EFFECT OF AGGREGATE PROPERTIES ON PAVEMENT SKID RESISTANCE

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Abstract: The skid resistance of an asphalt pavement is essentially a function of the properties of the aggregate in the surface wearing course. Depending on the shape, size, surface properties, and gradation of aggregate in the paving mixture of the wearing surface, the skid resistance performance of the road surface varies differently with environmental and traffic operating conditions. Field experience in Singapore has indicated that wearing surface with different aggregates differed in their skid resistance at different stages of their service life. This paper reports the findings of an experimental study designed to investigate the effect of aggregate properties on skid resistance for two common types of road paving aggregates used in Singapore. The British pendulum test was employed for the study. It was found that aggregate surface texture, aggregate packing and polish susceptibility all had significant influence on their skid resistance performance.

Keywords: Skid resistance, asphalt paving mixtures, aggregate properties, British pendulum test, wheel polishing test

1. INTRODUCTION

The resistance to skidding of a road surface is one of the fundamental requirements that highway engineers must consider in pavement design in order to provide a safe traveling surface. It is a major consideration in the geometric design of roads, particularly in curvature design and stopping distance determination. In the case of an asphalt pavement, its skid resistance performance is governed essentially by the properties of the aggregate in the surface wearing of the pavement. There are many aspects of aggregate properties that affect skid resistance provided by an asphalt pavement surface. These include aggregate texture, aggregate packing, their properties upon wetting, their behavior at different temperatures, and their susceptibility to wheel polishing.

This paper describes a laboratory research project undertaken by the authors to study the skid resistance performance of two aggregate types used in Singapore for road construction. They are granite aggregate and steel slag aggregate. Granite is the most common type of aggregate found in the Southeast Asian region. Practically all the asphalt roads in Singapore are constructed using granite aggregate. Singapore imports granite aggregates from her neighbors for road and building construction. The long-term skid resistance performance of granite is, however, only marginally satisfactory. Since the early 1990s, steel slag which is a waste material from steel mills has been introduced as an alternative material for road paving purpose. Field experience has not been able to identify distinctly the relatively merits of the two aggregates in terms of their skid resistance. This study was designed to characterize the skid resistance properties of the two aggregates in an attempt to explain their different skid resistance performance.

2. EXPERIMENTAL PROGRAM

The experimental test program consisted of the following main work elements: (a) Preparation of test specimens, (b) British pendulum test before wheel polishing treatment, (c) accelerated wheel polishing treatment, and (d) British pendulum test after wheel polishing treatment.

2.1 Specimen Preparation

The specimens used for British pendulum test and wheel polishing test were identical in dimensions. They were curved laboratory specimens prepared in accordance with the ASTM standard test method E303 (ASTM 2000) using moulds of a curved arc of 16 in. (406.4 mm) diameter. The aggregate size chosen for the test program was one that passed through the standard sieve size of 12.5 mm and retained on the standard sieve size of 9.5 mm. Only one aggregate was tested in view of the finding of an earlier by Fwa and Tan (1992) which had established that all other things being equal, the size of aggregate within the range of 5mm to 20 mm had negligible effect on the British pendulum test results. This size had been chosen essentially for ease of handling and specimen preparation. This was also the aggregate size specified for the wheel polishing test to be performed in the later phase of the test program.

One of the factors of interest in the present study was the effect of aggregate packing. As the gaps between adjacent aggregates could vary from 2 mm to 10 mm, the following three gaps were selected for the present study: 2 mm, 5 mm and 10 mm. A total of 9 specimens each for granite and steel slag aggregates respectively were tested. There were three replicates for each of the three gaps to be examined. However, due to the difficulties in maintaining the exact gap dimensions during specimen fabrication, some deviations of the gaps occurred in the final specimens fabricated. This did not affect the analysis as the actual gaps were measured and analyzed in the test program.

The preparation of specimen consisted of two steps. A high strength cement mortar was first mixed and placed into the curved mould. The high strength mortar was necessary in order to ensure that aggregate would not get dislodged during the skid resistance test and the wheel polishing treatment. Next, individual aggregates of as uniform a size as possible were forced into the top face of the mortar at specified locations to achieve the desired gaps between aggregates. The gaps were fixed at constant values in both the lateral and longitudinal directions. A straight edge was used to level the top surface of all aggregates in line with the top edge of the curved mould. Curing of in water bath for 7 days was applied before the specimens was tested for skid resistance.

