Performance of Asphalt Mixture Incorporating Activated Crumb Rubber as Additive

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Abstract. The major problem of dry mix method is poor interaction between asphalt binder and additive causing improper workability. Hence, air void content will be increased and reduced the strength of asphalt mixture. Activated Crumb Rubber (ACR) as additive is one possible approach to improve these issues. In this study, nine ACR contents were considered in the study i.e. 0%, 0.25%, 0.50%, 0.75%, 1.0%, 2.0%, 3.0%, 4.0% and 5.0% by weight of total mixtures. The performance of Marshall properties, Resilient Modulus, Tensile Strength Ratio and Hamburg Wheel Tracker (HWT) test were analysed. Based on the results, 0.75% of ACR gave optimum improvement to the performance of Marshall properties, resistance to rutting and cracking but susceptible to stripping.

1. Introduction

Recently, higher traffic volumes and new axles’ designs with heavier loads and different configurations have forced agencies and researchers to explore asphalt modification [1] to design and construct conventional pavement that perform better and last longer [2]. It is because when the conventional mixture experiences heavy traffic load repeatedly and continuously, it exhibits moisture-weakened asphalt which becomes main concerns where the pavement prone to rutting, cracking and stripping failures [3-8].

The issues of environmental problem due to improper waste management in landfill had urge many agencies and researchers to apply waste materials in road pavement which is not only suit in asphalt mixture but also in concrete block pavement such as crumb rubber [9] and rice husk ash [10]. For over 50 years, crumb rubber is one possible additive that has been reported to improve the performance of mixture and increase their service life [11, 12]. Crumb rubber is obtained from waste scrap tyres (consists of a truck tyres) [13] and has useful properties to provide elasticity, thermal stability, durability, noise reduction effect and improve low-temperature cracking resistance [14-17]. However, asphalt rubber mixtures are difficult to produce where it requires specialized plants and equipment due to high temperatures for a significant period of time (typically at about 190°C for 45 minutes to 1 hour) especially when incorporate by a dry mix process [18]. Thus, it needs a high cost more than conventional paving mixtures to manufacture.

Improper workability because of poor interaction between asphalt binder, aggregates and additive during dry mixing process becomes the major problem where it leads to increasing of air void content in mixture [19]. Therefore, a new approach of activation of crumb rubber was proposed to improve the compatibility between virgin asphalt and crumb rubber and change their interface combination [20].
Activated Crumb Rubber (ACR) were finer and well dispersed with binder compared to the non-activated crumb rubber [21] which give benefits to dry process method. ACR contains of about 62 - 65% fine crumb rubber, 20 - 25% soft bitumen, and 15 - 20% filler [22]. Activation agent was made up by a unique mineral and has been proven to improve rheology and crack resistance of dense mixtures besides works as prevention of re-coagulation of the product during mixing process [22].

Based on previous studies, typically about 1–3% of granulated crumb rubber (size between 0.4 and 10mm) by weight of total aggregate were used [23]. Hence, the significance of this study was aimed at investigation the effect of ACR as additive in asphalt mixture properties at various ACR contents which is potentially to improve the asphalt mixture by using dry mix method. 0, 0.25, 0.5, 0.75, 1, 2, 3, 4 and 5% were the selected design for ACR contents by using dry process method. Inequal interval between ACR contents were because the mechanical properties of the mixtures formed has been reported are very sensitive to the changes in rubber content [24].

2. Materials and method

2.1. Materials

Hot Mix Asphalt incorporating Activated Crumb Rubber (ACR) additive with nominal maximum aggregate size 14mm (AC 14) and 4.9% optimum bitumen content (OBC) (PEN 60/70) were prepared in this study. ACR obtained from Ahn Vertex Sdn Bhd sized 0.425mm was used.

2.2. Sample preparations

All samples were prepared in a standard Marshall mould with an average height of 65 mm and a diameter of 100 mm. The designated gradations and weight of aggregates were heated before mixing process. The heated aggregates were then mixed with 4.9% of bitumen and specified amount of ACR (with 0%, 0.25%, 0.5%, 0.75%, 1.0%, 2.0%, 3.0%, 4% and 5% by weight of total mix) at temperature ±180°C by using dry mix method. Dry mix method was more easy and simpler to control the addition of ACR contents during mixing even though the interval between ACR contents below 1.0% were only 0.25% (about 3g difference). In addition, ACR was in a powder form, thus, it was easy to add in exact amount. Accordance with ASTM D 6926-10 [25], each sample was compacted with 75 blows per face using Marshall compactor at temperature ±145°C. The bulk specific gravity of each sample shall be determined in accordance with ASTM D 2726 [26] as soon as the freshly compacted samples had cooled to room temperature.

