Transactions on Science and Technology Vol. 8, No. 3-3, 485 - 491, 2021

Effects of Sandstone River Aggregate on Crumb Rubber Warm Mix Asphalt

Lillian Gungat#,
Mohd. Ishaq Bin Selamat, Muhammad Saufi Bin Sulaiman, Nurmin Bolong
Faculty of Engineering, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, MALAYSIA.
Corresponding author. E-Mail: lillian@ums.edu.my; Tel: +6088-320000; Fax: +6088-320348.

ABSTRACT The performance of asphalt pavement is influence by the quality of materials. However, Sabah does not have ample resources of good quality aggregate and have to rely on the sandstone aggregate. Hence, this study investigates the effects of sandstone river aggregate incorporating crumb rubber and warm mix asphalt additive. Laboratory study were carried out on specimen containing 0%, 10% and 20% crumb rubber as replacement of fine aggregate. Optimum binder content for each types of mixtures were determined in the mix design. Specimens prepared at optimum binder content were evaluated in terms of resilient modulus, dynamic creep and moisture susceptibility. Findings from the study indicated that inclusion of crumb rubber increased the optimum bitumen content. It was found that addition of 10% crumb rubber improved the resilient modulus dan resistance to permanent deformation compared with conventional hot mix asphalt. Specimen with 10% crumb rubber also showed the highest moisture susceptibility when added with hydrated lime. Hence, the most ideal crumb rubber content to be used in the road construction is 10%.

KEYWORDS: Sandstone, river aggregate, warm mix asphalt, crumb rubber.
Received 26 October 2020 **Revised** 3 December 2020 **Accepted** 16 December 2020 **Online** 2 December 2021

Original Article

INTRODUCTION

Sabah has a road network of 21,607 km where 9,240 km or 43% is sealed (Department Statistic Malaysia, 2015). The sealed road is either concrete road or asphalt pavement. Road pavement are mostly built with asphalt due to good long-term performance and ride quality. Asphalt mixture is a viscoelastic material which mainly consists of binder, filler and aggregates. Basically, the performance of the asphalt pavement is influence by the mix design, quality of materials and construction.

Unlike Peninsular Malaysia, Sabah does not have ample resources of good quality materials such as granite for road construction, but predominantly sandstone from hill rock outcrop and gravel from the river. Sandstone (sometimes known as arenite) is a clastic sedimentary rock composed mainly of sand-sized minerals or rock grains. The suitability of sandstone aggregate for the construction materials depends on its strength, durability, and porosity. Several studies have stated that many type sandstones are not recommended for construction materials due to its high porosity and weak physical strength (Kumar *et.al*, 2016a; Kumar *et.al*, 2016b). In Sabah, sandstone aggregates are sourced from quarry through blasting and river sandstone. The river sandstone aggregates are characterized by rounded, smooth outlined and roughly uniform grain size. Transport of aggregate in a stream causes them to collide and rub against one another and the stream bed, and the resulting abrasion produces the familiar smooth and rounded shape of river rocks. They can be successfully used in concrete and other construction work as aggregates because they possess all the qualities of a good aggregate and can be exploited easily which lower the cost of transportation of materials, and also did not cause large effect towards the environment (Chandrashekar *et.al*, 2014; Sharma, 2014).

Due to raising environmental and economic concerns, the use of waste materials in asphalt pavement has become an urgent priority for both administrations and researchers to conserve limited resources, decrease construction costs and reduce environmental pollution. Utilizing recycled tire is an inexpensive sustainable technology which would transform unwanted trade waste into a new bituminous mixture with improved engineering properties. Used tires can be recycled into rubber granules that are less than or equal to six millimetres in size and named as crumb rubber. Warm mix asphalt can be incorporated into rubberised asphalt mixture in order to reduce the production and compaction temperatures. Hence, it helps reducing the odour and smoke coming from the asphalt mixture during production and laying of asphalt. It will also help to cut the cost of the burner fuel due to reduced usage of fuel and reduces the emissions, thus allowing more asphalt rubber to be produced without exceeding the maximum allowable emissions. Numerous laboratory and field studies have revealed that the performance of pavements produced with WMA shows better or equal performance to HMA (Ozturk *et al*., 2019). Tahami *et al.* (2019) stated that the use of crumb rubber powder (CRP) as a filler could reduce the resistance of asphalt mixes against moisture damage while conducting a curing process could enhance the moisture susceptibility.