2.2 British Pendulum Test

The skid resistance properties of the aggregates were studied using the British pendulum test as described in the ASTM standard test procedure E303 (ASTM 2000a). The measurement of the British pendulum test is expressed in terms of the British pendulum number (BPN). The British pendulum test is a low speed friction test that provides a skid resistance measure related to the microtexture of the aggregate (Forster1989). This is an important skid resistance property of the aggregate as it is desirable to provide a sufficiently high microtexture related skid resistance so that the reduction in skid resistance at higher speeds would still be high enough to meet the needs for safe traffic operation.

As it was an objective of the test program to investigate the effect of wetting on skid resistance, both the dry and wet skid resistance behavior of the test specimens were measured. The method of wetting adopted for the study followed the procedure outlined in the ASTM standard test procedure E303 (ASTM 2000a). To examine the skid resistance response to aggregate temperature, two test temperatures, 28°C and 60°C were selected for the test program to cover the main range of operational temperatures of asphalt pavements in Singapore.

2.3 Wheel Polishing Test

Wheel polishing action has been known to be an active mechanism that causes the skid resistance deterioration of road aggregates (Crouch et al. 1996). The polishing mechanism, however, is a complex process involving many factors which cannot be measured or evaluated directly. Laboratory accelerated wheel polishing tests are commonly employed to assess the relative polishing resistance of different aggregates. The procedure described in ASTM standard test procedure D3319 (ASTM 2000b) was followed in the present test program. All specimens were subjected to a total of 10 hours of polishing. Since the test wheel could only accommodate 14 specimens in each test, the granite and steel slag specimens were treated in two separate runs of the wheel polishing test.

2.4 Post-Polishing British Pendulum Test

The effect of wheel polishing treatment was evaluated by comparing the skid resistance properties of the aggregate before and after the treatment. The British pendulum test was conducted before and after the polishing test to determine the change in skid resistance in terms of BPN. The procedure of testing was identical to that described in Section 2.2.

3. TEST RESULTS AND ANALYSIS

3.1 Test Results

The test results are presented in Tables 1 and 2. Table 1 records the results of British pendulum test performed on the test specimens before the wheel polishing treatment, while Table 2 records those results after the wheel polishing treatment. The second column of the two tables lists the average aggregate gaps of the nine specimens. For easy reference, the

Table 1. British Pendulum Test Results on Test Specimens Before Wheel Polishing Treatment

Aggregate Type	Mean Agg. Gap (mm)	British Pendulum Numbers (BPN)			
		28°C Dry	60 °C Dry	28 °C Wet	60 °C Wet
Steel Slag	2.10	60	57	46	46
	2.96	55	55	44	44
	3.82	56	54	45	45
	5.02	50	51	44	39
	6.30	47	49	43	39
	6.44	49	50	43	40
	9.52	45	45	40	39
	10.38	46	46	35	35
	10.90	41	41	35	35
Granite	2.74	53	51	35	36
	2.82	50	50	36	36
	3.18	52	50	36	34
	5.24	49	46	36	34
	5.32	45	46	34	34
	5.60	45	45	34	34
	10.22	46	46	33	33
	10.50	42	40	30	31
	10.56	45	44	30	31

Table 2. British Pendulum Test Results on Test Specimens After Wheel Polishing Treatment

Aggregate Type	Ave. Agg. Gap (mm)	British Pendulum Numbers			
		28°C Dry	60 °C Dry	28 °C Wet	60 °C Wet
Steel Slag	2.10	50	50	36	36
	2.96	52	50	36	34
	3.82	53	51	35	36
	5.02	35	35	25	26
	6.30	30	32	20	21
	6.44	30	30	23	22
	9.52	27	27	16	15
	10.38	27	26	18	16
	10.90	26	26	19	18
Granite	2.74	33	35	25	25
	2.82	34	34	24	25
	3.18	34	35	25	24
	5.24	33	34	25	24
	5.32	32	33	24	24
	5.60	32	34	24	25
	10.22	25	26	16	15
	10.50	27	28	19	20
	10.56	28	27	20	20

records are arranged in ascending order in accordance with the average values of the aggregate gaps. The last 4 columns of each table contain the dry and wet British pendulum numbers (BPN) measured at the two test temperatures of 28°C and 60°C respectively. The results obtained in Tables 1 and 2 are plotted in Figures 1 to 8. The downward trends of skid resistance deterioration with aggregate gaps width are apparent from these plots.

