Journal of Engineering and Applied Sciences 14 (8): 2701-2706, 2019
ISSN: 1816-949X

Investigating the Effect of using Wasted Aluminum Strip on the HMA Characteristics

Hamid Athab Eedan Al-Jameel and Basim Jawad Kathim Al-Saeedi
Department of Civil Engineering, University of Kufa, Najaf, Iraq

Abstract: Million tons of wasted Coco-Cola tins are produced annually in the world, huge amount is produced, especially in Iraq. Therefore, using such wasted material has a sustainable importance for environmental. This study has focused on using strips of waste aluminum. The wasted material has been obtained from Coco-Cola tins. The wasted tins were shredded into strips. These strips have average dimensions of 5 mm width and 10 mm length. Then these strips have been added (from 0, 0.5, 1.0, 1.5, 2.0 and 2.5%) from the total weight of aggregate. The Marshall characteristics have been tested for reference sample (0%) of wasted aluminum strips and other different percentages. The results indicated that using 1% of these strips give acceptable values for stability, flow and density.

Key words: HMA, waste aluminum strips, surface layer, stability, Coco-Cola tins, aggregate

INTRODUCTION

In recent years there has been an increasing interest in using different admixture to construct more durable pavement for different pavement layers (i.e., subbase, base, binder and surface). A significant amount of literature has indicated the use of solid waste materials in Hot Mix Asphalt (HMA). These waste materials have been used in three folds. Firstly, they are used as modifiers to the asphalt binder (Dong and Tan, 2011; Colbert and You, 2012). Secondly, they are utilized as replacement of traditional aggregate and filler (Anderson *et al*., 1983; Zulkati *et al*., 2011; Al-Saeedi and Al-Jameel (2018). Thirdly, the waste materials have been used as additives such as polymers and fibers (Ahmadinia *et al*., 2012; Moghaddam *et al*., 2014). However, previous studies of using different admixtures for HMA have not deal with using waste aluminum strips. According to the available literature, the first attempt of using such material was implemented by Muwashee *et al*. (2018) but in mortar and concrete mixes not with HMA. The results indicated improving the performance for mechanical properties (compressive, tensile and flexural strengths) for both reinforced mortar and concrete mixes with waste aluminum strips up to 200% for some properties.

Ajam (2013) used a material in HMA which may be close to aluminum strips behavior in HMA. The researcher used shredded Tetra-Pak in HMA. The results showed just slightly increase in the stability of binder layer and the value of flow is out of specifications (more than 4 mm) with percent of Ttra-Pak is higher than 0.5% while the percentages of Tetra-Pak ranges from 0-2%. In addition, air voids and flow increase while voids filled with asphalt, stability and density decrease with increasing the percent of Tetra-Pak beyond 0.5% as indicated in Table 1.

Table 1: Marshall tests (Ajam, 2013)

TPA (%)	Flow (mm)	Density (/cm^3)	Stability (kN)	Air voids (%)	Voids filled with asphalt (%)
Specifications	2-4	-	7.00	3-5	70-85
0	2.53	2.522	7.25	3.14	82.30
0.5	4.65	2.484	7.32	4.16	80.20
1.0	6.67	2.460	7.47	5.64	78.10
1.5	12.58	2.270	7.70	13.25	72.60
2.0	18.96	2.351	6.39	12.02	67.50

Perhaps the most serious advantage of using waste aluminum strips resulting from Coco-Cola tins with HMA is to help protecting the green environment even if there is no significant improvement in other characteristics such as stability and flow. Then, this study aims to investigate the effect of using waste aluminum strips with HMA.

MATERIALS AND METHODS

The main step of this research is to focus on conducting Marshall tests on both control mix and mixes which have different ratios of waste aluminum strips. These percentages of waste aluminum strips are 0, 1.0, 1.5, 2.0 and 2.5%. These percentages from the total weight of aggregates. In addition according to several attempts using different percentages of waste strips it was found that 3% or more resulted in high value of flow which was more than acceptable limits (>4 mm) according to SCRB/R9, therefore, the above percentages have adopted in this study.

