Texture and Skid Resistance of Asphalt Concrete Surface Course incorporating Geopolymer Artificial Aggregates

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1. Introduction

Surface textures can represent different levels of roughness and/or smoothness of pavement surfacing. One of them is macrotexture that is broadly formed by graded aggregate mixtures, bonded and compacted to produce a relatively smooth running surface but with some irregularities. In this context, larger irregularities can be associated with voids between aggregate particles and these are often contributed by size and physical characteristics of aggregate particles [1]. Macrotexture is also essential in providing escape channels to water during the dynamic tyre-surface interactions, and therefore reducing risk to hydroplaning [2]. The macrotexture parameter is often represented as either texture depth or mean profile depth [3].

Skid resistance is the most important safety parameter in preventing incidents on road and airfield runway pavements. Therefore, careful consideration should be tak-en when selecting the right material, design, and construction of these pavements [4-5]. Skid resistance can prevent the wheels from slipping on the pavement surface [6]. External factors such as traffic speed, wheel load, surface water film thickness, and depth of wheel tyre-tread, can also affect skid resistance. Low skid resistance increases the stopping distance of running vehicles and can increase the risk of safety incidents [7-9]. Variations in vehicle speed and thickness of surface water are known to compromise skid resistance [8]. In the context of carrying out mix design for as-phalt concrete surface course (ACSC), excessive bitumen content must be avoided to prevent bleeding which can cause slippery on the pavement surface. Aggregate characteristics such as microtexture, shape, size and resistance to polishing, are known to influence skid resistance of the compacted asphalt mixture [5, 10].

Previous research has reported development of artificial aggregate, manufactured from by-product of manufacturing industry [11-13]. The resulting construction mate-rials can help reduce dependence on non-renewable resource materials [5]. In addi-tion, it will help the environment with regard to waste and reduce high energy con-sumption in the procurement of these materials [11]. However, the manufacturing process resulted in aggregate having relatively porous but rounded shape. The appar-ent shape and microstructure (under Scanning Electron Microscopy, SEM) of the artificial aggregate are illustrated in Fig. 1.

Fig 1. Artificial aggregate: (a) apparent shape [12] and (b) microstructure [13]

Fig 1 (a) shows the form of artificial aggregate produced using granulator. The size of artificial aggregate depends on the addition of alkali activator, the angle of granula-tor and the rotation speed of granulator [12]. Fig 1 (b) presents the microstructure of the artificial aggregate [13].

Further study was considered necessary to assess the impact from incorporating the relatively porous but rounded artificial aggregate on the macrotexture and skid resistance of ACSC. This paper presents findings from the study, aiming to examine the impact from using the artificial aggregate on the macrotexture (texture depth) and skid resistance of dense and open graded ACSC mixtures.

2. Material

2.1. Component materials

Based on the recommendation from the previous studies [11, 13], artificial aggregate was manufactured from a mixture of fly ash geopolymer paste and activator alkali at a ratio of 75%: 25%. The alkali activator was a mixture of sodium hydroxide and sodium silicate with a ratio of 2.5 [11-13]. In addition, natural material is mineral quarried aggregate which have been crushed into different fractions, namely: coarse aggregate, fine aggregate and filler. The physical properties of the natural and the artificial aggregates, as well as the organoleptic check of the apparent shape and surface texture (microtexture) of these aggregates, are summarized in Table 1.

Table 1. Properties of artificial and natural aggregates

Properties	Unit	Test Method	Artificial aggregate	Natural aggregate
Specific gravity	gr/cm3	SNI 1969:2008		
SNI 1969:2008	1.9	2.5		
Water absorption	%		6.1	2.3
Durability (soundness)	%	SNI 3407:2008	5.2	9.7
Toughness (Loss Angeles)	%	SNI 2417:2008	22.8	30.8
Apparent shape	-	-	rounded	angular
Apparent microtexture	-	-	porous	dense

The binder used to produce asphalt mixture was paving grade bitumen 60/70. The component materials used for producing the asphalt mixture met the requirements of the Indonesia National Specification (SNI) [14]. These component materials are illustrated in Fig. 2.

(a) (b) (c) (d) (e)

Fig 2. (a) artificial aggregate, (b) coarse aggregate, (c) fine aggregate, (d) filler, and (e) bitumen

2.2 Target ACSC mixtures

Two sets of ACSC mixtures were produced, namely open and dense graded ACSC mixtures. These two mixture gradations are illustrated in Fig. 3.

(a) (b)

Fig. 3. Combined aggregate gradations: (a) dense graded and (b) open graded ACSC mixtures

Each sample set comprises either 100% natural aggregate (therefore without artificial aggregate), or, a mixture of 25% artificial aggregate and 75% natural aggregate. The proportions between artificial aggregate, natural aggregate and bitumen in each sample set are summarized in Table 2.

