Utilization of Waste Plastic and Recycle Concrete Aggregate in Production of Hot Mix Asphalt

Basim H. Al-Humeidawi
University Lecturer, Civil Engineering Department, College of Engineering
University of Al-Qadissiyah
Basim.alhumeidawi@yahoo.com
Received 1 September 2014 Accepted 14 October 2014

ABSTRACT

Recycling of waste material is a recent technique aims to change the waste material into new products to reduce the pollution and detrimental effect on the environment and reduce the demand of new fresh natural sources. Plastic bags and Recycled Concrete Aggregate (RCA) are samples of these waste materials can be re-used in road construction. Over one million bags are used every minute worldwide, whereas, aggregate is consist of about 95% of asphalt mixture and can be obtained as RCA from demolished infrastructure. This paper presents laboratory tests results of using waste plastic and RCA in production of asphalt mixture. Since the cement past attached to RCA particles contribute to lower their density and increase the porosity, the waste plastic are used to enhance the engineering properties of asphalt mixture and consume these large amount of waste material. The results showed that Waste Plastic Modified Bitumen (WPMB) mix containing 100% RCA produces higher Marshall Stability, higher retained stability and higher indirect tensile strength compared with conventional mix. The percents of the increase were 10% for Marshall Stability, 7% for Marshall retained stability and 9% for higher indirect tensile

KEY WORDS: Asphalt mix, Road construction, Marshall Stability; Waste plastic; Recycled concrete aggregates; environment; Waste management

استخدام المخلفات البلاستيكيه والركام المدور في انتاج الخلطات الاسفلتيه

باسم حسن شناوة / دكتوراه هندسة مدنية - هندسة طرق ومطارات

الخلاصة :

اعادة استخدام المخلفات الصناعيه والانشائيه تقنيه حديثه تهدف الى اعاده تدوير المخلفات الى منتجات جديده لتقليل التلوث والاثار السلبيه على البيئه وتقليل الطلب على المصادر الطبيعيه للمواد الانشائيه. ان الاكياس البلاستيكيه والركام المدور (المعاد استخدامه) نماذج للمخلفات الصناعيه والانشائيه التي يمكن اعادة استخدامها في انشاء الطرق. اظهرت الدراسات السابقه ان اكثر من مليون كيس بلاستيكي تستخدم كل دقيقه حول العالم بينما يشكل الركام اكثر من 95% من مكونات الخلطة الاسفلتيه. يمكن الحصول على

الركام المدور من مخلفات الابنيه والمنشاءات الكونكريتيه القديمه المهدمه. هذا البحث يعرض نتائج دراسه مختبريه لاعادة استخدام مخلفات الاكياس البلاستيكيه والركام المدور في انتاج الخلطات الاسفلتيه. بما ان الاسمنت الملتصق بالركام المدور يساهم في تقليل الكثافة وزيادة المساميه للركام المدور , تم استخدام المخلفات البلاستيكيه لتحسين خصائص الخلطة الاسفلتيه الحاويه على هذا النوع من الركام ولاستهلاك الكميه الكبيره من هذه الاكياس والمتوفره على شكل مخلفات. نتائج البحث الحالي اظهرت ان قوة ثبات مارشال والثبات المتبقي بعد الغمر وفحص الشد غير المباشر للخلطه الاسفلتيه التي تحتوي المخلفات البلاستيكيه والركام المدور اعلى بمعدل يتروح من 7-10% مقارنة مع قيمها للخلطة القياسية ممايوفر تحسن في نوعيه الخلطه الاسفلتيه اضافة الى اعادة تدوير كميه كبيره من المخلفات المذكوره.

