Journal of Engineering and Sustainable Development
www.jeasd.org
Vol. 20, No.06, November 2016
ISSN 2520-0917

ASSESSMENT THE POLISHING OF LOCAL AGGREGATES BY MEANS OF SKID RESISTANCE FOR SURFACE PAVEMENT LAYER

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Abstract: During the entire life cycle of a pavement, highway agencies are expected to monitor and preserve an appropriate surface roughness (i.e. texture) to facilitate friction between pavement surface and vehicle tires. The resistance of pavement surface to sliding and skidding of the traveling vehicles is measured by skid resistance. There is a prime importance to provide skid resistance to preserve adequate surface roughness for pavement and prove resistance to polishing due to the traffic effects. The skidding resistance of an asphalt pavement is essentially depends on aggregate properties in the surface wearing course. Depending on the shape, size, 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 Iraq has indicated that wearing surface with different aggregates differed in their skid resistance at different stages of their service life. This research reports the findings of an experimental study for investigating the effects of aggregate properties on skidding resistance for three common types of local aggregates used in Baghdad for road construction, they are brought from Al-Nebae quarry in Salahdin governorate, Al-Sedoor quarry in Diala governorate and Chlatt quarry in Misan governorate. However, this study was designed to characterize the polishing properties of the three types of aggregates in an attempt to explain their different skid resistance performance. To achieve the objective of this research, Accelerated Polishing Machine is used (which it has been operated by the researcher as the first test conducted in Iraq) to produce aggregates samples of polished stone used in roads surface and to simulate actual roads conditions, and British pendulum test was employed for the study for determining the Polished Stone Value (PSV) for tested samples. The tests are conducted at temperatures of 60±1° C (140±2° F), 40 ±1° C (104±2° F) and 20±1° C (68±2° F) and at a rotation wheel speed of 320 rpm and applied loading of 400 N. The dry and wet conditions are employed for Pendulum test, with three traffic volume (in terms of time of testing) (1 hr, 2 hr, and 3 hr) for a nominal total of 54 tests are performed. Finally, a set of recommendations are presented for promoting the skidding resistance performance of Iraqi pavements including changes and adding to current construction quality assurance procedures.

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

تقييم صقل الركام المحلي بواسطة مقاومة الانزلاق لطبقة التبليط السطحية

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الخلاصة: خلال دورة الحياة الكاملة للتبليط، اهتمت وكالات الطرق بالمراقبة والحفاظ على خشونة (ملمس) سطح ملائمة لتسهيل الاحتكاك بين اطارات المركبة وسطح التبليط الانزلاق هو مقياس لمقاومة سطح التبليط للانزلاق او التزلج للمركبات المتحركة. ان الحفاظ على ملمس مناسب للتبليط وتوفير مقاومة للصقل نتيجة تأثيرات الحمل المروري تعتبر ذات اهمية كبيرة لتوفير مقاومة الانزلاق. ان مقاومة الانزلاق للتبليط الاسفلتي يعتبر كدالة اساسياً لخصائص الركام في الطبقة السطحية. اعتمادا على الشكل، الحجم، تدرج الركام في الخلطة الاسفلتية لسطح التبليط، اداء مقاومة الانزلاق لسطح الطرق تتباين بصورة مختلفة مع الظروف الجوية والاحمال المرورية المسلطة .
اشارت الخبرة الميدانية في العراق بأن الطبقة السطحية الواقية باختلاف نوع الركام المستخدم تختلف بمقاومتها للانزلاق اثناء المراحل المختلفة للعمر الخدمي. هذا البحث بين نتائج دراسة مختبرية لفحص تأثير خواص الركام على مقاومة الانزلاق لثلاثة انواع من الركام الشائعة الاستخدام في انشاء الطرق في بغداد، تم جلبه من مقالع النباعي في محافظة صلاح الدين ومقلع الصدورفي محافظة ديالى ومقالع جلات في محافظة ميسان. ومع ذلك فان هذه الدراسة وضعت لتمييز خواص الصقل لهذه الانواع الثلاثة من الركام في محاولة لوصف اداؤها المختلف لمقاومة الانزلاق . لتحقيق الهدف من هذا البحث تم استخدام جهاز الصقل المعجل لانتاج نماذج حجرية مصقولة من الركام المستخدم لاسطح الطريق وكذلك ليحاكي ظروف الطرق الحقيقية، وكذلك تم استخدام جهاز البندول البريطاني في هذه الدراسة لحساب قيمة الحجر المصقول PSV للنماذج المفحوصة. طبقت الفحوص بدرجات حرارة٢٠± ١° م (٦٨±٢ ° فهرنهايت) ، ٤٠± ١ ° م (١٠٤±٢ ° فهرنهايت) و٦٠± ١ ° م (١٤٠±٢ ° فهرنهايت) بسرعة عجلة دورانية قدرها ٣٢٠ دورة/دقيقة، وحمل مسلط قدره ٤٠٠ نيوتن. طبقت ظروف الفحص الجافة والرطبة لفحص البندوليوم الانكليزي، لثلاثة حجوم مرورية (معبرا عنها بزمن الفحص) بمقدار ١، ٢، و ٣ ساعة لمجموع عينات كليه مقدارها ٥٤ عينة طبقت لهذه الفحوص. اخيرا، تم عرض سلسلة من التوصيات لتحسين اداء مقاومة الانزلاق للتبليط العراقي شاملا بعض التغيرات لاجراء ضمان الجودة للانشاء الحالي.