Meanwhile, the samples for rutting test were prepared based on ASTM D6925-15 [27] by using Superpave Gyratory Compactor set.

2.3. Marshall stability and flow test

Accordance to ASTM D6927 [28], Marshall stability and flow test was conducted by universal compressive machine for a compacted mixture at 60°C where the specimens were conditioned first by immersed in water bath at temperature 60°C for a period 45 minutes. The maximum load was applied to the specimen at a constant loading rate of 50.8mm/ minute in order to measure the stability by using the stability portion. Generally, the load was increased until it reached a maximum then the load just begins to decrease, the loading was stopped and the maximum load was recorded. The properties were checked against specification for wearing course [29] as shown in Table 1.

Table 1. Marshall mixture specification for wearing course [29].

| Type of mixture | Conventional mixture (HMA) |
|----------------|---------------------------|
| Parameter      | Wearing course            |
| Stability, S (N) | >8000                     |
| Flow, F (mm)   | 2.0 – 4.0                 |
| Stiffness, S/F (N/mm) | >2000                   |
| Void in total mix, VTM (%) | 3.0 – 5.0               |
| Void filled with bitumen, VFB (%) | 70 – 80                |
2.4. Resilient modulus test 
Accordance to ASTM D7369 – 09 [30], by using Universal Testing Machine (UTM-5), indirect tensile modulus test was conducted with five pulses to evaluate the elasticity behavior of the asphalt mixture under repetitive load. For prior, the specimen has been conditioned about 4 hours at temperature 25°C. Total resilient modulus was depend on total recoverable deformation including both the instantaneous reversible and the time-dependent during the unloading and the rest period position of one cycle. Each specimen was subjected to 5 pulses for every test and the average reading was taken by rotating the sample from 0⁰ up to 90⁰ position.

2.5. Tensile Strength Ratio (TSR) test 
Accordance to ASTM D4867 [31], six samples of Marshall mix design were prepared which then split into two sets of three samples each. One set was tested in wet condition (conditioned) and the other one set was tested in dry condition (unconditioned). For dry condition, the samples were placed at a constant temperature of 25 °C in water bath for 2 hours. Meanwhile, for wet condition, the samples were conditioned under 35 kPa pressure by the vacuum pump to achieve the saturation level of 55% - 80%. Once the sample achieved the saturation level, it was then placed to a 60°C water bath for 24 hours. After that, the conditioned samples were placed in a 25°C water bath for 2 hours. The tensile strength ratio was used to evaluate the strength of the samples against moisture caused by stripping.

2.6. Hamburg Wheel Tracker (HWT) test 
Accordance to AASHTO TP 63 [32], the test was used to measure the rut depth formed under repeated passes of loaded wheel at temperature 50°C. Each sample was subjected under repetitive wheel load of 700N (100lbs) for 10000 cycles as a complete test for about 8 hours and 30 minutes.

3. Results and discussions 

3.1. Density 
Figure 1 shows the result of density of the mixtures. Based on the graph’s pattern, it can be seen that when ACR additive was added in the mixture, the density was increased until reached the maximum at 0.75%, but then the density was decreased consistently until 5% of ACR. One of the factors that influence the changes of density in the mixture was because the bitumen content and addition of ACR percent. The bitumen content used for 0.25, 0.50 and 0.75% of ACR was 4.90%. Meanwhile as the ACR content increased more than 1.0%, the bitumen contents used also increased which were 5.07, 5.08, 5.09, 5.18 and 5.26% respectively. For the ACR mixtures, it shows that 0.75% of ACR obtains the highest density which is 2.359g/cm³, meanwhile 5% of ACR gives the lowest density which is 2.165g/cm³. Based on control mixture, 0.75% of ACR gives higher density by 1% improvement only where it shows the increasing of ACR content at this level have insignificant effect.

