The use of Crumb Rubber as Substitute of Fine Aggregate for Hot Asphalt Mixture using Polymer Modified Bitumen

A Setyawan1, S K Nugroho1, A M Irsyad1, H F Mutaqo1, P Ramadhan1, A Sumarsono1, F P Pramesti1

1 Roadmate Research Group, Civil Engineering Department, Sebelas Maret University, Jl. Ir. Sutami 36 A Solo 57126 Indonesia

E-mail: cenase@yahoo.com

Abstract. The development of road pavement to fulfilled the need of modern life is not only focused on heavy duty road, but also a light duty road for the convenience of road users according to its function. For example the use of pavement on the jogging track, rail crossing, playground and so on. Due to the need of an alternative and the innovation of a comfortable pavement layer, but sufficiently strong in holding the load on the layer. The alternative innovation that can be used for the respective requirement is the utilization of waste old tires as substitute material in pavement construction. In this case the use of crumb rubber made from old tire rubber as an 100% fine aggregate substitute on the asphalt mixtures is investigated. To improve the strength and durability of the mixtures, the addition of polymer modified bitumen was incorporated. The two types of asphalt mixture selected in this study by using a continuous gradation of asphalt concrete and a gap gradation of hot roll asphalt. Testing to be implemented in this research is volumetric characteristics, Marshall characteristics, resistance to abrasion and impact and permeability. Replacement of fine aggregate with crumb rubber on asphalt concrete mixture with 60/70 penetration grade bitumen and polymer modified asphalt SBS E-55 in this research are expected to be an alternative in improving the quality of pavement and overcoming the environmental problems by reuse the waste materials.

1. Introduction

Crumb Rubber is one of the results of processing a waste old tires used in vulcanized industry. The number of used old tire rubber is increasing with increasing the number of vehicles. Therefore, tire processing is an important issue. The use of crumb rubber in the pavement industry is to use the crumb rubber as an aggregate replacement in asphalt [1] and concrete [2]. In Indonesia, there have been several studies on crumb rubber. As an aggregate, CR can be used as a substitute for stone dust for the filler of a mixture of the Hot Rolls Sheet - Abrasioning Coarse so that it has stability, flow, residual stability, durability, flexibility and abrasion tires better than conventional filler. Partial replacement of aggregates with used the crumb rubber can increase the resilience of asphalt mixture to water, thus reducing road damage [3]. This study has attempted to utilize crumb rubber as a substitute of 100% fine aggregate on the HRA and AC mixtures. The bitumen used in this study were 60/70 asphalt pen and SBS E-55 polymer modified asphalt. This study will review the results of asphalt mixtures test in volumetric and Marshall, permeability and resistance to disintegration properties. The product of this research is expected to be a new innovation in the field of pavement, and can be applied on special need of pavement especially for very flexible pavement.
2. Experimental

2.1. Mixture design

There are two types of aggregate gradation of Asphalt Concrete and Hot Rolled Asphalt, the illustration of each gradations are presented in Figure 1.

![Figure 1. Gradation for Asphalt Concrete (a) and Hot Rolled Asphalt (b)](image)

Job mix design calculations are used for conversion from weight to volume to achieve the expected thickness of the test specimens. The aggregate were then weighted according to their proportion to active total weight (aggregate + bitumen) of 900 gr. The example of the aggregate calculation as presented in Table 1.

| Sieve Number | % Pass | % Retain | Aggregate Volume | SG | Aggregate Weight | Information |
|--------------|-------|---------|------------------|----|-----------------|-------------|
|              |       |         | Per Sieve        |    | Per Sieve       | Cumulative  | Gr/c m³ | Gr | Gr |
|              |       |         | Cumulative       |    | Cumulative      |             |         |    |    |
| 1/2"         | 100   | 0       | 0                | 0  | 0.00            | 0           | 0.00    | 0.00| CA |
| 3/4"         | 95    | 5       | 5                | 22.10| 22.10           | 2.63        | 58.11   | 58.11| CA |
| # 4          | 61    | 39      | 22.5             | 99.43| 172.34          | 2.63        | 261.49  | 453.26| CA |
| # 8          | 43    | 57      | 18               | 79.54| 251.88          | 1.1         | 87.50   | 540.75| CR |
| # 16         | 30.5  | 69.5    | 12.5             | 55.24| 307.12          | 1.1         | 60.76   | 601.52| CR |
| # 30         | 22    | 78      | 8.5              | 37.56| 344.68          | 1.1         | 41.32   | 642.83| CR |
| # 50         | 15.5  | 84.5    | 6.5              | 28.72| 373.41          | 1.1         | 31.60   | 674.43| CR |
| # 100        | 10.5  | 89.5    | 5                | 22.10| 395.50          | 1.1         | 24.30   | 698.73| CR |
| # 200        | 6.5   | 93.5    | 4                | 17.68| 413.18          | 1.1         | 19.44   | 718.18| CR |
| PAN          | 0.00  | 100.00  | 6.5              | 28.72| 441.90          | 3.15        | 90.48   | 808.66| PC |
| Total        | 100   | 441.90  | 808.66           |     |                 |             |         |     |    |
| Bitumen at % Volume | 8.84 | 42.86 | 484.76 | 1.03 | 44.24 | 852.89 |
3. Results and Discussion