3.2 Dry Skid Resistance Measurements Prior to Polishing

The results in Table 1 indicate that the dry skid resistance of both granite and steel slag aggregate in terms of BPN values decreased as the gap between adjacent aggregate increased. This was true for the two series of tests conducted at 28°C and 60°C. However, the rates of deterioration of skid resistance with gap width of the two aggregate types were not the same. Steel slag aggregate suffered more severe loss of skid resistance as compared to granite aggregate. As the aggregate gap widened from about 2 mm to 10 mm, the steel slag specimens lost more than 15 BPN points, while the corresponding loss of granite aggregate was only around 10 BPN points. When the gap width was small (say 2 or 3 mm), the steel slag aggregate had about 5 BPN points higher than granite aggregate. This difference diminished when the gap width increased to 10 mm or more.

3.3 Wet Skid Resistance Measurements Prior to Polishing

The results in Table 1 also indicated that both steel slag aggregate and granite aggregate offered substantially reduced skid resistance upon wetting. The effect of wetting was more significant on granite aggregate than on steel slag aggregate, especially for specimens with larger gap widths. The decrease in skid resistance of steel slag caused by wetting was less than 5 BPN points when the gap width was 5 mm or larger (with the exception of the case of 10.38 mm gap). On the other hand, granite the corresponding fall in skid resistance for granite aggregate due to wetting was more than 10 BPN points for all the gap widths tested.

The results in Table 1 thus revealed that both wetting and widening of gap width had caused reductions in skid resistance measured by BPN. In respect of these two aspects, it is interesting to note that the two aggregate types behaved rather differently. While the steel slag aggregate, as compared with the granite aggregate, suffered a higher skid resistance deterioration rate as aggregate gap widened, its loss in skid resistance upon wetting was considerably less than the corresponding loss of the granite aggregate. With a mean aggregate gap of about 2 mm, steel slag aggregate had higher dry skid resistance than granite aggregate. As the aggregate gap increased to 10 mm, the dry skid resistance of steel slag aggregate fell below that of granite aggregate. However, upon wetting, the steel slag regained its skid resistance superiority to the granite aggregate. These relative changes in skid resistance of the two aggregate types were observed for both of the test temperatures, 28°C and 60°C.

3.4 Effect of Wheel Polishing on Skid Resistance Measurements

An important requirement of a road aggregate is to be polishing resistant so as to maintain a high level of skid resistance throughout the service life of the pavement. The possible different behavior of wearing surface aggregate against polishing was investigated by means of the laboratory accelerated wheel polishing test described under Section 2.3. All the specimens examined earlier under the two preceding sections (Sections 3.2 and 3.3) were subjected to the accelerated laboratory polishing treatment. The post-polishing British pendulum tests on these specimens therefore provide a good basis for assessing the effect of wheel polishing.

Comparing the test results recorded in Tables 1 and 2, the following observations can be made:

(a) After polishing, the dry skid resistance of the steel slag aggregate fell by less than 10 BPN points at 2 mm aggregate gap to close to 20 BPN points at 10 mm gap. The specimens with larger aggregate gaps appeared to be affected more by the polishing action. For the granite aggregate specimens, there was a more uniform effect of between 15 to 20 BPN points drop for all gap widths.

(b) The corresponding fall of wet skid resistance after polishing were less than those of dry skid resistance. The reductions in the steel slag wet skid resistance after polishing were about 10 BPN points at 2 mm aggregate gap and about 16 BPN points at 10 mm aggregate gap, and those of granite aggregate were about 10 BPN points.

(c) After polishing, the effect of aggregate gap remained. Both the dry and wet skid resistance fell as the aggregate gap width increased. At small gap with of 2 mm, the steel slag aggregate had higher skid resistance than the granite aggregate. As the gap width increased to 5 mm and more, there were practically no differences in the skid resistance performance of the two types of aggregate.