1. INTRODUCTION AND BACKGROUND

The availability of different waste materials is increasing day by day and the disposal of these materials is a big problem. These wastes are increasing the concern of environmental pollution since many of these materials are non-biodegradable. Plastic one of these materials, which is a very versatile material widely used in packaging of many outputs of industry. A survey has shown that 500 billion plastic bags are used worldwide every year (Plastic bag pollution 2005). Without thinking in a suitable way to utilized these materials in recycling industries, these wastes have occupied landfill areas and become source of pollution. Several studies have been conducted to investigate the use of plastic waste in bitumen mixture of the flexible pavement (Chavan 2013; Gawande *et al.* 2012; Sangita and Verinder 2011; Swami and Jirge 2012). In addition to re-use of waste plastic can significantly reduce the disposal problem of these waste and minimize the concern of pollution, they can enhance pavement performance and reduce the cost of construction of roads.

The results of previous studies showed that the using of waste plastic in asphalt mixture improve the engineering properties such as Marshall Stability, resistant to water (measure by retained stability) and resistant to crack propagation (indicated by indirect tensile strength of modified asphalt mixes). This approach of modification also produces better binding property for the bitumen mix and increase the road life (Chavan 2013; Gawande *et al.* 2012; Sangita and Verinder 2011; Swami and Jirge 2012).

The other waste material which can be recycled to be used in road construction is the Recycled Concrete Aggregate (RCA). RCA can be obtained from construction debris, where demolished concrete structures are crushed to smaller units for diverse uses. Aggregate is main component of asphalts mixture, it composes about 95% of asphalt mix. The continuous use of this material is threatening the natural resources of it; especially, it is known that the flexible pavement is one of most worldwide pavement type. Therefore, the recycled of this material can protect the environment, provide sustainable construction and reduce the demand on natural resources, moreover, reduce the construction cost of the road (Huang *et al.* 2007).

However, the engineering properties of RCA differ from natural aggregates due to remaining cement paste on their surfaces after the recycling process. The attached cement paste contributes to lower density, increase porosity and water absorption of RCA (Mills-Beale and You 2010; Paranavithana and Mohajerani 2006). Other investigations showed that RCA can be a good and economical alternative to fresh aggregate and can produce asphalt mixtures withstand traffic load especially in light and medium traffic (Akbulut and Gurer 2007; Moghadas Nejad *et al.* 2013).

The current article focuses on using both the waste plastic and RCA in asphalt mixture to produce asphalt mixture with higher engineering properties compare to conventional mix and consume the waste materials. This approach also reduces the construction cost of the road and minimising the consumption of natural resources.

2. METHODOLOGY

The laboratory tests in this research consist of four aspects. These aspects involved production of four different asphalt mixes:

1- Standard asphalt mix with optimum bitumen content.
2- Waste Plastic Modified Bitumen Mix (WPMB-Mix).
3- Asphalt mix contains 100 % Recycled Concrete Aggregate (RCA-Mix).
4- Waste Plastic Modified Bitumen Mix contains 100 % Recycled Concrete Aggregate (WPMB + RCA).

In order to obtain and evaluate these mixes the test methodology involved four steps:

1- Preliminary test for the component of asphalt mix and obtaining optimum bitumen content for asphalt mix. This phase involved several standard tests such as Penetration Test, Flash Point Test, Softening Point Test and the Ductility Test. Then, six mixes with different bitumen content (4.0 %, 4.5 %, 5.0 %, 5.5 %, 6.0 % and 6.5%) were produced to select optimum bitumen content using Marshall Method. The optimum bitumen content was 4.85%.
2- Mixing of waste plastic with bitumen: generally, there are three different methods to mix the plastic with bitumen as shown below.

- Dry Process: In this method, the waste plastic is added to hot aggregate particles to produce a plastic coated aggregate. The plastic coated aggregate is then mixed with optimum quantity of bitumen to get a WPMB Mix.
- Wet process: This process involves melting and mixing the waste plastic with hot bitumen a round 150 ^{0}C using a bitumen mixer to get WPMB. The modified bitumen (WPMB) is added to heated aggregate to get a WPMB Mix. This process was adopted in the current research, where waste plastic bags were melted and stirred in bitumen according to above mentioned procedure. The percent of waste plastic was 8 % of the weight of the bitumen, adopted according to previous studies in literature (Gawande *et al.* 2012; Sangita and Verinder 2011; Swami and Jirge 2012)
- Semi wet process: This method refers to non-completely melting of waste plastic in hot bitumen where small plastic particles are still insoluble during cooling of WPMB to ambient temperature. In this process, the waste plastic acts as modifier for the bitumen and as a coating for aggregate when it is added to aggregate to get a WPMB Mix.