3.1. Volumetric testing

Volumetric testing is intended to determine the porosity or VIM (Void in Mixture) of the specimen, which normally is required between 3-5% as reviewed by Daniel and Lachance [4]. Transportation Research Record: Journal of the Transportation Research Board, (1929), pp.28-36. The guidance on assessing the performance testing for hot mix asphalt has been reported by Brown et al [5]. The porosity was calculated based on the specific gravity and density of the specimen. The comparison of density, specific gravity and porosity of four types of mixture can be seen in Figure 2. The use of crumb rubber as a substitute for fine aggregate in Asphalt Concrete with SBS E-55 yields the porosity value of 1.78%, while using conventional asphalt penetration 60/70 resulted in porosity of 1.957%. The porosity value of Hot Rolled Asphalt with SBS E-55 polymer modified bitumen gave the porosity value of 1.179%, while using asphalt Penetration 60/70 resulted in porosity value of 1.201%. All the porosity values are below the requirement of 3%. However, it is expected that the flexibility of crumb rubber’s fine aggregates could accommodate the expansion of bitumen when the temperature increase, so it needs more experimentation to study this phenomenon. The advantages of using crumb rubber have been reported in Microscopic analysis of the interaction between crumb rubber and bitumen in asphalt mixtures using the dry process [6].

![Figure 2. Volumetric Properties of Rubberized Asphalt Mixture, (a) Density, (b) porosity and (c) Specific Gravity](image-url)
3.2. Marshall performance

Marshall testing is an assessment procedure of the specimen to determine the optimum bitumen content (OBC) and by reviewing their stability, flow, and Marshall Quotient as also reviewed in the laboratory comparison study of the use of stone matrix asphalt in hot weather climates [7]. Comparison of Marshall characteristics of four types of mixture can be seen in Figure 3. The properties of Asphalt Concrete with SBS E-55 polymer modified bitumen gave the stability value of 130.23 kg, flow 8.98 mm and Marshall Quotient of 14.16 kg/mm, meanwhile with conventional asphalt penetration 60/70 gave the stability value of 115.49 kg, flow 8.49 mm and Marshall Quotient 13.44 kg. On Hot Rolled Asphalt SBS E-55 Marshall Quotient 13.44 kg/mm, while with Asphalt Penetration 60/70 resulted in the stability value of 137.439 kg, flow 13.420 mm, Marshall Quotient 10.240 kg/mm. All the stability values are below the requirement of 800 kg but having higher Marshall flow as expected to have more flexibility, the value of Marshall quotient were also indicated the similar pattern.

The result of bitumen content with crumb rubber as a substitute for fine aggregate was found as optimum asphalt content of 6.02% on Asphalt Concrete with SBS E-55 and 6.04% at Asphalt Concrete Penetration 60/70. Hot Rolled Asphalt SBS E-55 gave the optimum value of 6.86% and 7.19% on Hot Rolled Asphalt with asphalt penetration 60/70. The optimum bitumen contents of all rubberized specimens were quite similar to the conventional mixture, however, some researcher gave different conclusion on the effect of crumb rubber on the optimum bitumen content [8,9].

![Figure 3. Comparison of Marshall Quotient for four types of mixtures](image-url)
3.3. Cantabro Test.
Testing Cantabro done to determine the weight loss of the test specimen after the abrasion and impact test using the Los Angeles machine for 300 rotations with the average speed of 30-33rpm without a steel ball. Previous research on assessing the resistance to abrasion and impact have been done by Chiu on the use of ground tire rubber in asphalt pavements, field trial and evaluation in Taiwan[10]. Comparison of the values of four mixed types can be seen in Figure 4. The properties of Asphalt Concrete with SBS E-55 polymer modified bitumen gave the lost of particles of 0.02%, meanwhile with 60/70 pen gave the value about 0.10%. On Hot Rolled Asphalt SBS E-55 gave the particle lost about 0.10%, meanwhile with asphalt Penetration 60/70 abrasion 0.98%. It could be seen that the resistance to abrasion and impact are extremely high, the use of polymer modified seems to strengthen the bond of aggregate particles on the mixture.

![Figure 4. Comparison of Cantabro Test Results of four types of mixtures](image)

3.4. Permeability test
The permeability test is performed to find out the permeability coefficient value. The permeability test has been carried out by Sharma and Goyal in the comparative study of performance of natural fibres and crumb rubber modified stone matrix asphalt mixtures[11]. The comparisons of the permeability values of the four mixture types are presented in Figure 5. The properties of Asphalt Concrete with SBS E-55 polymer modified bitumen gave the permeability index of of 3.24x10^-4, while using 60/70 penetration gave the permeability index of 1.02x10^-4. On Hot Rolled Asphalt with SBS E-55 polymer modified bitumen gave the permeability index of 1.90x10^-4, meanwhile using asphalt penetration 60/70 gave the permeability of 1.02x10^-4. It could be concluded that the rubberized asphalt mixtures in this research are impermeable.

![Figure 5. Comparison of Permeability Index of four types of mixtures](image)
4. Conclusion
From the results of research and data analysis conducted can be obtained a conclusion as follows:

The addition of crumb rubber and polymer modified bitumen in Marshall properties of asphalt Concrete and Hot Rolled asphalt indicates the lower value of Marshall Stability, the higher the flow rate and the lower the Marshall quotient. The influences on the volumetric properties indicate the lower the density and specific gravity values, so that resulted in the low porosity or air voids.

This suggests that with the substitution of fine aggregates with crumb rubber levels lead to the lower use of petroleum asphalt, so more friendly to the environment. With elastic and durable blending properties, the innovation of crumb rubber as a substitute for fine aggregates on asphalt mixes is quite feasible for pavement with special requirements as playgrounds, jogging track or rail crossing. The more resistance to disintegration and the impermeable layer are the advantages of rubber substitution to protect the underneath layer.

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