3.5 Effect of Temperature on Skid Resistance Measurements

An earlier study by Fwa and Tan (1992) on the same aggregate types had concluded while the dry skid resistance was not affected by temperature changes, the wet skid resistance decreased as the test surface temperature increased. It was also concluded that the decreases in wet skid resistance were positively related to the viscosity of water which was significantly affected by temperature. This earlier study was conducted on specimens with aggregates placed side-by-side by hand forming a densely packed arrangement. In the present study, gaps of pre-specified widths were intentionally fixed between aggregates. The presence of such gaps apparently had reduced the effect of water viscosity during testing. Hence the effect of temperature changes was hardly noticeable in the test results of Tables 1 and 2.

3.6 Comparison of Aggregate Types

The behaviors of the steel slag and granite aggregates with respect to the different test parameters have been examined in the preceding sub-sections. Their main different responses to the various test conditions are as follows:

(a) The skid resistance of the two types of aggregate fell as the aggregate gap width increased from 2 mm to 10 mm. The skid resistance of the steel slag aggregate was found to be affected more by the increase of aggregate gap width. This was the case for both wet and dry skid resistance. For the range of aggregate widths investigated, the steel slag aggregate lost about 15 BPN and 10 BPN points for dry and wet skid resistance respectively. The corresponding losses for the granite aggregate were 10 BPN and 5 BPN.

(b) While both aggregate types suffered significant skid resistance loss upon wetting, the granite aggregate was more severely affected. At 2 to 3 mm aggregate gap width, the granite aggregate had about 15 to 20 BPN loss, while the steel slag aggregate had 10 to 15 BPN loss. At 10 mm aggregate gap width, the skid resistance losses were about 10 to 15 BPN points for the granite aggregate and 5 to 10 BPN points for the steel slag aggregate.

(c) The skid resistance of both aggregate types deteriorated when subjected to wheel polishing. The rate of skid resistance deterioration, however, differed between the two aggregate types. At 2 to 3 mm aggregate gap width, the steel slag maintained after polishing about a 10 BPN points higher skid resistance than the granite aggregate. However, for larger aggregate gap widths, the difference between the skid resistance of the two aggregate types diminished.

(d) The effect of temperature was not found to be significant for both aggregate types. The aggregate gaps had weakened the influence of the temperature effect which was related to the viscosity of water.

4. CONCLUSION

This paper has described the test program and presented the results and findings of a project conducted to study the skid resistance behavior of the two types of paving aggregate, granite and steel slag aggregate, which are used for road construction in Singapore. The skid resistance tests were performed using the British pendulum tester. The test program was designed to examine the different skid resistance performance of the two aggregates, and to evaluate the effects of the following factors: water wetting effect, aggregate gap width, wheel polishing effect, and test specimen surface temperature.

The test results revealed interesting insights into the skid resistance behaviors of the two aggregate types. It was found that, except for temperature, the other three factors, water wetting, aggregate gap width, and wheel polishing action all had significant impacts on the skid resistance of the two aggregate types. The skid resistance behaviors of the two aggregate, however, were different under the influence of these factors. The skid resistance of the granite aggregate was affected more by wetting, while that of the steel slag aggregate deteriorated more as the aggregate gap width widened. The effect of wheel polishing was affected by aggregate gap width. For small aggregate gap width of 3 mm or less, both aggregate types suffered about the same amount of BPN reduction and the steel slag retained its higher value of skid resistance. For larger aggregate gap widths, the steel slag aggregate suffered higher skid resistance losses, and there were negligible differences in the resultant skid resistance levels of the two aggregate types.

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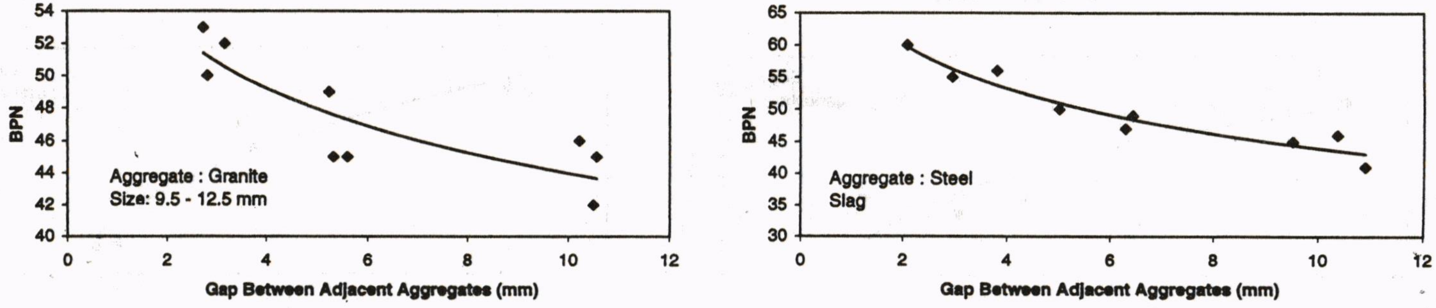