3- Obtaining of recycled concrete aggregate (RCA): In this work, the RCA was obtained from waste concrete testing cubes. Cubes were crushed and abraded using Los Angles abrasion machine for 20-30 minutes to get different sizes of aggregate particles. These particles were washed and dried using electric oven for 24 hours. The resulting particles where classified according to mid-range of specification of aggregate gradation using sieve analysis for these particles.
4- Evaluating the four mentioned mixes using the following tests:

The evaluation process for the four mixes included in this study involved conducting three tests. These tests are:

- Marshall Stability Test: The standard Marshall test for mix design was carried out on the standard asphalt mix, WPMB-mix, asphalt mix contains 100 % RCA and WPMB-Mix contains 100 % RCA. The Marshall Stability, Flow and density were evaluated for three samples of each mix.
- Marshall Retained Stability Test: This test was conducted to evaluate the pavement performance under severe conditions such as soaking of the pavement in water for long time. Marshall Stability tests were carried out after immersion the specimen in water at 60 ^{0}C for 24 hours.

- Indirect Tensile Strength Test: This test comprises of applying compressive loading along the vertical diameter of a cylindrical specimen to produce tensile stresses cracks perpendicular to loading axis. The specimen was prepared and tested according to AASHTO T 283 specification. The indirect tensile strength (ITS) is calculated as shown in Equation (1) below.

$$ITS = \frac{2 \times P}{\pi \times h \times d} \quad (1)$$

Where:
ITS = indirect tensile strength (MPa)
P = applied load (N)
h = average height of specimens (mm)
d = average diameter of specimens (mm)

Fig.1 presents the whole picture of the research frame work.

3. RESULTS AND DISCUSSION

Standard Marshall Test: After adopting the optimum content of bitumen, the standard Marshall test was carried out on the four mixes. The Marshall Stability and Flow were record for each type of mix as shown in **Fig.2** and **Fig.3**. Marshall Stability refers to maximum load sustain by asphalt mix, this can be an indication for pavement distortion, rutting and shear stress.

Fig.2 shows the Marshall stability for the four mixes. It can be observed that the Marshall Stability increases by about 30% and 15% for the WPMB mix and WPMB mix containing RCA respectively compared with standard mix. While it decreases by about 10% for the RCA mix compared with standard mix. This can be attributed to that, the using of waste plastic in asphalt mixes may lead to better blending and binding of asphalt mix also decreasing of the air voids which consequently lead to higher stability for mixes. For the RCA mix, the cementation material attached with aggregate particles leads to increase the porosity, water absorption and decrease density (Paranavithana and Mohajerani 2006); which, consequently decreases Marshall stability and increases Marshall flow (See **Fig.4**). **Fig.3** shows the comparison of displacement or flow of the mixes during the Marshall test. The addition of waste plastic to asphalt mixture produces less flow due to better binding of mix components. **Fig.4** presents the densities for the four mixes, the WPMB mix shows less density compared with conventional mix due to less density of waste plastic. The reduction in density is increasing by adding the RCA due to higher porosity and water absorption for RCA.

Marshall Retained Stability Test: This test can assesses pavement condition when it subjected to severe conditions such as soaking in water for long time. **Fig.5** presents the Marshall Retained Stability results after socking in water for 24 hours at 60 ^{0}C. **Fig.5** reveals generally that the Marshall Stability decrease for all mixes, but all values are more than 70% of Marshall Stability values as shown in **Fig.6**. The Marshall Retained Stability is higher by about 10% and 7% for the WPMB mix and WPMB containing RCA mix respectively compared with Marshall Retained Stability for the standard mix. While it is less by about 15% for the RCA mix compared with standard mix.