1. Introduction

Skid resistance is one of the most critical performance parameters for asphalt pavements as it has a great effect on the safety of the traveling public. Many researchers around the world have reported a strong relationship between pavement skidding resistance and rate of accidents or crashes, [1-3].

Pavement skid resistance is depends on different factors including the microtexture and macrotexture of the pavement surface. Microtexture, which is highly related to characteristics of the surface and mineralogical composition of aggregates, provides a rough surface that impedes the water film continuity and produces frictional resistance between pavement and the tire through creating intermolecular bonds. Macrotexture, which is more affected by gradation of aggregate and mix design, improves wet frictional resistance, particularly at high speeds, by providing surface drainage [4,5]. The literature review shows that aggregate characteristics are mainly affected on the frictional properties of flexible pavement.

To reach to specification for the selection for used aggregates directly and ensure satisfactory frictional performance, it was focused by many researchers and transportation agencies. At present, the aggregate selection for use in asphalt mixtures mainly depends on the historical background of the aggregate performance or construction of test sections forms, [6,7].

2. Background and Significance of Work

Skidding; it is defined as the loss of adhesion between a road surface and car's tyres occurs in many road crushes whether or not it is the real reason of the accident. Through the years, tyres manufacturers have done many researches on different types of tread patterns and rubber to improve the safety of running vehicles. Regulations concerning the depth of tread patterns and general condition of the tyres were introduced by governments. Highways researches have also investigated ways to improve the skidding resistance of road pavement surfaces.

One of things they did was the devise of the British Pendulum Tester (BPT) which being portable and can be taken to the site or used for laboratory tests. The BRT gives a number, or being as a percentage, somewhat considered to a coefficient of friction, the BPT simulates the skidding resistance offered by a motor vehicle travelling at (50) km/h to a road surface.

Skidding resistance and roughness (texture) of road surface are two important parameters often determined during the service life of the road pavement to ensure that the pavement meets the minimum required criteria of safety. Theoretically, the friction that develops between a pavement surface and a travelled rubber tire consists of two components: adhesion and hysteresis [8]. As shown in Figure 1, adhesion is defined as the shear force between the tire and the road pavement surface generated when the tire rubber skids over the aggregate surface asperities due to microtexture and the aggregate particles indent onto the rubber. In essence, adhesion can be viewed as the molecular bonds generated when the tire rubber deforms under load. The second friction component, hysteresis, is generated when the tire rubber deforms due to macrotexture (or irregularities) of the road pavement surface. In essence, it can be viewed as the energy loss that occurs as the rubber is alternately compressed and expanded as it slides over the irregular pavement surface texture.

