Skid resistance of gap graded hot-mix asphalt with added crumb rubber

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Abstract. Road surface condition is a critical factor that determines road safety. The paved surface of the road should have sufficient skid resistance to enable a vehicle passing over it to accelerate and stop/brake safely and comfortably. Gap graded hot-mix asphalt is generally used as a non-structural and an impermeable layer to protect the structural layers. The hot rolled sheet (HRS) asphalt mixture has larger cavities that require more asphalt compared to other asphalt pavement types. The addition of crumb rubber (CR) to the asphalt mixture was carried out using the dry mixture method, and the resulting mixture was added to the aggregate. This study utilizes gap graded asphalt pavements containing natural asphalt from a processed product called Asbuton Retona blend 55. CR was added to the asphalt mixture in proportions of 0.5%, 1%, 1.5%, and 2%. This added material improves the performance of the asphalt mixture. The skid resistance of the paved surface layer studied herein used the British pendulum tester for pavement surface temperature variations of 25 °C, 30 °C, 35 °C, 40 °C, 45 °C, and 50 °C. Utilization of CR derived from used tire rubber powder provides the benefit of reusing waste materials that can help preserve the environment. The gap graded hot-mix asphalt with added CR and asphalt modified Asbuton Retona blend 55 has shown an improvement in the skid number. These results show that the hot-mix asphalt pavement with modified asphalt is more impermeable and provides better slip resistance.

1. Introduction
Skid resistance of paved road surfaces can affect the safety of road users and efficiency of their journey. This value determines the friction force on the wheel of the vehicle that will avoid slipping on the surface under wet or dry conditions [1]. When the asphalt surface is newly laid, micro-texture from the aggregates under the asphalt binder film tends to reduce resistance slippage during the initial life of the pavement, usually in the first two years depending on the volume of traffic. However, owing to traffic polishing, the skid resistance of a newly paved surface increases as a consequence of the asphalt binder rubbing, which gradually reveals the micro-texture. Once fully exposed, the micro-texture is incrementally polished by traffic and tends to reduce skid resistance, thereby causing the sidewalk to become more slippery in the long run [2].

A common method to rehabilitate aging asphalt pavements is to remove the upper portion of the existing surface and place a new layer (mill and overlay). This method helps smooth the pavement surface and improve ride. This is usually done with a milling machine, which uses a cutting drum with teeth to remove the asphalt [3]. The friction performance of an asphalt pavement is very much dependent on the type and quality of coarse aggregates used. The different hot-mix asphalt (HMA) classifications
generally have similar micro-textures. Their friction performances follow the same trends as their macrotextures [4].

Macrotexture surface of the asphalt mixture has a significant effect on slip resistance. Increasing the asphalt pavement resistance is achieved by increasing the amount of aggregates exposed to the pavement surface and using a sharp aggregate sharpener [5]. Skid resistance is one of the most important parameters of surface mixtures because of its influence on road safety. In addition, adherence between layers of the surface enables the layers to work together, which has a major impact on the useful life of the pavement. The addition of residual polymer modifies the surface properties of the mixture, and the performance of the asphalt concrete changes greatly depending on the proportion of polymer waste added [6]. To obtain the actual contact area and voltage distribution between the tire and asphalt, a pressure-sensitive film is utilized to measure the radial tire contact pressure. Voltage distribution increases with an increase in the texture depth of the sidewalk, tire load, or decrease in tire inflation pressure. The effect of road roughness and tire load are more significant than tire pressure for stress concentration. Compared to the general texture depth of the curb (sand patch method), the fractal surface dimensions simply describe the surface roughness, including macrotexture and micro-texture, which is directly affected by the proportion of coarse aggregates [7]. Long-term skid resistance has a significant negative correlation with the contents of the binder and characteristic shape of the aggregate gradation. In addition, specific gravity is the most important factor that affects long-term slippage resistance [8].

Therefore, it is very important to correct the measured value of skid resistance based on field temperature. To achieve this, several asphalt sheets were prepared and tested using the British pendulum tester (BPT). Many researchers have studied the effect of temperature on the measured skid resistance of pavement surfaces, none of them has studied such effect below the freezing temperature. The main objective of this research is to correct the measured skid resistance values of airfield asphalt mixes for the wide variation of field temperatures including below freezing temperatures.