Indirect Tensile Strength: This test is conducted to assess the tensile properties of asphalt mix which can be further linked to the cracking properties of the flexible pavement. Several distresses of pavement such as low temperature cracking, fatigue and rutting are related to tensile properties of asphalt mix. A higher tensile strength leads to higher cracking resistance and higher strain prior

to failure of the pavement(Tayfur *et al*. 2007). **Fig.7** presents the comparison of tensile strength for the mixes under consideration. It can be clearly seen that waste plastic improved the tensile properties of the asphalt mix; however, this improvement are slightly decrease with using of RCA in bitumen mixes. The indirect tensile strength increases by 30 % and 10 % respectively for the WPMB mix and WPMB mix containing RCA respectively compared with that of the standard mix. While it decreases by about 20% for the RCA mix compared with standard mix.

4. SUMMARY AND CONCLUSIONS

This paper has presented an experimental investigation for using waste plastic and RCA in hot mix asphalt (HMA) for road pavement. The results showed that the using of RCA alone (without of waste plastic as modified) causes reduction in Marshall Stability and indirect tensile strength of the asphalt mix; which, consequently produces reduction in the resistance of pavement to deterioration and cracks formulation. On the other hand, the using of waste plastic in asphalt mix which has 100% RCA can produce better asphalt mixture compared with conventional mix.

The use of recycled material (RCA and waste plastics) in the pavement of the road has helped to solve the problem of disposal of waste plastic and demolished concrete structural elements by providing better place for burying them. At the same time, a better pavement can be achieved by improving the Marshall Stability, strength, fatigue life and other desirable properties of asphalt mix, consequently improves the longevity and pavement performance. Finally, the using of these waste materials can significantly reduces the construction cost of the roads.

REFERENCES

[1] Akbulut, H., and Gurer, C., 2007. "Use of aggregates produced from marble quarry waste in asphalt pavements." *Building and environment*, 42(5), 1921-1930.

[2] Chavan, M. A. J., 2013. "Use of plastic waste in flexible pavements." *International Journal of Application or Innovation in Engineering and Management*, 2(4), 540-552.

[3] Gawande, A., Zamare, G., Renge, V. C., Tayde, S., and Bharsakale, G., 2012. "An overview on waste plastic utilization in asphalting of roads." *Journal of Engineering Research and Studies*, 3(2), 01-05.

[4] Huang, Y., Bird, R. N., and Heidrich, O., 2007. "A review of the use of recycled solid waste materials in asphalt pavements." *Resources, Conservation and Recycling*, 52(1), 58-73.

[5] Mills-Beale, J., and You, Z., 2010. "The mechanical properties of asphalt mixtures with recycled concrete aggregates." *Construction and Building Materials*, 24(3), 230-235.

[6] Moghadas Nejad, F., Azarhoosh, A. R., and Hamedi, G. H., 2013. "The effects of using recycled concrete on fatigue behavior of hot mix asphalt." *Journal of Civil Engineering and Management*, 19(sup1), S61-S68.

[7] Paranavithana, S., and Mohajerani, A., 2006. "Effects of recycled concrete aggregates on properties of asphalt concrete." *Resources, Conservation and Recycling*, 48(1), 1-12.

[8]Plastic bag pollution, 2005. "Retrieved from http://www.googobits.com/articles/1604-plastic-bag-pollution.html."

[9] Sangita, G. R., and Verinder, K., 2011. "A novel approach to improve road quality by utilizing plastic waste in road construction." *Journal of Environmental Research And Development Vol*, 5(4), 1036-1042.

[10] Swami, V., and Jirge, A., 2012. "Use of waste plastic in construction of bituminous road." *International Journal of Engineering Science & Technology*, 4(5), 2351-2355.

[11] Tayfur, S., Ozen, H., and Aksoy, A., 2007. "Investigation of rutting performance of asphalt mixtures containing polymer modifiers." *Construction and Building Materials*, 21(2), 328-337.