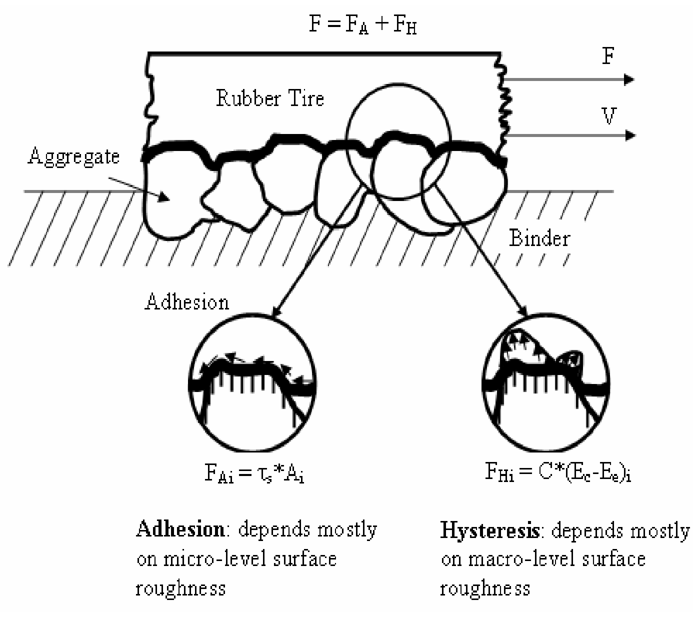

Figure 1: Schematic of adhesion and hysteresis of rubber-tire friction,[7]

The Accelerated Polishing Machine of aggregate is simulating the polishing action of running tyres, grit and water on road surfaces, as highway engineers are concerned about the aggregates. Then, the skidding resistance is measured with the British pendulum and the reading called Polished Stone Value (PSV).

The main objectives of this research are evaluating aggregates with different characteristics and by studying polishing performance of mixtures constructed using these aggregate types, establishing a laboratory polishing test to simulate accelerated field polishing of sampled aggregates though using new accelerated polishing equipment to measure aggregate surface microtexture of all sampled aggregates, and measuring skidding resistance of a pavement surface using BPT Skid Resistance Tester and to estimate the vulnerability of aggregates to polishing under traffic loads by measuring its Polished Stone Value (PSV).

3. Laboratory Testing

The The testing program consists of physical tests include particle shape, specific gravity, water absorption and Los angles abrasion test, and the mechanical tests included the accelerated polishing of aggregate and BS pendulum test. The experimental test program consisted of the following main work elements: (a) Preparation of test specimens, (b) British pendulum test before Accelerated polishing treatment, (c) Accelerated wheel polishing treatment, and (d) British pendulum test after wheel polishing treatment.

3.1. *Material*

The materials used in this study are locally available. They are included three types of aggregate from three resources Al-Nebaee quarry in Salahdin governorate, Al-Sedoor quarry in Diala governorate, and Chlatt quarry Misan governorate. This aggregate is widely used in local asphalt paving. The properties of these materials were evaluated using routine type of tests and the obtained results were compared with the SCRB (R/9, 2003) specification requirements [9] as presented later.

3.2. Sample Preparation

The specimens used for British pendulum test and Accelerated polishing test were identical in dimensions. They were curved laboratory specimens prepared according to the ASTM standard test method E303: 2006 [10] using molds of a curved arc of 16 in. (406.4 mm) diameter. One aggregate size was chosen for the test program that passes through the standard sieve size of 0.5 inch. (12.5 mm) and retained on the standard sieve size of 3/8 inch. (9.5 mm) accordance with specification. This size was essentially easy for handling and specimen preparation. This was also the aggregate size specified for the accelerated polishing test to be performed in the later phase of the test program. Figure 2 shows the procedure of sample preparation prior to testing in the Accelerated wheel polishing apparatus. Two specimens are prepared for each test. Almost each specimen consists of at least 24 aggregate particles, placed in single layer shoulder to shoulder in a curve metal mold of specified dimensions.

3.3. Accelerated Wheel Polishing Test

Accelerated wheel polishing action; Figure 3; has been known to be an active mechanism that causes the skid resistance deterioration of road aggregates. 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 [11] was followed in the present test program.

a- Fill the interstices between the aggr. Particles with fine sand

b- Mix the resin and fill the mould to overflowing.

c- The resin has hardened

d- Remove the specimen from moulds, then clean the weight.