Corresponding Author: Basim Jawad Kathim Al-Saeedi, Department of Civil Engineering, University of Kufa, Najaf, Iraq

Table 2: Properties and specification of coarse aggregate

		Results			
Test description	Test method	12.5-19 (mm)	9.5-12.5 (mm)	4.75-9.5 (mm)	Specification requirements
Los angeles abrasion (%)	AASHTO (T96)	18	18	25	<30
Soundness (%)	AASHTO (T104)	2.116	2.119	2.837	<12
Specific dravity (Bulk)	AASHTO (T85)	2.618	2.615	2.610	-
Flat and elongated particles (%)	AASHTO (M323), ASTM(D4791)	3.1	2.2	2.6	<10
Clay lumps and friable particles (%)	AASHTO (T112)	0.72	1.04	1.67	<3
Coating and stripping (%)	AASHTO (T182)	>95	>95	>95	>95
Percentage of fractured particles (%)	ASTM (D5821)	90	90	92	>90

Table 3: Fine aggregate-physical properties and specifications

The test	The specification of test	Results	Specification requirements
Liquid limit plasticity index	AASHTO (T89) AASHTO (T90)	NonNon	-<4
Specific gravity (Bulk)	AASHTO (T84)	2.646	-
Water absorption (%)	ASTM (C-127)	1.53	<2
Clay lumps and friable particles (%)	AASHTO(T112)	1.83	<3
Sand equivalent (%)	AASHTO (T176)	47	≻45

Table 4: Used asphalt physical properties

Type of test	Specification	Result	Specification limits
Penetration at 25(1/10 mm)	ASTM (D5)	40	40-50
Ductility at 25 (cm)	ASTM (D113)	140	Min. 100
Softening point (°C)	ASTM (D36)	55	-
Flash point (°C)	ASTM (D92)	+232.0	Min. 232
Solubility (%)	ASTM (D2042)	99.5	Min. 99.0
Specific gravity at 25 (g/cm^3)	ASTM (D70)	1.03	-
Kinematic viscosity at 135°C (Centistokes)	ASTM (D2170) and SCRB (R9)	710	≻ 400
Retained of original			
Penetration (%)	ASTM (D5)	75	≻ 55
Ductility (cm)	ASTM (D113)	35	≻ 25

The raw materials: The raw materials used in this study have been brought from Al-Diwaniyah Lab., in Al-Diwaniyah city which is located about 200 km south of Baghdad. These materials are the aggregate, filler and bitumen. Table 2 and 3 demonstrate the characteristics of both coarse and fine aggregates. These materials satisfy with the (SCRB/R9) for dense graded paving mixtures of surface coarse. The physical characteristics of asphalt are indicated in Table 4. Whereas the used mineral filler characteristics have been presented in Table 5. Accordingly, the characteristics of all used materials are within the limits of specification as indicated in Table 2-5.

The used waste aluminum strips: The waste aluminum strip was used as additives to the HMA mix. These strips were prepared from Coco-Cola tins after cutting these tins into strips with average 5 mm width and average 10 mm length as indicated in Fig. 1. Furthermore, the mechanical properties of aluminum are as indicated in Table 6.

Method of mix design: Marshall design method has been adopted in this study. This method of design is utilized to find out the Optimum Asphalt Content (OAC) and evaluate other asphalt mixture characteristics such as stability and flow. The weight of aggregate is about 1.2 kg and the grade of asphalt is 40/50. Then these specimens have been increased to temperatures of 130.0°C and 180.0°C by heating them. In addition, aluminum strips with various percentages of replacement from 0.0-2.5% of total weight has used. The asphalt content for all prepared mixes has been considered as a percent of weight from the total weight of the mixture. A preheated model and 75 blows on top and bottom faces of the specimen have been conducted. After compacting the samples they were permitted to cool for 24 h and removed from the mold

Table 5: Mineral filler properties (SCRB/R9)

Sieve size			
mm	In	Result	Specification
0.600	#30	100	100
0.300	#50	100	95-100
0.075	#200	83	70-100
Liquid limit		Non	-
Plasticity index		Non	<4
Specific gravity AASHTO-T84	2.716	-	

Table 6: Mechanical properties of the strips used in the study (Kaufman, 2000)

Density	Tensile strength	Modulus of elasticity	Elongation after tensile test
2700 kg per cubic meter	310 MPa (ultimate) and 276 Mpa (yield)	70 Gpa	12% at break

Fig. 1: Waste aluminum strips raw materials

Table 7: The characteristics of control mixture

Type of test	Results	Specification limits
Stability (kN)	13.3	Min. 8
Flow (0.25 mm)	2.8	2-4
Bulk density (Gmb), (gm/cm^3)	2.343	-
Air Voids in Total mix VTM), (VA) (%)	4.5	3-6
Air Voids in Mineral Aggregate (VMA) (%)	15	Min.14
Air Voids Filled with Asphalt (VFA) (%)	75	-
OAC (%) 4.6	4-6	
Index of retained strength (%)	75	Min. 70

Table 8: Marshall characteristics with different percentages of aluminum strips

Percentage of added (%)	Stability (kN)	Flow (mm)	Density (g/cm^3)
0.0	13.3	2.9	2.343
0.5	12.6	3.2	2.327
1.0	12.0	3.4	2.288
1.5	11.3	3.8	2.253
2.0	8.5	4.2	2.227
2.5	8.1	5.3	2.208

using an extrusion jack. Then, the unit weight, void ratios, flow and stability tests have been achieved complying with the Marshall procedure.