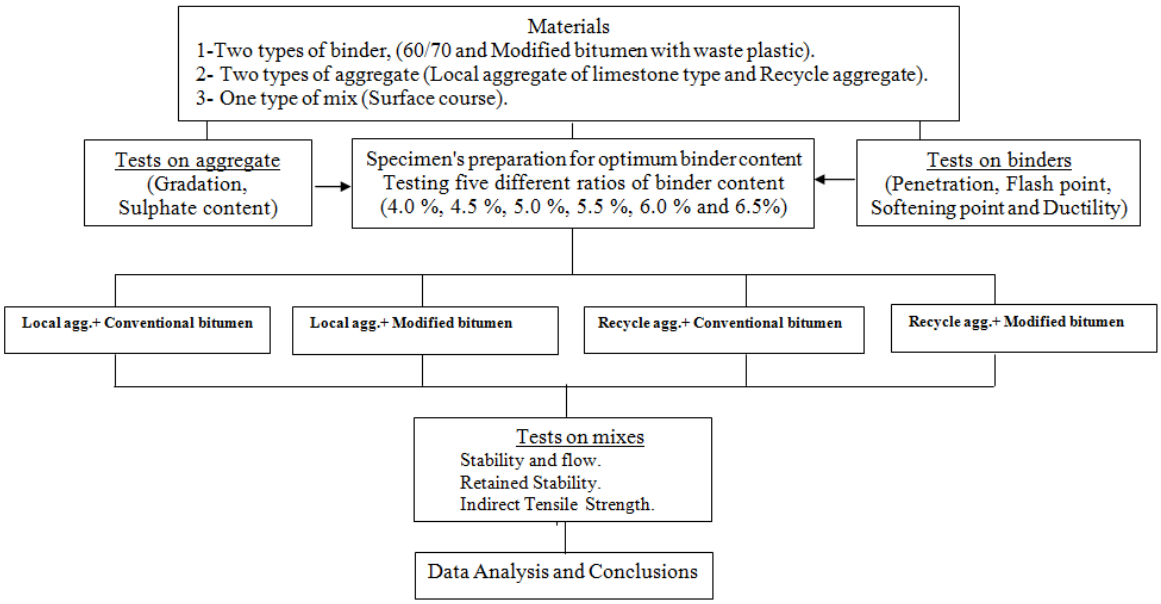

Figure1: Research frame work

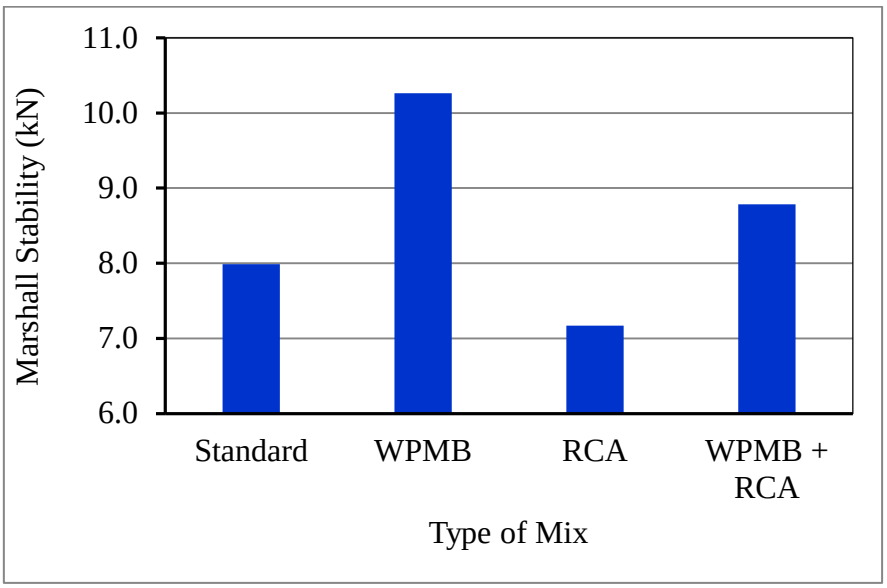

Figure 2: Marshall Stability

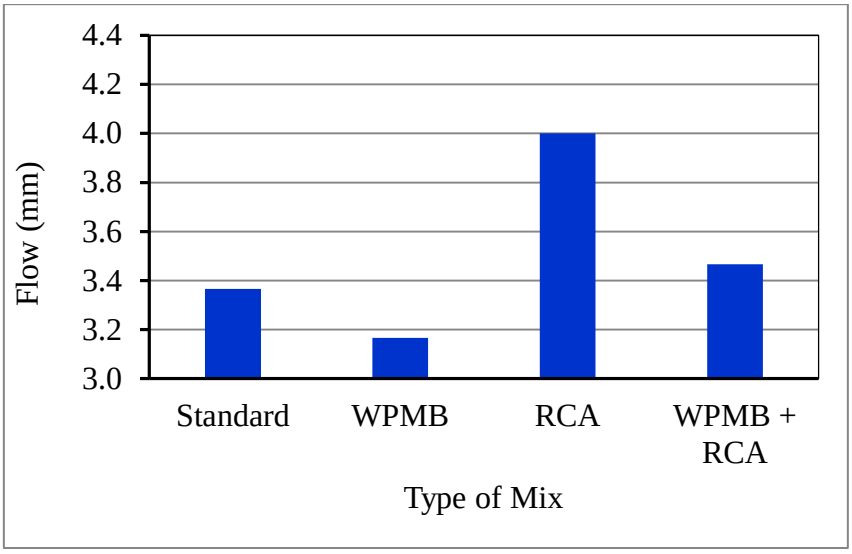

Figure 3: Marshall Flow