Many researches indicated the positive outcomes of crumb rubber warm mix asphalt. However, there is not much study on the locally available materials such as sandstone river aggregate. Therefore, there is a need to study the WMA and crumb rubber with sandstone river aggregate for local road construction.

METHODOLOGY

Materials and Sample Preparation

The materials used in this study were sandstone river aggregate, asphalt binder, filler, WMA additive, crumb rubber (CR) and hydrated lime (HL). Aggregate was obtained from Kadamaian river through a local quarry and graded based on AC20 which commonly used for road construction in Sabah. Table 1 shows the aggregate properties of sandstone river aggregate. Asphalt binder with 60/70 penetration were obtained from local supplier. Quarry dust was the type of filler used in this study which following the local practice. The CR supplied by a tyre recycling factory located at Johor Bahru, Johor. For the inclusion of CR, it was added to replace 0.425 mm aggregate at 0, 10 and 20% by the weight of aggregate. A wax-based WMA additive called RH-WMA developed by China was used as an additive to be blended with asphalt binder according to the method by Gungat *et al*. (2016). The RH-WMA was added at 3% of the weight of the asphalt binder. Hydrated lime was used as stripping agent. Figure 1 shows the main materials used in asphalt modification in this study.

Table 1. Aggregate properties

Properties	Value	Requirement	Standard
Specific Gravity of Coarse Aggregate	2.82	-	BS 812-2
Water Absorption of Coarse Aggregate (%)	0.53	< 2	BS 812-2
Specific Gravity of Fine Aggregate	2.64	-	BS 812-2
Water Absorption of Fine Aggregate (%)	1.01	< 2	BS 812-2
Aggregate Crushing Value (%)	12.05	< 25	BS 812-110
Flakiness Index (%)	13.63	< 25	BS 812-105

a. Sandstone river aggregate b. Crumb rubber c. RH-WMA

Figure 1. Main materials studied for asphalt modification

The specimen preparation requires two processes which were mixing of crumb rubber with aggregates and asphalt binder with RH-WMA additive respectively. Upon completion of both processes, the WMA was added prior to the blending of crumb rubber and aggregate. The optimum binder content (OBC) was determined for various CR content in accordance with Marshall mix design by Jabatan Kerja Raya (JKR, 2008). All specimens were mixed and compacted at 145°C and 135°C, respectively.

Experimental Procedure

Experiments were conducted to evaluate the resilient modulus, resistance to permanent deformation and moisture susceptibility. Resilient modulus test was carried out using Universal Testing Machine (UTM) based on ASTM D4123 and performed at 25°C. Dynamic creep test was conducted to examine the resistance of pavement to permanent deformation due to traffic loading at high temperature. The Dynamic creep test was performed using UTM based on BS EN 12697-25. All specimens were condition for 2 hours at testing temperature prior testing to ensure equilibrium of temperature inside the chamber. For investigation of moisture susceptibility, Modified Lottman test was adopted. In Modified Lotman test, Resilient modulus test was used to replace the indirect tensile strength test. Test was performed on dry and wet specimens.

RESULTS AND DISCUSSION

Mix Design of Crumb Rubber Warm Mix Asphalt and River Sandstone Aggregate

Modification in asphalt mixture affect the optimum binder content in a mixture. In this study, the design mix was done in accordance to the Marshall Mix Design of JKR (2008).