![Figure 1. Density of Control (0%) and ACR mixtures.](image-url)
3.2. Volumetric analysis
The volumetric properties of the mixtures as presented in Figures 2 and 3 show significantly depended on the ACR contents. Figure 2 shows the result of VFB. The range for accepted VFB is within 70%–80% [29]. The result shows 0.25, 0.5 and 5.0% of ACR failed to achieve within the range. Meanwhile for Figure 3, it represents air voids in mix (VTM) which targeting of 4.0%±1% air voids [28]. The result of VTM was in contrast with VFB because only 0.5 and 0.75% of ACR met the requirement. Based on the pattern, roughly, the results show that as the ACR content increased, the VFB also increased as well as VTM value. The low value of VTM represents the mixture prone to bleeding and rutting, while high value of VTM represents the mixture susceptible to low resistance of durability [33].

![Figure 2. VFB of Control (0%) and ACR mixtures.](image1)

![Figure 3. VTM of Control (0%) and ACR mixtures.](image2)

3.3. Stability
Figure 4 illustrates the stability of the mixtures. The graph shows that only 5% of ACR failed to achieve the requirement of the stability more than 8000N [29]. If based on control mixture, the results for ACR mixtures showed no improvement because the stability obtained for control mixture was higher twice than minimum requirement. As shown in Figure 4, when the ACR content increased, except for 1.0% of ACR, the stability continuously to decrease as the increasing in air void percentage (presented in Figure 3). However, different for 0.75% of ACR, where the stability value records forth higher (12314N), although the VTM value records the lowest value which is 4.6% (within the requirement). Higher stability value represents the more strength of asphalt mixture [34]. There could be various reasons for the stability loss where it may be due to sample-to-sample variation [35]. Upon all the ACR mixtures studied, the stability of 5% of ACR was significantly lower than other mixtures and obtains highest VTM value. This also revealed as the ACR content increased, the interaction between binder and ACR during dry process mixing reduced.

![Figure 4. Stability of Control (0%) and ACR mixtures.](image3)
3.4. Flow
Figure 5 shows the result of flow numbers of the mixtures. The flow numbers represent the measurement of the vertical deformation of the mixture. Based on the result, the flow numbers were inconsistent as the ACR content was increased. Only 3.0% of ACR was out of the targeting flow range [29] which is more than 4.0mm which is the highest flow number compared to other mixtures. High flow number shows the mixtures were not stiff enough as they had poor interaction between the binder and ACR content. Meanwhile, 1.0% of ACR records the lowest flow number with 2.1 mm, which in agreement with its high stability.

![Figure 5. Flow of Control (0%) and ACR mixtures.](image)

3.5. Stiffness
Figure 6 shows the stiffness’s results for all the mixtures. The stiffness of the mixture was obtained from the ratio of stability and flow as shown in Figures 4 and 5 respectively. According to the specification [29], the stiffness should more than 2000N/mm and only 5.0% of ACR failed to achieve. Based on the trend, the stiffness decreased as the ACR content increased except 1.0% of ACR. The decrease of stiffness due to the increment of the vertical deformation which led to the loss of internal strength of the mixture. The trend was significantly different in 1.0% of ACR where it attains highest stiffness (6504 N/mm) compared to other mixtures, which could be related to the lowest flow value.

![Figure 6. Stiffness of Control (0%) and ACR mixtures.](image)

3.6. Verification of Marshall performance
Table 2 presents the verification results of the mixtures based on the requirements [29]. The optimum mix design was highly dependent to an adequate VTM value of 4.0%±1% air voids which must be achieved since it directly influences the performance of the ACR mixtures [35]. Based on the results, it proves that 0.75% of ACR with air voids 4.5% met all requirements. Concurrently, 5% of ACR attains the least performance which represents the maximum limit for the addition of ACR in the mixture.
Table 2. Marshall properties of control (0%) and ACR mixtures.

| HMA Mix Requirement [29] | Percentages of ACR in mixtures (%) | 0  | 0.25 | 0.50 | 0.75 | 1.0  | 2.0  | 3.0  | 4.0  | 5.0  |
|--------------------------|-----------------------------------|----|------|------|------|------|------|------|------|------|
| Stability, N             | >8000                             | 15893 | 15708 | 13261 | 12314 | 13627 | 11505 | 10165 | 10063 | 6536 |
| Flow, mm                 | 2.0 – 4.0                         | 3.5  | 3.4  | 3.6  | 3.1  | 2.1  | 3.4  | 4.2  | 3.7  | 3.6  |
| Stiffness, N/mm          | >2000                             | 4537  | 4643  | 3640  | 3994  | 6504  | 3419  | 2451  | 2728  | 1758 |
| VTM, %                   | 3.0 – 5.0                         | 4.0  | 5.5  | 4.9  | 4.5  | 6.8  | 6.7  | 6.4  | 8.0  | 12.1 |
| VFB, %                   | 70 – 80                           | 74   | 67   | 69   | 71   | 73   | 72   | 75   | 76   | 65   |