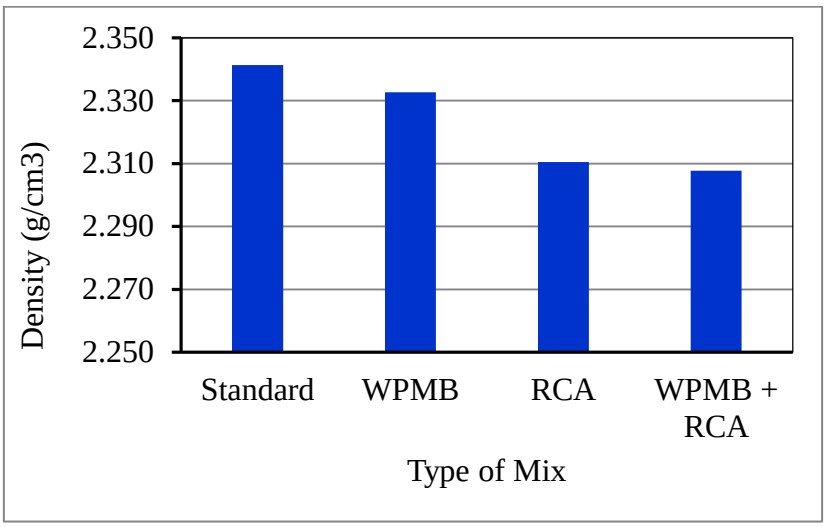

Figure 4: Density of Asphalt mixes

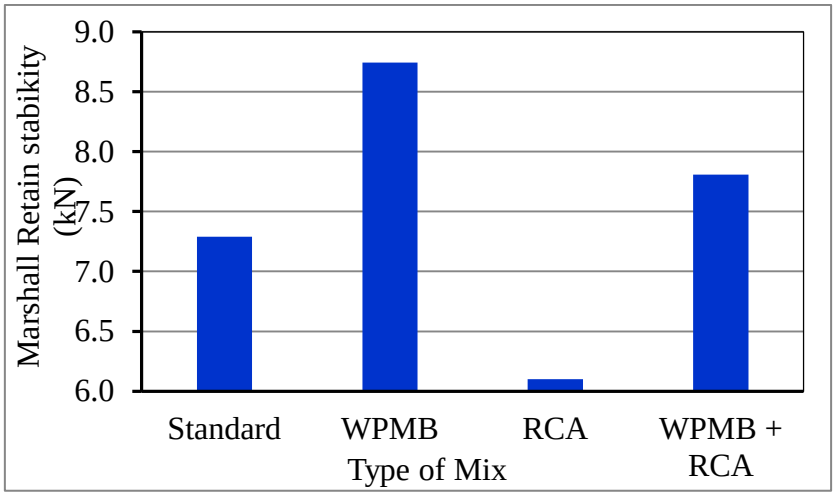

Figure 5: Marshall Retained Stability

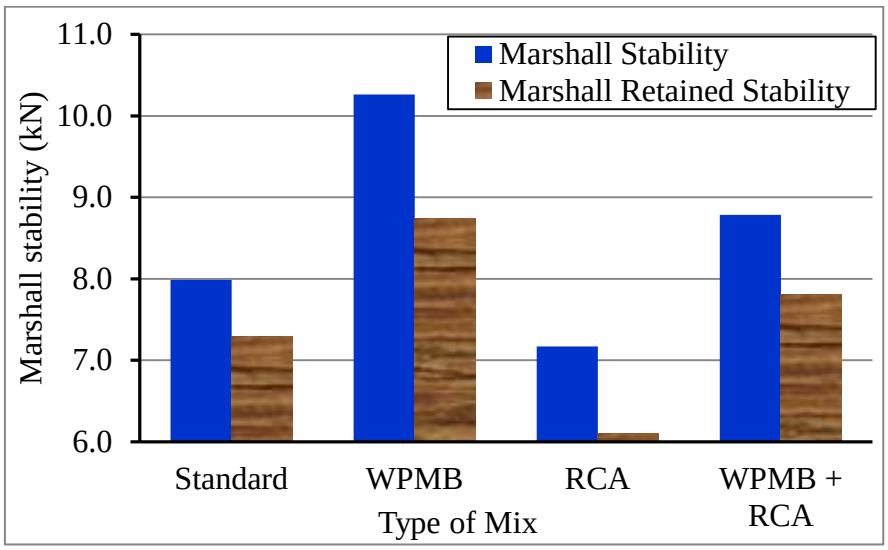