Fig 1 Effect of Aggregate Gap on Unpolished Surface Dry Skid Resistance Measurements at 28 degree C

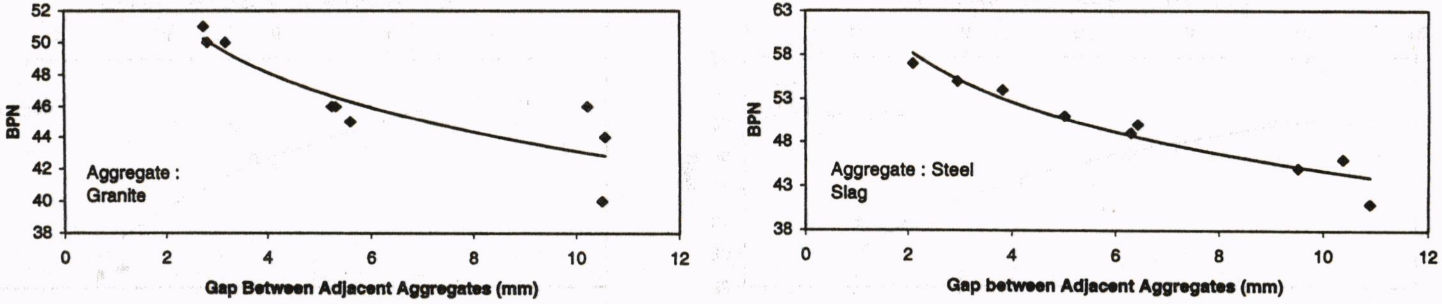

Fig 2 Effect of Aggregate Gap on Unpolished Surface Dry Skid Resistance Measurements at 60 degreeC

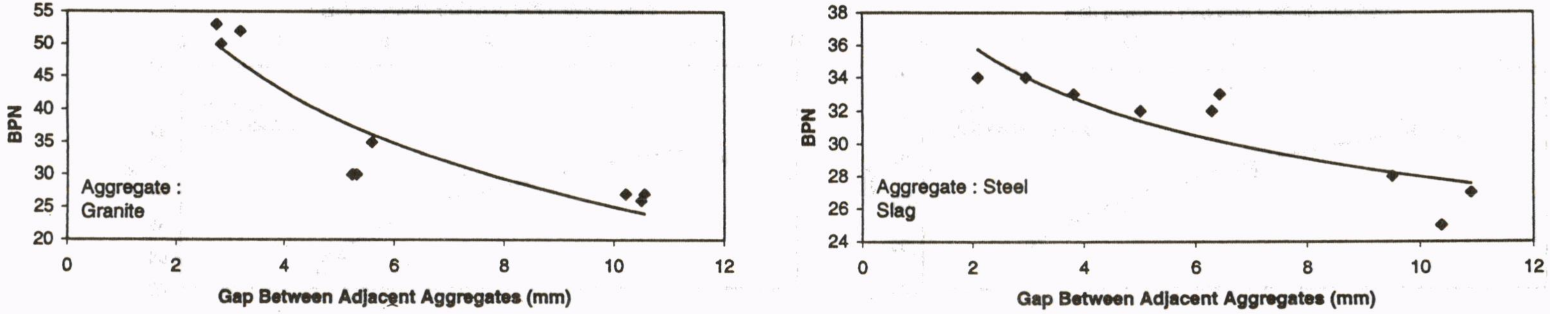

Fig 3 Effect of Aggregate Gap on Polished Surface Dry Skid Resistance Measurements at 28 degree C