Important parameters in Marshall mix design such as volumetric and strength properties were determined from test in order to calculate the OBC. The optimum binder content for mixture containing various crumb rubber content and RH-WMA additive is shown in Table 2. In general, the addition of RH-WMA reduces the OBC about 19%. This indicates that RH-WMA improves the coating of aggregate. When CR incorporated into the mixture, the OBC increase with CR content. According to the JKR standard, ideally the OBC for AC20 wearing should be in the range of 3.8% to 5.8%. The OBC for the 20% CR is slightly above the ideal range. For easier identification of mixture, designation of specimen is also shown in Table 2.

Table 2. Optimum binder content of mixture

Asphalt mixture	RH-WMA (%)	Optimum binder content (%)	Designation
0% CR (control)	0	5.8	CR0%-HMA
0%	3	4.7	CR0%+RH-WMA
10%	3	5.1	CR0%+RH-WMA
20%	3	5.9	CR0%+RH-WMA

Effects of Crumb Rubber Addition on Resilient Modulus

Specimens with various CR content were prepared at OBC from Table 2 content and tested for resilient modulus test which presented in Figure 2. Resilient modulus of a specimen is the ratio of applied stress to recoverable strain at a temperature for a given load The addition of RH-WMA shows the highest resilient modulus. On the other hand, CR causes reduction in resilient modulus. CR20%+RH-WMA shows the highest reduction. According to Hamad *et al.* (2014), this could be due to the loss of structural capacity of the rubberize mixture which cause low cohesion of mixture and lead to poor interaction between crumb rubber and binder. The reduction of resilient modulus also occurs due to increasing of the rebound of the mixture due to addition of crumb rubber. Therefore, more deformation can take place due to the compression of rubber particles (Kim, 2001).

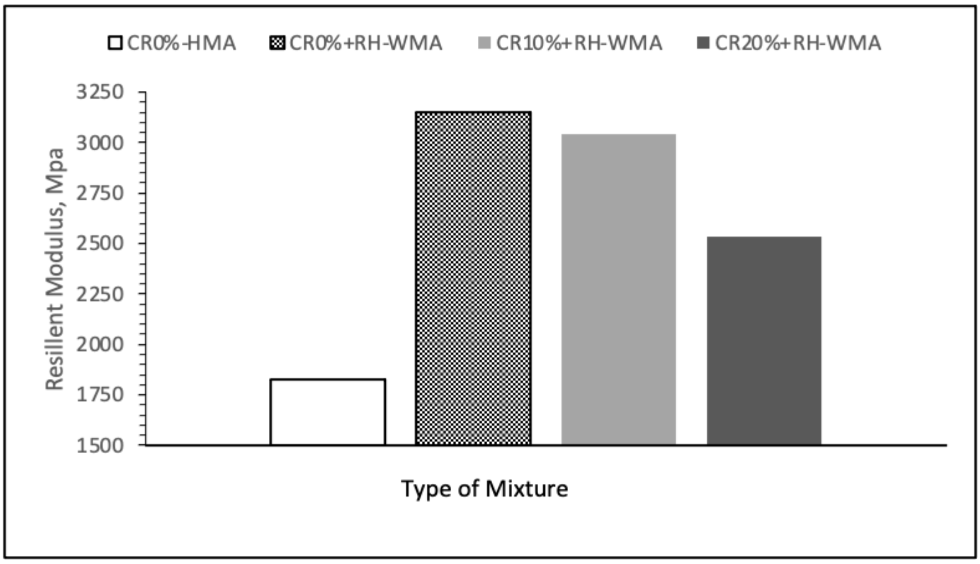

Figure 2. Resilient modulus of CR mixtures

Effects of crumb rubber addition on rutting resistance

Figure 3 exhibits the dynamic creep test result for 3600 cycle at test temperature of 50°C. The cumulative permanent strain indicates the permanent deformation of the specimen.