Figure 6: Comparison of Marshall Retained Stability values with Marshall Stability values

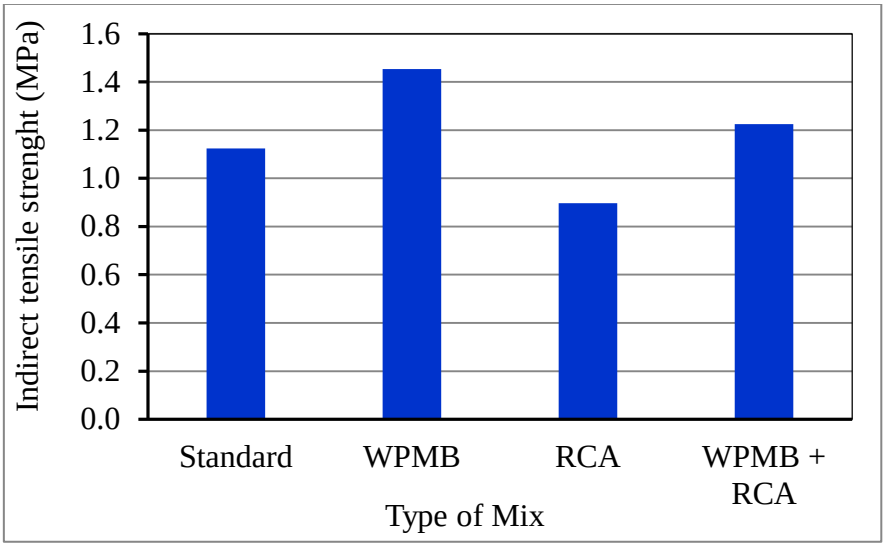

Figure 7: Results of indirect tensile strength (ITS)