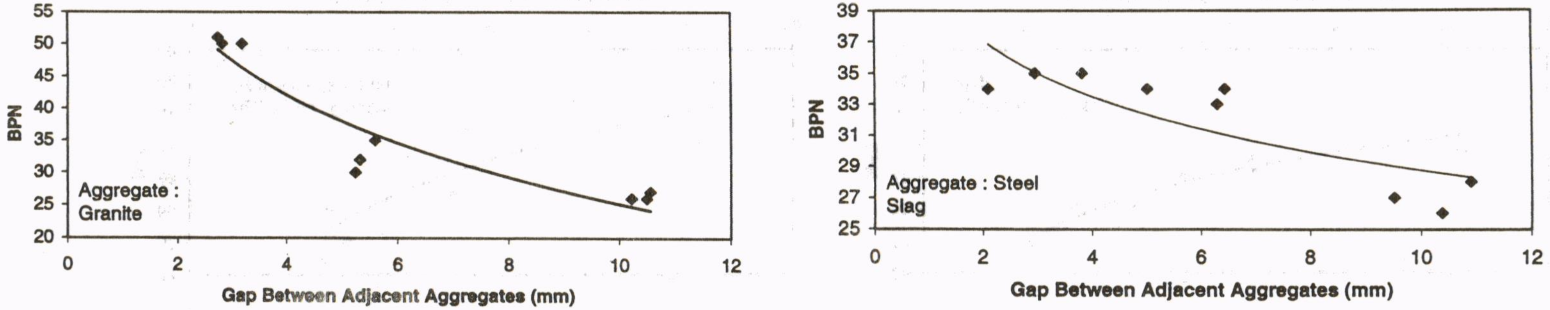

Fig 4 Effect of Aggregate Gap on Polished Surface Dry Skid Resistance Measurements at 60 degree C

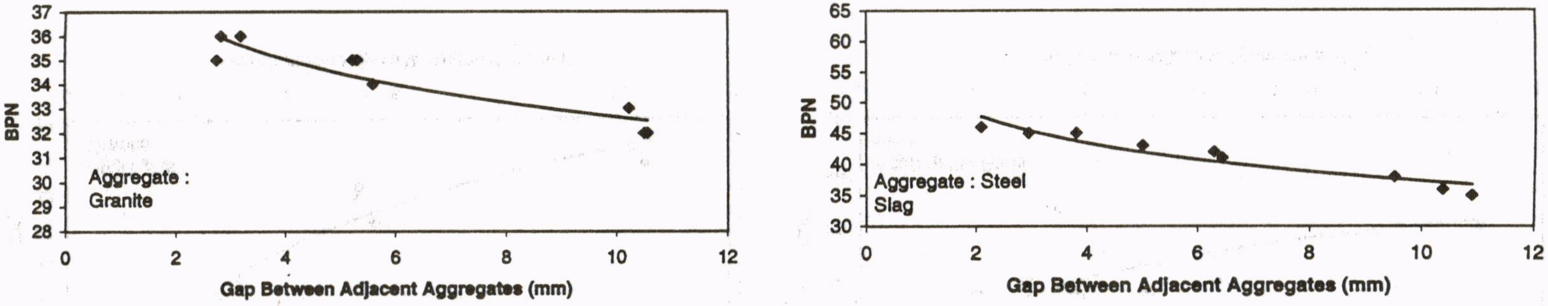

Fig 5 Effect of Aggregate Gap on Unpolished Surface Wet Skid Resistance Measurements at 28 degree C