Permanent deformation occurred due to repetitive traffic loading. Increasing number of cycle count had increase the permanent strain of each mixture, due to the repetition of loading that causing the sample to deform. The highest permanent strain is recorded at 20%CR+RH-WMA, while CR0%+RH- WMA shows the lower permanent strain. Lower permanent strain indicates lowest deformation of asphalt specimen and hence has better resistance on permanent deformation or rutting. Rutting is a type of road deterioration which commonly occurred due to repetition traffic loading. Katman *et al*. (2015) explained that the addition of crumb rubber into asphalt mixture shows a lower cumulative permanent strain compared to control specimen. This situation could be due to the crumb rubber that partially blended with the asphalt and absorbs the binder oil into the rubber's polymer chains and then forms gel-like material that results in higher viscosity and elasticity of the asphalt. Such interactions improve the binder networking and allow greater film thickness surrounding the aggregate in the mixture. This will reinforce the aggregate bonding of the mixtures thus resulting in higher strength. Furthermore, the crumb rubber which is not fully blended in the asphalt will maintain their agglomeration, interweave together, and form a three-directional network when mixing. This spatial reinforcing network could reinforce the mixtures and resist damage propagation.

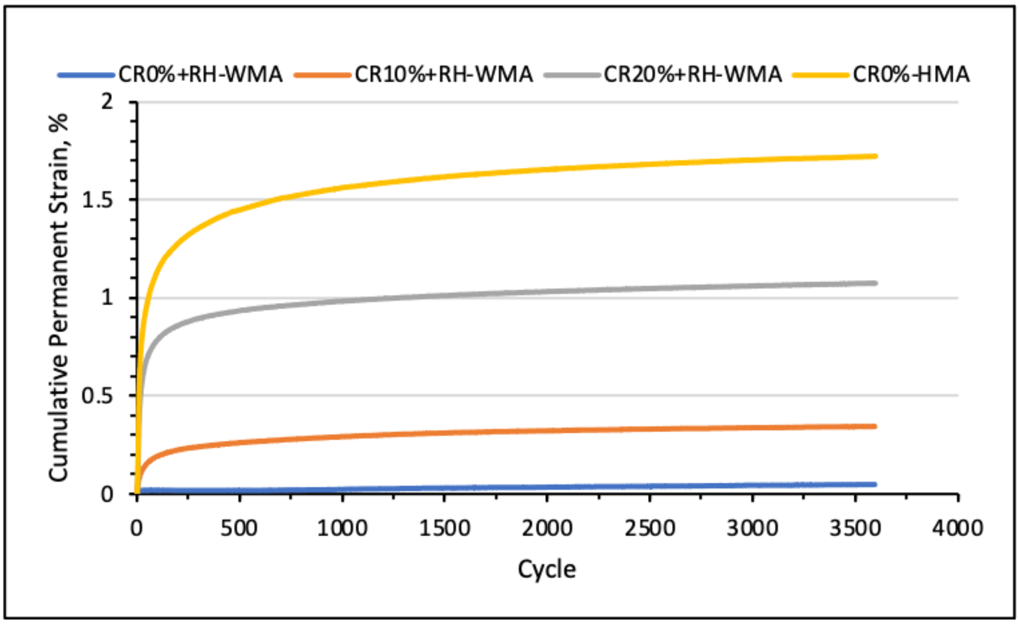

Figure 3. Effects of CR addition on cumulative permanent strain

Effects of Crumb Rubber Addition on Moisture Susceptibility

Moisture susceptibility is crucial in Malaysia due to the high annual rainfall intensity. The presence of water causes the bitumen to loss the adhesive bond with the aggregate and detached from the surface of aggregate that led to decrease in resilient modulus (Khani Sanij *et al*., 