Figure 2. Procedure for Sample Preparation Prior To Testing

3.4. British Pendulum Tester and Polished Stone Value PSV

The procedure for measuring frictional properties of the road surface using British Pendulum Skid Resistance Tester is covered in this method. The British Pendulum Tester; (as shown in Figure 4); is a dynamic pendulum impact type tester used for measuring the energy loss when a rubber slider edge is propelled over a test surface. The British Pendulum tester is used for laboratory tests as well as field tests on flat surfaces, in addition to polish value measurements on curved laboratory specimens from accelerated wheel polishing test.

The value determined from British Pendulum tester Number (BPN) for curved specimens and polish values for accelerated wheel polishing tests, represents the frictional properties of aggregate with the apparatus and procedure stated herein.

Figure 3. Accelerated Polishing Wheel Test

Figure 4. British Pendulum Tester

- *Polished Stone Value (PSV):* is a value of aggregate resistance to lose its skid-friction properties and becoming polished, it is usually referred to as its “Microtexture”. The PSV test assesses the aggregate susceptibility to polishing. The test consists of two stage process, firstly the accelerated wheel polishing and secondly measuring the results of friction values using the British Pendulum tester BPN. Aggregates used in asphalt surface courses typically have results from 50 to 68, as the number is higher means greater friction or skid resistance, the equation for determining the PSV is;

$$PSV = S + 52.5 - C \tag{1}$$

Where: S: Mean of 3 last reading for tested aggregate
C: Mean of 3 last reading for Control Aggregate

4. Results and Analysis

Whereas the shape of aggregate particle effects on its performance during both construction and service, angular and cubical aggregates are mostly preferred. While elongated and very flaky particles are relatively weak and also have high binder or bitumen demands due to their large surface area. The European standard BS 812 [13] classifies aggregate shapes into six categories as; rounded, irregular, angular, flaky, elongated and flaky- elongated aggregate. The test results for physical tests for three types of aggregate are presented in Table 1.

Table 1. Physical tests for the selected aggregate

Property	ASTM designation	Aggregate Type	Test results	SCRB specification
particle shape, flat and elongated%	D4791	Al-Nebaee quarry	1.5	Max. 3.0
		Al-Sedoor quarry	2.0	
		Chlatt quarry	1.1	
specific gravity, $Gs_{S.S.D}$	C127	Al-Nebaee quarry	2.63	-
		Al-Sedoor quarry	2.59	
		Chlatt quarry	2.6	
water absorption,%	C 127	Al-Nebaee quarry	0.66	-
		Al-Sedoor quarry	1.51	
		Chlatt quarry	1.3	
Los angles abrasion test, %	C131	Al-Nebaee quarry	11.0	Max 30%
		Al-Sedoor quarry	13.2	
		Chlatt quarry	12.97	

4.1. BPN prior to polishing

Table 2 records the results of British pendulum test performed on the test specimens before the wheel polishing treatment, for three types of aggregate, three degrees of test temperature and two condition of wetting. The results indicate that the dry skid resistance of aggregate in terms of BPN values decreased when using rounded instead of crushed aggregate.The BPN decreases by 25.7 percent of Al-Nebae quarry aggregate at 20ºC test temperature, while it is decreased by 28.8 and 25.2 for Al-Sedoor and Chlatt aggregate at same temperature.

Table 2. British Pendulum Test Results on Test Specimens before Wheel Polishing

Agg. Type	Agg. Shape	British pendulum number, BPN					
		Temp20˚C		Temp40˚C		Temp60˚C	
		Dry	Wet	Dry	Wet	Dry	Wet
Al-Nebae quarry	Crushed	51.2	43	49.5	37	48	37
	Rounded	38	32	38	31	37	32
Sedoor quarry	Crushed	46.4	45	46	43	45	42
	Rounded	33	27	32	27	32	26
Chlatt quarry	Crushed	47.5	37	47	36	45	36
	Rounded	35.5	28	34	27	34	27
Control aggregate	Crushed	54	45	53	44	52	44

4.2. Wet Skid resistance

As it was an objective of the test program to investigate the effect of wetting on skidding resistance, the dry and wet skid resistance behavior of the test specimens were evaluated due to inadequate friction on the pavement surface is a major cause for wet weather related accidents on highways. The method of wetting adopted for the study followed the procedure outlined in the ASTM standard test procedure E 303 ASTM 2000[10].