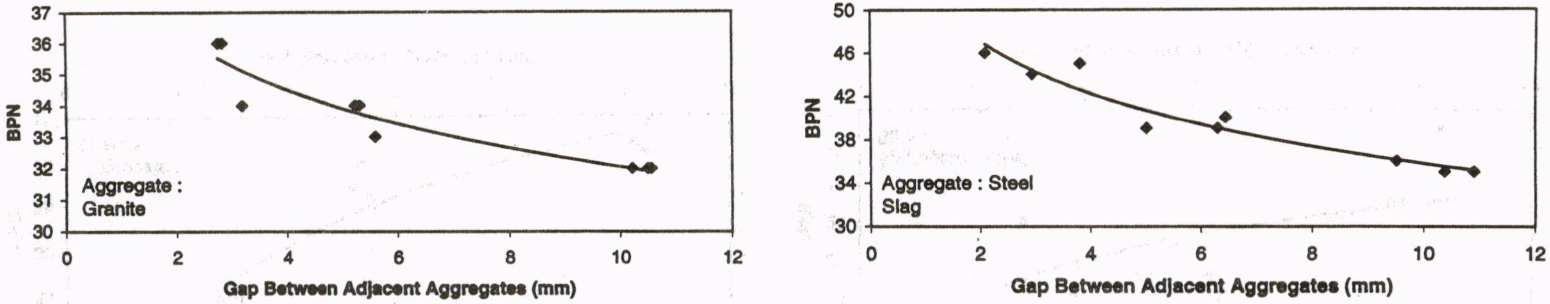

Fig 6 Effect of Aggregate Gap on Unpolished Surface Wet Skid Resistance Measurements at 60 degree C

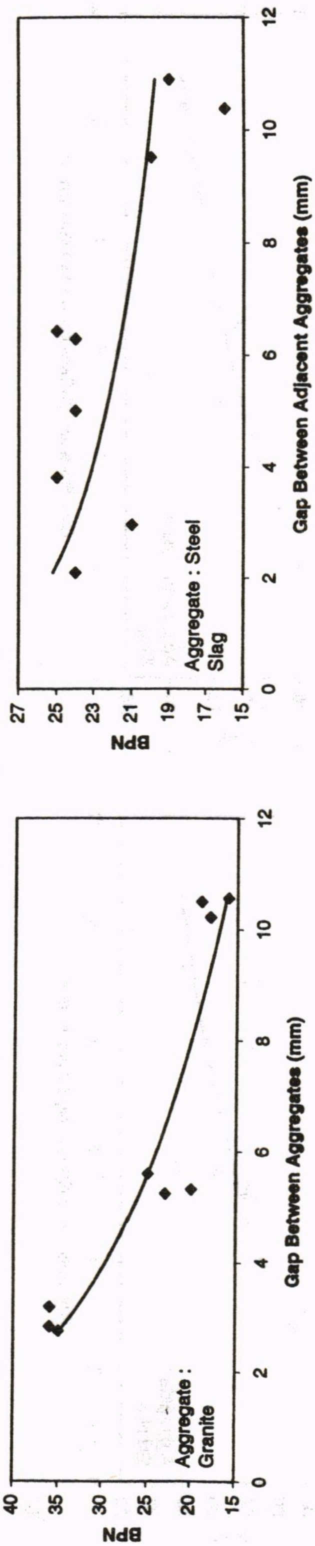

Fig 7 Effect of Aggregate Gap on Polished Surface Wet Skid Resistance Measurements at 28 degree C

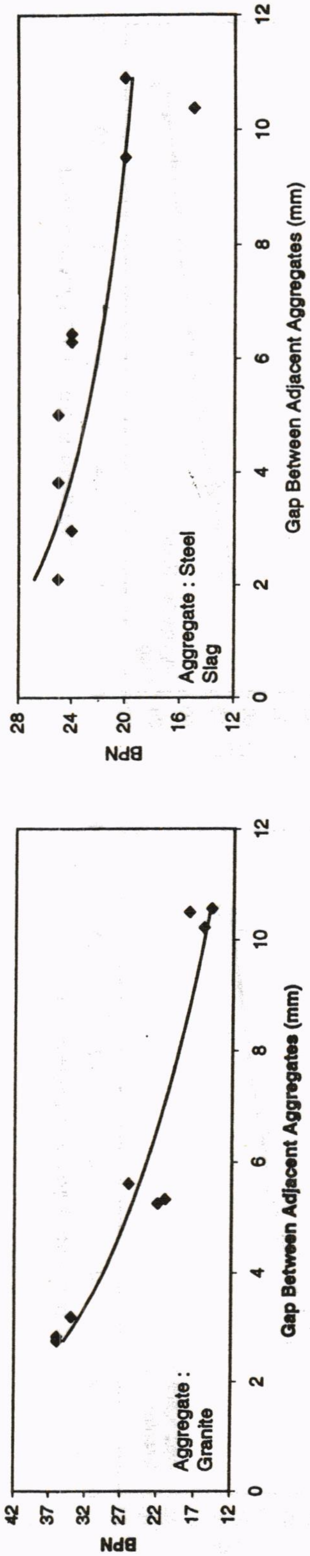

Fig 8 Effect of Aggregate Gap on Polished Surface Wet Skid Resistance Measurements at 60 degree C