2019). Hence, the effects of mixture modification were investigated by performing modified Lottman indirect tension on mixture with crumb rubber only since CR addition shows positive improvement for resilient modulus and resistance of permanent deformation. Figure 4 presents the effects of CR addition on moisture susceptibility. In general, all types of mixtures have passed the minimum resilient modulus ratio of 80% except the CR0%+RH-WMA and CR20%+RH-WMA. The addition of 10% CR with hydrated lime shows the highest ratio with 87.8%. According to Nazirizad *et al*. (2015), hydrated lime as antistripping agent improves the moisture resistance. The hydrated lime reduces the number of pores in the asphalt mixture and thus increases the surface are for better coating and bonding between particles. The improvement in moisture resistance is crucial in road construction due to high annual rainfall in Malaysia particularly in Sabah.

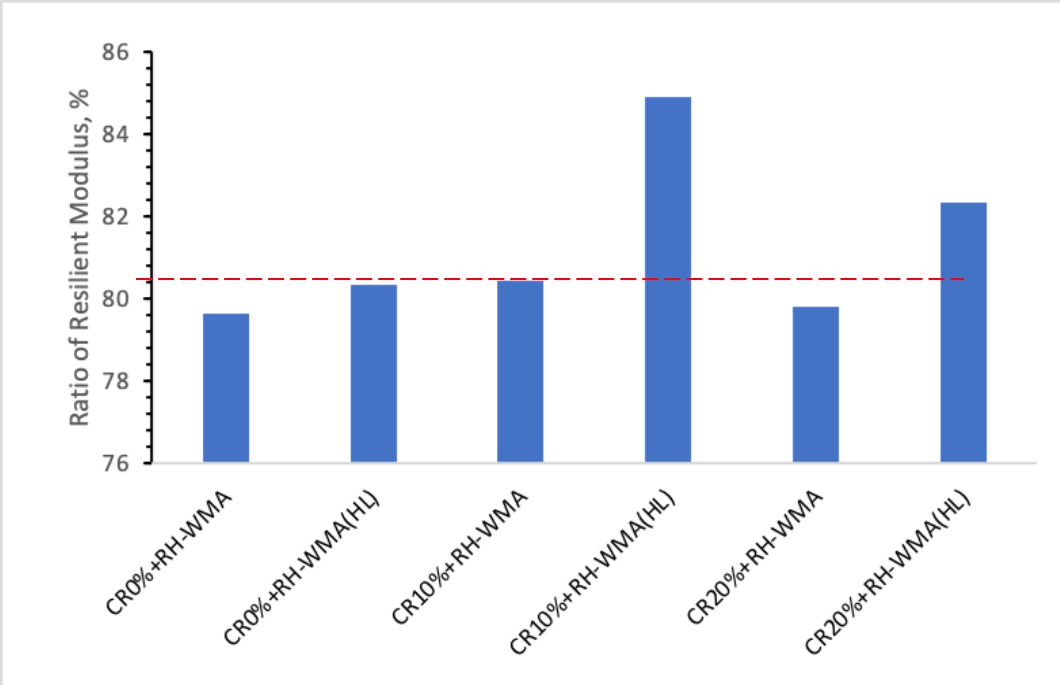

Figure 4. Effects of CR addition on moisture susceptibility

CONCLUSION

Based on this study, locally available sandstone river aggregates are suitable to use in road construction. Mix design indicated that addition of CR increased the OBC, however the OBC of mixture containing 10%CR was within the acceptable range. Modification of the mixture by addition of WMA additive RH-WMA and replacement of 10% and 20% CR show improvement in resilient modulus and resistance on permanent deformation when compared with control. In terms of moisture susceptibility, 10% CR with hydrated lime is the best mixture. Based on the results from the resilient modulus, dynamic creep and moisture susceptibility, 10CR% is the most suitable replacement for mixture using sandstone river aggregate. Hence, by considering the engineering properties of mixture, 10% CR content is the most suitable to be used in road construction using sandstone river aggregate.

