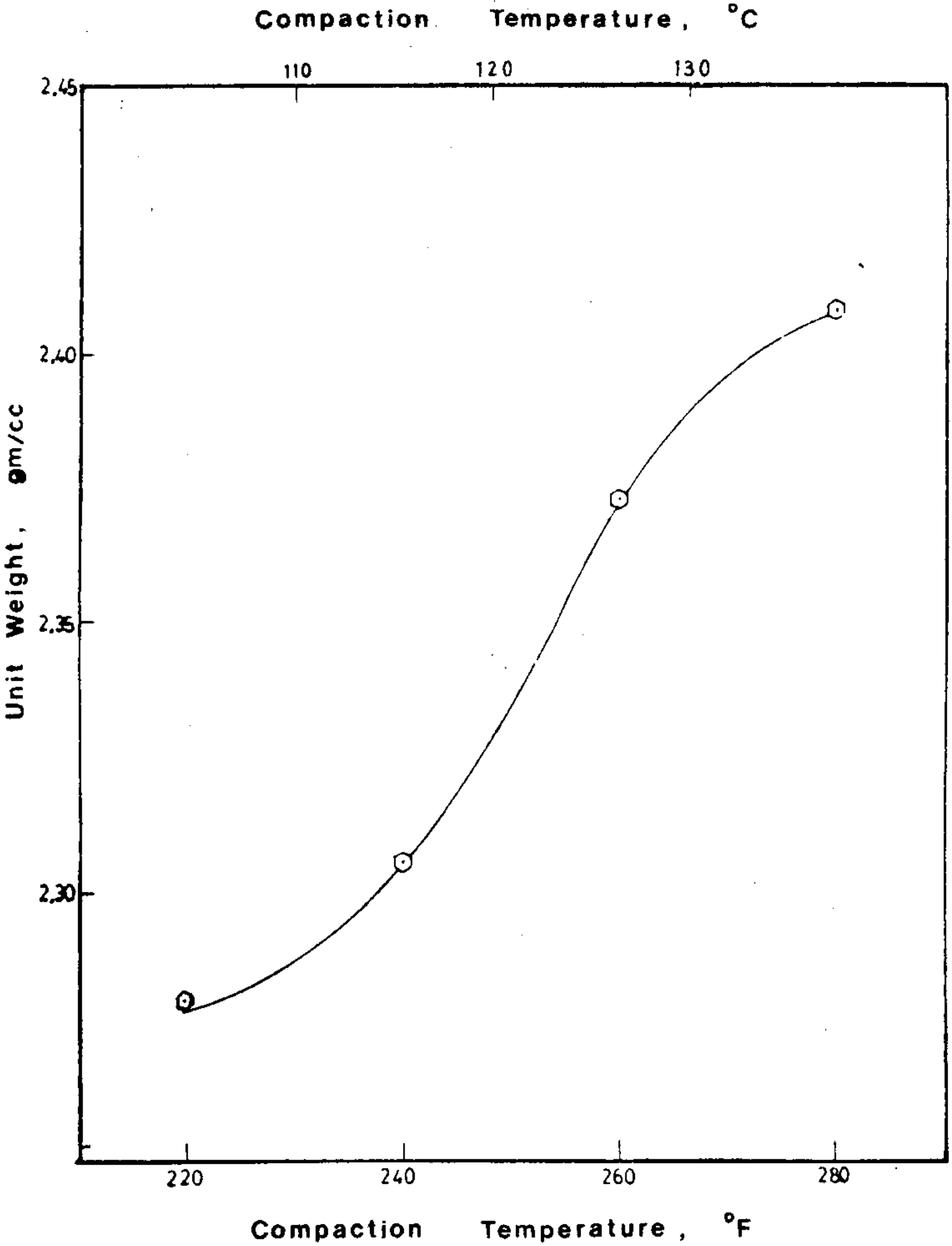

FIGURE 22. EFFECT OF COMPACTION TEMPERATURE ON UNIT WEIGHT.