Table 2. The proportions of material for each set of asphalt mixture

Sample set	Density (gram/ cm3)	Total sample weight (grams)	Artificial aggregate weight (gram)	Natural aggregate (gram)	Bitumen weight (gram)
Dense graded without artificial aggregates	2.330	10490	0	9871	619
Dense graded with 25% artificial aggregate	2.180	9810	2328	6982	500
Open graded without artificial aggregates	2.320	10440	0	9814	626

Open graded with 25% artificial aggregate	2.220	9990	2345	7036	609

3. Methodology

This section presents the methodology for sample manufacturing and testing.

3.1 Sample manufacturing

The four sets of ACSC samples were manufactured by using a laboratory roller compactor. Each loose asphalt mixture was compacted in a mould with a dimension of 30 cm x 30 cm x5 cm (see Fig. 4). The four sets of compacted ACSC samples are illustrated in Fig. 5.

(a) (b) (c) (d) (e)

Fig 4. Asphalt slab manufacturing process: (a) material preparation, (b) heating of the material, (c) mixing process, (d) compaction process, (e) samples ready to be tested.

(a) (b) (c) (d)

Fig 5. Four asphalt mixture sample sets: (a) dense graded without artificial aggregate, (b) dense graded with 25% artificial aggregate, (c) open graded without artificial aggregate, (d) open graded with 25% artificial aggregate

3.2. Macrotexture and skid resistance measurements of samples

Surface characteristics of the ACSC sample sets were assessed under two conditions: (1) pre-wheel track loading and (2) post-wheel-track loading. Wheel track loading was carried out using a laboratory small scale wheel track tester, running at 21 passes per minute for 60 minutes at 60°C. Measurement of surface characteristics includes: a) determining texture depth using the sand patch method, and b) assessing skid resistance using a British Pendulum Tester (BPT). These methods are illustrated in Fig. 6. Test results and discussions are presented in section 4.

(a) (b)

Fig. 6. (a) Sand Patch to measure texture depth, (b) BPT to measure skid resistance.

3.2.1 Macrotexture

The sand patch tests were carried out on the test section to determine an equivalent mean texture depth (MTD) [15]. The texture depth was calculated based on the amount of fine sand that is required to cover irregularity and pores of the sample surface. This process involves pouring fine sand with a certain volume (Vs) over the sample surface and then spread evenly with a circular motion in a circle until the sand is levelled with the surface (ASTM E965-06) [16]. The final diameter of the circled sand (d) is measured in 4 directions (horizontal, vertical, and diagonal) and the results are averaged. The area of the circle (As=1/□□d2□, then the mean texture depth (MTD), can be calculated using “Eq. (1)”.

MTD = Vs/As = Vs/(1/□□d2)= 4Vs/□d2 (1)

The texture depth was measured in two conditions: pre- and post- wheel track loading. For the post-wheel track loading condition, two set of measurements were made, namely outside and inside the wheel track. The pre loading test process is shown in Fig. 7, and post loading in Fig. 8.

(a) (b) (c) (d)

Fig. 7. Texture measurements on the ACSC sample (pre-wheel track loading): (a) the sample, (b) the sand is poured onto the sample surface, (c) the sand is leveled using a circular motion, (d) measurement of the diameter of the sand circle in four positions.

(a) (b) (c) (d) (e)

Fig. 8. Texture measurements on the ACSC sample (post-wheel track loading): (a) the sample under the wheel track load conditions, (b) the sand is poured onto the sample surface (outside the track), then leveled, (c) measurements in the four directions of the circle diameter, (d) the sand is poured and smoothed on the track, (e) measurement of the length of the sand distribution on the track.

3.2.3 Skid Resistance

Skid resistance was determined using a BPT. For this test, a small rubber foot (75 mm x 25 mm) was used. The pendulum was released, swinging over the test surface and the skid resistance value was determined as the British Pendulum Number (BPN). The final BPN value is the average of the five readings after temperature correction was applied to normalize the test condition to 20°C, according BS EN 13036-4; see Table 3 [17].

Table 3. Temperature correction for BPN when tested at other than 20°C [17]

Measured slider temperature (°C)	Correction to measured value
36 to 40	+3
30 to 35	+2
23 to 29	+1
19 to 22	0

16 to 18	-1
11 to 15	-2
8 to 10	-3
5 to 7	-4

NOTE The temperature correction can be affected by the texture of the surface

The samples used for skid resistance testing were the same sample as those subjected to the texture depth assessment. With a note that the skid resistance assessment was carried out before measuring the texture, so that the test surface remained clean without contamination from traces of sand on the surface.

The skid resistance assessment was carried out under two conditions: pre and post wheel track loading. In the post-loading condition, the skid resistance test was only carried out on the outside of the wheel track. The section within the wheel track was not tested, because the pendulum head is wider than the track width, which prevented it from reaching the tracked surface. The pre loading test process is shown in Fig. 9, and post loading in Fig. 10.

(a) (b) (c) (d)

Fig. 9. Measure the skid resistance on the ACSC plate using a BPT (pre-wheel track loading): (a) the sample, (b) setting the BPT, (c) wetting the sample surface, then swinging the pendulum, (d) reading the dial.