Table 2 also indicated that skid resistance of aggregates is reduced substantially upon wetting especially for specimens with rounded and no cubic particles. The effect of wetting was more significant on Chlatt aggregate than on AlNebae and AlSedoor aggregates, BPN are decreased by 16, 18, and 21percent upon wetting for AlNebae, AlSedoor, and Chlatt aggregate respectively.

The analysis performed on BPN values vs. wet condition for different crushed types of aggregate tested at 20ºC testing temperature is shown below in Figure 5.

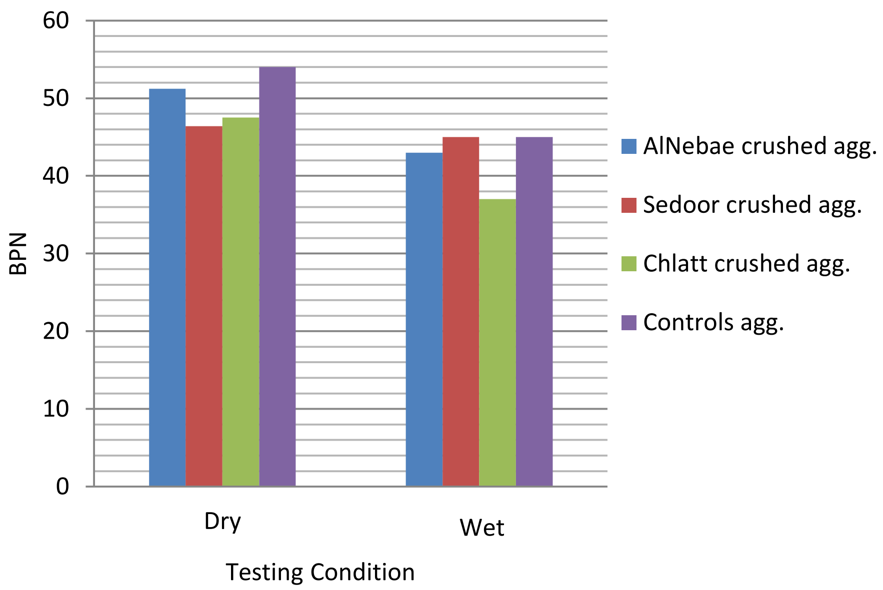

Figure 5. BPN vs. wet condition for different cubic types of aggregate at 20ºC testing temperature

4.3. Traffic volume Effects

The behavior of wearing surface aggregate against polishing was investigated by means of the laboratory accelerated wheel polishing test described under Section 3.3 to polish the laboratory prepared specimen surfaces to mimic different stages of actual pavement surface during the life span of the pavement. While the surface friction values were determined using the British Pendulum Tester.

The specimens are examined earlier under 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.

The results show that BPN decreased with traffic volume (in terms of 3 time of testing: 1 hr, 2 hr, and 3 hr), the percent drop in BPN for the polished aggregate of Al-Nebae quarry are (7.6, 5.9, and 11.2%) at three testing time respectively as shown in Figure 6. It is noticed that, the dry aggregate of Al-Nebae quarry lost in the first hour of polishing about 5.2 to 7.6 % of the BPN for crushed and no crushed aggregates in the first hour of polishing, as shown in Figure 6. It is mean that aggregate lost in the first hour of accelerated polishing about 33 % of the total BPN loss. While the high polish susceptibility non crushed aggregate lost in the first hour of polishing about 55% of the total BPN loss. The specimens with dry aggregate appeared to be affected more by the polishing action.

The results of PSV are shown in Figures 7 and 8 with polishing time at different types of aggregate at 20ºC temperatures.