ACKNOWLEDGEMENTS

The authors would like to thank and acknowledge the financial support from Universiti Malaysia Sabah (SBK 0327-2017 and SDK0064-2018). We wholeheartedly thank the anonymous reviewers for their helpful comments.

REFERENCES

[1] Chandrashekar, A. & Maneeth, P. D. 2014. Performance Appraisal of River Stone as a Coarse Aggregate in Concrete. *Int. Journal of Engineering Research and Applications*, 4(1), 93 - 102.

[2] Department Statistic Malaysia, Sabah. 2015. *Buku Tahunan Perangkaan Sabah 2014*.

[3] Gungat L, Yusoff N.I.M & Hamzah, M.O. 2016. Effects of RH-WMA Additive On Rheological Properties Of High Amount Reclaimed Asphalt Binders. *Construction and Building Materials*, 114, 665–672.

[4] Hamad, G. S., Jaya, R. P., Hassan, N. A., Aziz, M. M. A. & Yusak, M. I. M. 2014. Influences of Crumb Rubber Sizes on Hot Mix Asphalt Mixture. *Jurnal Teknologi*, 71(3), 63-68.

[5] JKR. 2008. *Standard Specification for Road Works (Section 4: Flexible Pavement)*. Cawangan Jalan, Jabatan Kerja Raya Malaysia, Kuala Lumpur, Malaysia.

[6] Katman, H. Y., Ibrahim, M. R., Karim, M. R., Salim Mashaan, N. & Koting, S. 2015. Evaluation of Permanent Deformation of Unmodified and Rubber-Reinforced SMA Asphalt Mixtures Using Dynamic Creep Test. *Advances in Materials Science and Engineering*, 2015(1), 1-11.

[7] Khani Sanij, H., Afkhamy Meybodi, P., Amiri Hormozaky, M., Hosseini, S. H. & Olazar, M. 2019. Evaluation of Performance and Moisture Sensitivity of Glass-Containing Warm Mix Asphalt Modified with Zycothermtm as An Anti-Stripping Additive. *Construction and Building Materials*, 197, 185–194.

[8] Kim, B.J.R. 2001. Characteristics of Crumb Rubber Modified (CRM) Asphalt Concrete. *KSCE Journal of Civil Engineering*, 5(2), 157-164.

[9] Kumar, S., Gupta, R. C. & Shrivastava, S. 2016a. Strength, Abrasion and Permeability Studies on Cement Concrete Containing Quartz Sandstone Coarse Aggregates. *Construction and Building Materials*, 125, 884-891.

[10] Kumar, S., Gupta, R. C., Shrivastava, S., Csetenyi, L. & Thomas, B. S. 2016b. Preliminary Study On The Use Of Quartz Sandstone As A Partial Replacement Of Coarse Aggregate In Concrete Based On Clay Content, Morphology And Compressive Strength Of Combined Gradation. *Construction and Building Materials*, 107, 103–108.

[11] Nazirizad, M., Kavussi, A. & Abdi, A. 2015. Evaluation Of The Effects Of Anti-Stripping Agents on The Performance of Asphalt Mixtures. *Construction and Building Materials*, 84, 348–353.

[12] Ozturk, H. I. & Kamran, F. 2019. Laboratory Evaluation Of Dry Process Crumb Rubber Modified Mixtures Containing Warm Mix Asphalt Additives. *Construction and Building Materials*, 229, 1-10.

[13] Sharma, N. 2014. A Comparative Study of River Borne Coarse Aggregates Of The Rivers - Pagladiya, Kopili And Kulsi (Assam) In Their Natural Form Form For Their Utility As a Road Construction Material. *Journal of Civil Engineering and Environmental Technology*, 1(4), 49–52.

[14] Tahami, S. A., Mirhosseini, A. F., Dessouky, S., Mork, H. & Kavussi, A. 2019. The use of high content of fine crumb rubber in asphalt mixes using dry process. *Construction and Building Materials*, 222, 643–653.