These test results are then used to develop a correction model for skid resistance under temperature variations to enable easy use by airport operators [9]. The skid resistances of asphalt mixture plates were measured using the sand patch test and British pendulum number (BPN) test. Sand patch testing mainly explores the macrotexture of the sidewalk, whereas the BPN test mostly investigates the micro-texture of the sidewalk [10]. One of the basic safety requirements for a highway is skid resistance, which plays a very important role especially during wet and rainy conditions. Skid resistance is a pavement surface characterization that describes the interaction between a vehicle’s wheels and the road surface. In particular, less skid resistance or complete lack of resistance is the reason for slippery roads; therefore, the risk of traffic accidents increases [11].

Ultra-thin wearing course (UTWC) has relatively good slip resistance, and stone matrix asphalt (SMA) has very stable friction performance that maintains an almost similar friction level. Dense asphalt concrete (DAC) and rubber asphalt concrete (RAC) have relatively bad friction performance, while RAC has better macrotexture than DAC [12]. The minimum skid threshold for safe wet-weather driving has been determined by Bina Marga Indonesia based on technical assessments and past experience. It is shown here that a single point minimum skid threshold is inadequate to offer a complete description of the sloping resistance performance of a sidewalk for effective road network management. The skid resistance of a wet pavement varies with the thickness of water film on the pavement surface. For a given test speed, the thicker the water film, the lower is the skid resistance. In pavement skid resistance survey of a pavement management system, a standard skid resistance test procedure and test equipment is adopted, and the test speed and water film thickness are fixed [13].

At low speeds, hardened mixtures of Asphalt Concrete (AC) have better slip resistance than SMA and are exposed to Portland Cement Concrete (PCC) aggregates, whereas at high speed, SMA and PCC aggregate exposure provide better slip resistance than the AC pavement. This information is valuable for maintaining proper sidewalks and during the design stage [14]. The purpose of this study was to analyse the skid resistance and the effect of adding CR to gap graded HMA using British pendulum testing for various temperatures.
2. Materials and methods

The materials used in this study are aggregates with gap gradation; aggregates are added to crumb rubber from used waste rubber tires. The asphalt used is Retona blend 55, which is a mixture of oil asphalt and natural asphalt from Buton island, which has a penetration number of 55.

2.1. Aggregates

In general, aggregates have three types of gradations: tight graded aggregates, uniform graded aggregates, and gap graded aggregates. The gap graded aggregate is a type of aggregate gradation that is characterized by non-uniform sizes or very few aggregate fractions. Gap graded aggregates have the combined characteristics of the two other types of gradations. The results of the aggregate gradation used in this study are shown in Figure 1. Aggregates used in this study were obtained from a quarry in Serpong Tangerang Selatan, where the aggregate composition was designed in accordance with the requirements of the Bina Marga Indonesia gap graded specification as a surface layer.

![Figure 1. Sieve Analysis with Gap graded Aggregates](image)

2.2. Asphalt

Buton Retona asphalt is a type of bitumen extracted from Asbuton. The material properties of Retona are characterized by high viscosity; thus, for ease of use, Retona is mixed with oil asphalt, and displayed in Table 1.

| Bitumen property                  | Standard    | Unit     | Value |
|-----------------------------------|-------------|----------|-------|
| Penetration at 25 °C              | ASTM-D5     | 0.1 mm   | 55    |
| Softening point                   | ASTM-D36    | °C       | 55    |
| Flash point                       | ASTM-D92    | °C       | 284   |
| Ductility at 25°C                 | ASTM-D113   | cm       | >140  |
| Specific gravity                  | ASTM-D70    | g/cm³    | 1.032 |
| Loss on heating (TFOT)            |             | %        | 0.224 |
| Penetration after TFOT            | ASTM-D5     | %        | 52    |

Product development for this blend was carried out by PT Olah Bumi, which manufactures the Retona blend 55 product. Retona blend 55 is a Buton natural oil asphalt, which is processed using a tool with a minimum bitumen specification of 90% and a maximum mineral content of 10%.
2.3. Crumb Rubber