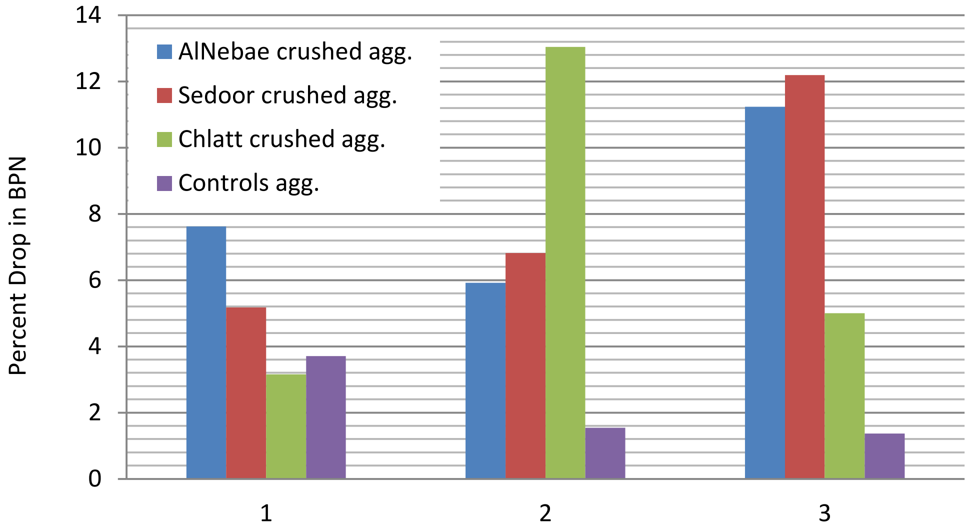

Figure 6. Average percent hourly drop in BPN vs. polishing time for20ºC

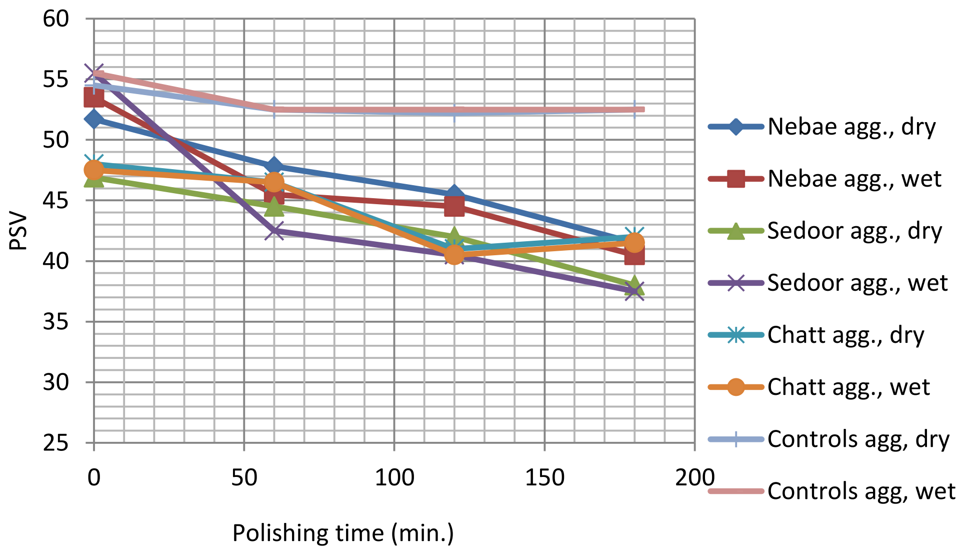

Figure 7.PSV vs. polishing time at different types of cubic aggregate at 20ºC temperatures