(a) (b) (c) (d)

Fig. 10. Measuring the slip resistance on the ACSC plate using a BPT (post- wheel track load-ing): (a) a sample plate that has been given a wheel track load, (b) setting the BPT, (c) wetting the sample surface, then swinging the pendulum, (d) reading the dial.

4. Results and Discussion

The properties of artificial aggregates show advantages over the natural aggregates, specifically in terms of durability and toughness, as shown in Table 1. The durability by soundness test showed that the artificial aggregate has better resistance to degradation than the natural aggregate. Also, the toughness by Los Angeles abrasion test showed that the artificial aggregate has better wearing resistance than the natural aggregate. The organoleptic check of the apparent shape and microtexture of these aggregates suggested that the more rounded and porous artificial aggregate has surface characteristics which are less favourable than those of the more angular and dense natural aggregate. These can be seen as potential risks to compromising the surface characteristics of the asphalt mixtures, therefore, subsequent assessment of texture depth and skid resistance on the ACSC samples containing these aggregates were carried out.

Fig. 11 shows that the inclusion of artificial aggregate did not have practical impact to the texture depths of both sets of ACSC samples, dense and open graded. The texture depth values appear to be comparable for both samples sets. Similar trend is also observed for the texture depth values obtained before and after wheel track loading where the observed reduction in texture depths appear to be of a similar magnitude for both sample sets. Note that the reporting requirement for texture depth values is typically to the nearest 0.1 mm, however the test results are presented to the nearest 0.01 mm for the purpose demonstrating the slight differences in the values.

(a) (b)

Fig. 11. Comparison of the results of ACSC texture depth measurements without (0%) and with 25% artificial aggregate (a) dense graded, (b) open graded, pre- and post-wheel track loading

Higher skid resistance value is known to be related to rougher surface. In the BPT test, the measurement scale starts from 0 to 120. A scale of 0 means that the surface is very slippery (zero resistance against skidding). Conversely, the value 120 is the maximum value at which the pendulum does not swing further, after touching on the test surface. The test results show that for dense graded ACSC samples, the skid resistance value for those without artificial aggregate is higher than those with artificial aggregate. In contrast, for open graded ACSC samples, the skid resistance of those with artificial aggregates is slightly higher than those without artificial aggregate, after being loaded by the wheel tracking test (see Fig. 12).

(a) (b)

Fig. 12. Comparison of the results of ACSC skid resistance measurements without (0%) and with 25% artificial aggregate (a) dense graded, (b) open graded, pre- and post-wheel track load-ing.

Fig. 12 explains the impact from apparent aggregate shape on skid resistance. For the ACSC mixture without artificial aggregate (therefore containing 100% angular natu-ral aggregate), the skid resistance value seems to be higher than those containing 25% artificial aggregate. As stated previously, the apparent shape of the artificial aggregates was rounded. These results suggest that the rounded artificial coarse aggregate used in the mixture has contributed to the skid resistant values being lower than those containing 100% crushed natural aggregate. Overall however the skid resistant values for these samples are not less than BPN 65, indicating good skid resistance characteristics under the adopted test condition. When compared against the site category for the minimum values of 'skid resistance' as measured with the portable tester suggested by Road Note 27 [18], the BPN results for these samples meet the requirements for category B, for site where traffic speed does not exceed 95 km/h (reproduced in Ta-ble 4).

Table 4. Suggested minimum values of 'skid resistance' [18]

Category	Type of site	Minimum 'skid-resistance' (wet surface)
A	Difficult sites such as:	
a)	Roundabouts	
b)	Bends with radius less than 150 m on unrestrict-ed roads	
c)	Gradients, 1 in 20 or steeper, of lengths greater than 100 m	

d)	Approaches to traffic lights on unrestricted roads	65
B	Motorways, trunk and class 1 roads and heavily traf-ficked roads in urban areas (carrying more than 2000 vehicles per day)	55
C	All other sites	45

NOTE: For category A and B sites where speed of traffic is high (in excess of 95 km/h) an additional requirement is a minimum ‘texture depth’ of 0.65mm

5. Conclusion and Recommendation

Tests on aggregate properties demonstrated durability and toughness values of the artificial aggregate being better than those of the natural aggregate. The macrotexture of the ASCS produced with a blend of artificial and natural aggregates was found to be comparable to that produced with 100% natural aggregate. The apparent aggre-gate shape and surface texture seems to have influenced the skid resistance. The results showed that the use of 25% artificial aggregate resulted a decrease in skid resistance of the ACSC surface. Dense graded ACSC showed slightly lower texture depth and skid resistance values than the open graded ACSC. Post-wheel track load-ing, the texture depth and skid resistance of open graded ACSC were found to be higher than those of dense graded ACSC, regardless the type of aggregates used in these ACSC samples.

It is necessary to explore in the next research how to increase the skid resistance on the ACSC surface. The scope of the study on the shape of the aggregate, the strength of the aggregate, its impact on the area of contact with tyre and the grading of the aggregate still needs to be developed. Therefore, further research is recommended to explore these and other influencing factors such as finding alternatives to assess the sensitivity of the dimension of the contact area between the rubber wheel and the ACSC surface on the skid resistance value and carrying out field validation testing.

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