Figure 7 presents the relationship between the stability and density of the asphalt mixture. The result shows that the density influences the performance of the stability of the mixture where at first, the density of the mixtures increased as the ACR content increased but the density begins to decrease when the ACR content increased more than 1.0%. Different with stability value where the stability of the mixtures decreased consequently to the increasing of the ACR mixtures from 15708N to 6356N. Based on the graph, clearly, the asphalt mixture that had an adequate density provides high stability and it can be seen from 0.25% of ACR and followed by 0.5, 1.0, 0.75, 2.0, 3.0, 4.0 and 5.0%.

Figure 8 shows the relationship between stiffness and density of asphalt mixtures. The graph gives the same pattern with the graph of stability against density where the density of the mixtures increased as the ACR content increased but when the ACR content increased more than 1.0%, the density begins to decrease. The results also indicate the stiffness gives inconsistent pattern when ACR was added for 0.25 to 0.75% but when the ACR content more than 1.0%, the stiffness decreased from 6504N/mm to 1758N/mm. Based on Figure 7 and 8, it can be concluded that the optimum ACR content, 0.75% records highest density for both data compared to others mixture with stability 12314N and stiffness 3994N.

3.7. Resilient modulus

Figure 9 shows the results of control (0% of ACR) and 0.75% of ACR mixtures to resilient modulus at temperature 25°C. Based on the results, the addition of 0.75% of ACR in asphalt mixture records higher resilient modulus value than control mixtures with an average 3123MPa. It improves the resistance to fatigue crack for conventional mixture about 20%.
Figure 8. Stiffness versus Density.

Figure 9. Resilient modulus at 25ºC for both control and 0.75ACR mixtures.

3.8. Tensile Strength Ratio (TSR)

Figure 10 summarizes the main findings from the test which comprised of Indirect Tensile Strength (ITS) and Tensile Strength Ratio (TSR) value of control and 0.75ACR mixtures for both unconditioned (UC) and conditioned (C) samples. The graph shows that the addition of 0.75% of ACR increased the ITS in dry condition rather than in wet condition compared to control mixtures. It represents that even though the presence of 0.75% of ACR resulted in higher strength of asphalt mixture but in the presence of water, it resulted in a reduction in cohesion. Also, it can be seen the TSR value of 0.75% of ACR records lower TSR value than the specified requirement by JKR (TSR>0.80) which led to stripping.

Figure 10. Indirect Tensile Strength and Tensile Strength Ratio (TSR) for both control and 0.75ACR mixtures.
3.9. Hamburg Wheel Tracker (HWT)

Figure 11 illustrates rut depth for both control and 0.75ACR mixtures. Based on the graph, 0.75ACR mixture records rut depth lower than control mixture (0% of ACR) with 1.58 mm. It shows the addition of polymer in asphalt mixture improves resistance to rutting by reduction of rut depth about 32% compared to control mixture. Higher resistance to rutting represents higher strength of asphalt mixture.

![Graph showing rut depth for control and 0.75ACR mixtures]

**Figure 11. Rut Depth for both control and 0.75ACR mixtures.**

4. Conclusions

This study focused on the Marshall properties of dry process in asphalt mixture incorporating with various ACR contents. It was concluded that the addition of ACR content has various positive effects on the mixture performance in terms of Marshall properties, resistance to fatigue cracking, rutting and stripping. Overall, the following findings were drawn from this study:

- Based on JKR specification, 0.75% of ACR was selected as the optimum percent of ACR content because it met all the requirement. 0.75% of ACR content had the highest density with high stability and stiffness with 12314 N and 3994N respectively.
- The addition of 0.75% of ACR additive, improved the resistance to fatigue cracking and rutting about 20% and 32% respectively but susceptible to stripping.

As a conclusion, even though the addition of ACR additive showed insignificant improvement between ACR and control mixture in Marshall properties, but based on the mechanical performance, the ACR additive eligible to apply and provide the same or better performance compared to conventional and non-ACR mixtures. ACR mixture may initiate higher cost for initial construction but in long term may reduce the cost of maintenance [11, 12]. According to the findings of this study, it is recommended to study further on the combination with other materials in order to overcome stripping issue in ACR asphalt mixture to verify more in the field applications.

5. References

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