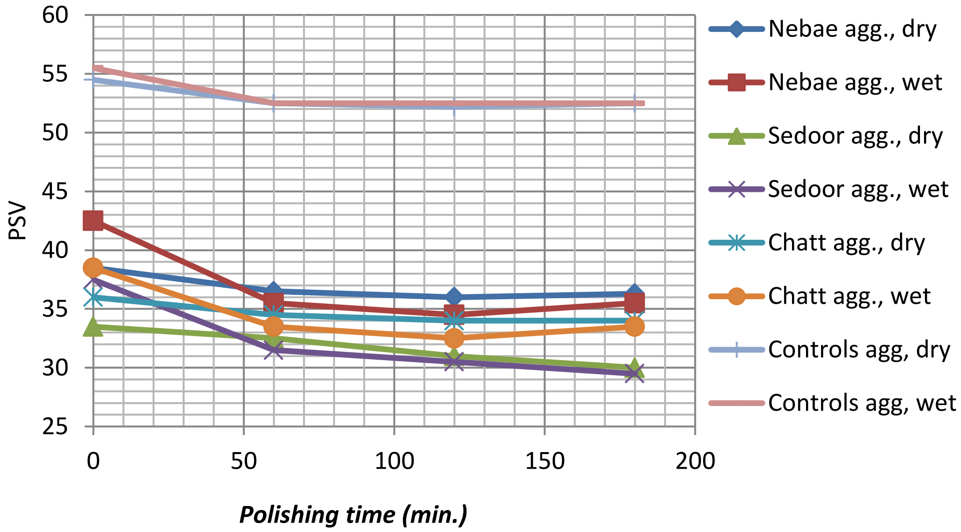

Figure 8. PSV vs. polishing time at different types of no cubic aggregate at 20ºC temperatures

4.4. Temperature Effects

To examine the skid resistance response to aggregate temperature, three test temperatures, 20oC, 40oC and 60oC were selected for the test program to cover the main range of operational temperatures of asphalt pavements in Iraq. The temperature of the test specimens and the rubber slider of the BPT, as well as the spraying water temperatures were carefully controlled in the laboratory test program through placing it in the oven.

For the temperature effect, the results obtained from the laboratory tests include friction (BPN) at three different temperatures and three stages of polishing.

The variation of friction (BPN) values with temperatures in the unpolished conditions is plotted in Figures 9 and 10 for dry and wet condition. It can be seen that the BPN values decrease with an increase in temperature for different types of aggregate.

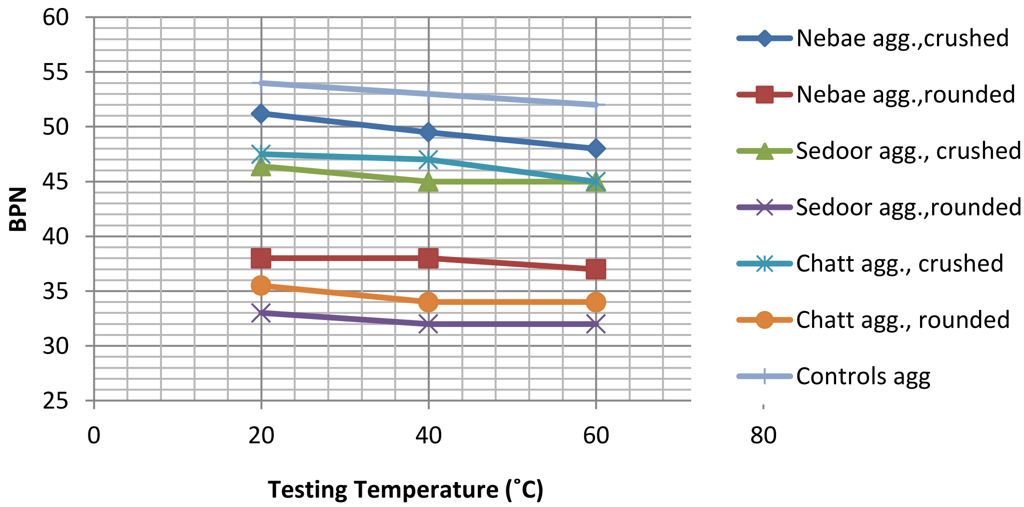

Figure 9. BPN vs. testing temperature for different types of aggregate for dry conditions

The effect of temperature changes was noticeable in the test results of Tables 3; it is concluded that the wet skid resistance was more affected by temperature changes than dry skid resistance, the skid resistance for crushed AlNebae aggregate decreased as the test surface temperature increased from 20ºC to 40 ºC by 3.3% and 13 % for dry and wet conditions, as plotted in Figure 10.