The efficient reutilization of waste tires includes processing them into new materials, e.g., rubber powder. Scrap tire application to roads dates back to the 1960s when Charles MacDonald used waste tires for maintenance work in urban areas. Tire rubber has advantages as an additive in asphalt cement. CR is made from scrap tire rubber in the form of a fine powder that passes through sieve no. 30 (0.6 mm). CR used in this study corresponded to CR processed by ambient grinding produced by PT. Daur Indo at 26 °C. The use of CR in concrete asphalt mixtures considers the size of the grain to obtain the right mixture proportion. The CR replaced a proportion of the aggregate volume. The CR was mixed into the aggregate asphalt mixture using the dry mix method that involves pouring CR over the aggregate when it reaches a temperature of 152 °C (mixing temperature). The mixing method involved the following: the aggregate was heated at the mixing temperature; CR was then poured on the heated aggregate, and Retona was added to the aggregate and CR mixture. The most important point to be considered in mixing CR is that increasing the CR level in the asphalt mixture decreases the aggregate volume. This condition caused the amount of asphalt content on the surface of the aggregate to vary.

2.4. Skid Resistance Test

The skid resistance testing using the BPT tool was adjusted to the SNI 4427:2008 standard. BPT was used to measure the friction characteristics of the pavement surface. The BPT produces low-speed shear contact forces between standard rubber sliders with pavement surfaces and calculates the friction properties by determining the kinetic energy loss from the slider when making contact with the pavement surface. The loss of kinetic energy is converted into friction force, which is then referred to as pavement friction and expressed BPN. The BPT offers ease of use and can provide friction and micro-texture indicators at low speeds such as 10 km/h for all pavement types, in both the field and laboratory conditions. The test object was derived from the compaction of a wheel tracking machine (WTM) and had a size of 300 × 300 × 50 mm³. The skid resistance test was conducted with the WTM test results, by cutting the sample from the test into a smaller part with a size of 80 × 150 × 50 mm³ (Figure 2).

![Figure 2](image_url)

(a) British pendulum tester (BPT), (b) Samples of BPT.

Each BPT sample type was tested at temperature variations of 25 °C, 30 °C, 35 °C, 40 °C, 45 °C, and 50 °C. The test was conducted by conditioning the sample in a water immersion bath from the start of BPT modification until the sample surface temperature reached the measured temperature (Figure 2a). Each test was carried out five times so that the average value of the skid resistance data could be obtained with the temperature variations.

Correlation between the skid number (SN) and BPN is given as follows:

\[
SN = 0.862 \times (BPN) - 9.69
\]  
(1)
3. Results and discussion

The effect of CR on the asphalt mixture from the gap gradation on the value of skid resistance has been tested using a BPT at temperatures in the range of 25–35 °C. The result of a skid resistance test with changes in CR content from 0.5% to 2% with an increment of 0.5% and changes in temperature between 25 °C and 50 °C. SN value at 25 °C was highest (40.74) without CR content. Increasing temperature on the sample surface up to 50 °C showed a very sharp decrease in SN value (30.82). The decrease in SN value due to heating of the sample surface occurs also due to the addition of CR to the asphalt mixture, as shown in Figure 3.

![Figure 3. Skid Number with Increasing Temperature](image)

The change in SN value at the lowest temperature of 25 °C decreased with the addition of CR, the addition of 2% CR content produced the lowest SN value (33.41), although the SN value with 2% CR is still higher than the SN value without CR. The addition of CR 1% and 1.5% shows that the SN value is almost the same, but when compared to these two mixtures, the addition of CR 1.5% is better than the addition of CR 1%, because at a temperature of 50 °C, a higher SN value (32.63) was obtained from the addition CR 1% (Figure 4). From the test results with the addition of CR, it can be seen that the gap graded asphalt mixture with the addition of CR has contributed to the resistance to temperature. The decrease in SN value due to the influence of temperature on the surface of the sample is smaller in the mixture of gap graded asphalt without CR. A mixture of gap graded asphalt has more asphalt content compared to other types of asphalt mixtures. This condition causes the asphalt mixture from the gap grading to be sensitive to changes in temperature. Addition of CR helps inhibit the decrease in SN value due to an increase in temperature on the sample surface.

![Figure 4. ΔSkid Number with Increasing Temperature](image)
4. Conclusions
CR in the form of fine fibers from processed tire wastes can be used in gap graded asphalt mixtures to reduce the level of decline in SN value due to road surface heating. The SN value decreases with the addition of CR than the asphalt mixture without CR at 25 °C. The decrease in SN value due to the increase in road surface temperature is reduced by the addition of CR. The addition of 1% CR has shown the best results because it produces the smallest decrease in SN value.

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