OAC value: To determine the OAC using Marshall method, the percentages of 4, 4.5, 5, 5.5 and 6.0 of asphalt cement have been utilized to produce 15 samples dividing into 3.0 samples for each percentage and after that the optimum value of asphalt will be used. Based on both ASTM D6927 and AASHTO R-12, the OAC could be determined from the average values of asphalt which corresponding to the variables that indicates in Eq. 1. Table 7 demonstrates the characteristics of reference HMA and the index of retained strength:

$$\text{OAC}(\%) = \frac{\text{AC for maximum stability} + \text{AC maximum density} + \text{AC median percent of air voids}}{3}$$

Adding aluminum strips: The OAC of reference mixture is 4.6% which is used for preparing the mixtures with Aluminum strips in HMA with (0.5, 1, 1.5, 2, 2 .5%) weight of total aggregate three molds for every percentage. The obtained results are indicated in Table 8.

Calculation of volumetric properties: To investigate the effect of adding aluminum strips on VA, VFA and VMA and by using Marshall relationships and pervious data, Table 9 and 10 express the percentage of material and all volumetric properties of HMA. Bulk specific gravity of combined aggregate (Gsb) is 2.547g/cm^3 (Fig. 2).

Fig. 2: a, b) Raw materials for mixes and prepared samples

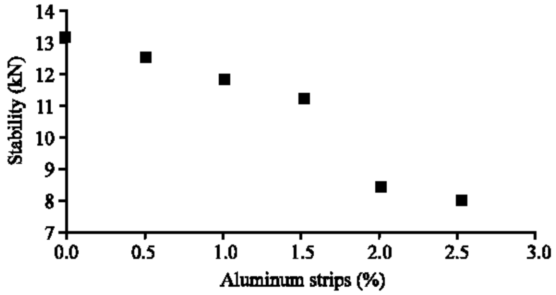

Fig. 3: Relationship between Aluminum strips and stability

Effect of strips on Marshall characteristics: Having reported the control mix, Table 7, the adding of strips with different percentages for the surface layer slightly decreases the stability as indicated in Table 8 about (10%) at 1% additives while sharply decrease around 15-39% at 1.5-2.5 the percent of additives as shown in Fig. 3, may be the lack of interlock between particles because of existence aluminum strips lead to this behavior. Whereas the flow increases from approximately 10-83% at 0.5-2.5 the percent of addition consequently to exceed the specification limits (>4 mm) for the percentage of equal or more than 2% of aluminum strips as indicated in Table 8 and Fig. 4 explain that. The flow unsatisfactory in 2 and 2.5% from replacement. It seems that smooth texture of aluminum may be the main reason who is responsible of reducing the cohesion in asphalt

Table 9: Percentage of materials in HMA in 1% addition

Aggregate data						
Material type	Coarse agg. (1)	Coarse agg. (2)	Coarse agg. (3)	Fine agg. (4)	Aluminum strips (5)	Filler (6)
Size (mm)	19-12.5	12.5-9	9-4.75	5-0	-	-
Individual percentages	P1%	P2%	P3%	P4%	P5%	P6%
by weight of agg. In mix	7	18	23	46	1	5
Bulk specific Gravity (G)	2.618	2.615	2.610	2.464	2.565	2.716

Table 10: Volumetric properties of HMA in 1% addition

Properties	Values
Asphalt content by weight of total mix (Ps)	4.6
Aggregate content by weight of total mix Pa = 100-Ps (Pa)	95.2
Maximum specific gravity for mix. according to (ASTM D 2041) (Gmm)	2.447
Bulk specific gravity of Marshall specimen (ASTM D 2726), g/cm^3 (Gmb)	2.288
Air Voids (VA)	5.6
% Voids in Mineral Aggregate (VMA)	14.3
% Voids Filled with Asphalt (VFA)	61