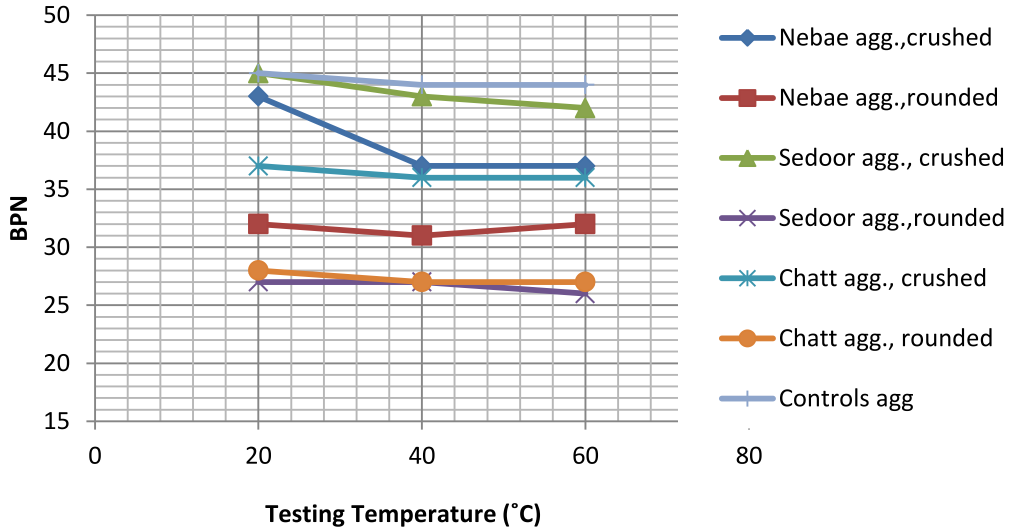

Figure 10. BPN vs. testing temperature for different types of aggregate for wet conditions

5. Conclusions

This research has described the test program and presented the results and findings of a study conducted to investigate the skid resistance behavior of the three types of paving aggregate from three resources; A-Nebae, Al-Sedoor, and Chlatt quarries, which are used for road construction in Iraq and to evaluate the effects of the following factors: aggregate shape, water wetting effect, traffic volume in terms of wheel polishing time, and test specimen surface temperature. The skid resistance tests were performed using the Accelerated polishing wheel and British pendulum tester.

The test results show that skid resistance behaviors of the three aggregate types. It was found that, except for temperature effect, the other three factors, wet conditions, aggregate shape, and wheel polishing action all had significant impacts on the skid resistance of the three aggregate types. However the skid resistance behaviors of the three types of aggregate were different under the influence of these factors.

It was found that aggregate shape had significant influence on their skid resistance performance. Aggregate from Alsedoor quarry suffered more severe loss of skid resistance as compared to other types of aggregates.

The results indicate that the dry skid resistance of aggregate in terms of BPN values decreased when using rounded instead of crushed aggregate. The BPN decreases by 25.7 percent of Al-Nebae quarry aggregate at 20ºC test temperature, while it is decreased by 28.8 and 25.2 for Al-Sedoor and Chlatt aggregate at same temperature.

The skidding resistance of the Al-Sedoor aggregate was affected by wetting more than other types of aggregate.

However, it is noticed that, the dry aggregate of Al-Nebae quarry lost in the first hour of polishing about 5.2 to 7.6 % of the BPN for crushed and no crushed aggregates in the first hour of polishing. It is mean that aggregate lost in the first hour of accelerated polishing about 33 % of the total BPN loss. While the high polish susceptibility non crushed aggregate lost in the first hour of polishing about 55% of the total BPN loss. The specimens with dry aggregate appeared to be affected more by the polishing action. This shows that, in terms of field performance, most surface aggregates (depending upon traffic loads) will polished significantly in relatively short periods of time (one or two years) compared to their design life. The effect of temperature changes was noticeable in the test results; it is concluded that the wet skid resistance was more affected by temperature changes than dry skid resistance, the skid resistance for crushed AlNebae aggregate decreased as the test surface temperature increased from 20ºC to 40 ºC by 3.3% and 13 % for dry and wet conditions.

6. Recommendations

- Further research into developing a direct relationship between PSV and the results from other field equipment like Dynamic Friction Tester so that it can be applied directly to road surfaces.
- Several field sections would be constructed using the same aggregate types and evaluated in terms of macrotexture and microtexture and testing results would be evaluated to explore correlation with pavement friction field performance.

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