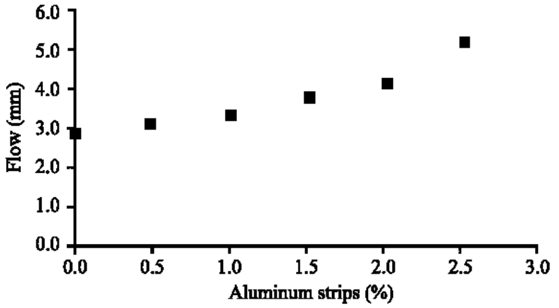

Fig. 4: Relationship between aluminum strips and flow

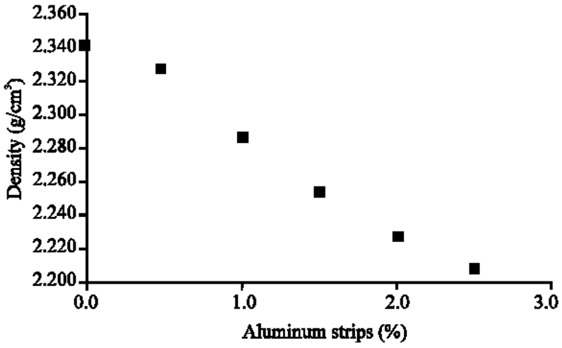

Fig. 5: Relationship between aluminum strips and density

mixture and increasing slide between the particles of mixture gradually leads to increase flow on asphalt specimens.

The inverse behavior has been noticed for the density where it drops at various rates in every increasing of aluminum strips as shown in Fig. 5. It is likely that the low specific gravity for aluminum is the main reason. The portions 0.5 and 1.5 achieve the requirement specifications but the percent 1% is the one which has to be preferred because it ensures high performance to HMA. From the available information from Table 7 and 10, VA increase approximately 24% while VMA and VFA decrease about 5, 19% consequently.

In the light of above, the results of using strips, however were not encouraging if the comparison has been made with the effect of using the same strips in concrete materials as reported by Muwashee *et al*. (2018). In one hand, the reason for this is not clear but it may have something to do with strip dimensions. These dimensions may be not as small as for the fiber. Therefore, this study recommends to reduce the width up to 3 mm, however, such a process needs additional efforts to be done. On the hand these strips are likely to be more suitable with other layers such as binder and base due to the size of aggregates in these layers.

Moisture susceptibility: The presence of water has complex effect on the performance of HMA which relays on different variables. The immersion test utilizes the compressive test which was achieved according to AASHTO T167-97 as a strength parameter (Al-Saeedi and Al-Jameel, 2018). Two groups, reference mix and mix with 1% Aluminum strips content are used in this test. From each group 3 samples are immersing for period 24 h at 60°C and 2 h at 25°C in a water bath and the others are kept dry inside air bath for 4 h at 25°C where this is depended here. The retained compressive strength could be illustrated as a percentage for the ratio of conditioned compressive strength to controlled compressive strength:

$$\text{Index of retained strength\%} = \frac{S1}{S2}$$

where, S1 and S2 = Compressive strength of immersed and dry specimens, respectively. Preceding results demonstrate that the percent 1% of adding the waste strips is the recommended value to be used. Therefore, this percent has been used to determine the index of retained strength. The results show that the calculated value is within the acceptable limits even this is less than the value for control mix as indicated in Table 11.

Table 11: Results for index of retained strength

Items	Condition	Index of retained strength (%)
1	Reference mixture	75
2	Adding 1%	70

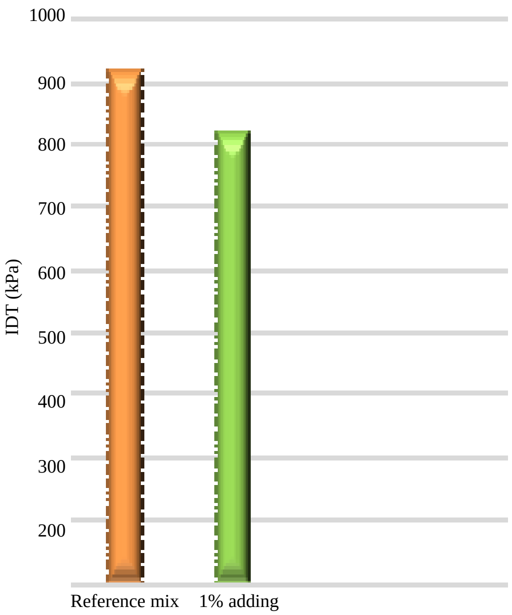

Fig. 6: Indirect tensile strength (IDT) test

RESULTS AND DISCUSSION

Indirect tensile strength of bitumen mixture: This test is stated in ASTMD 693. The specimens have been prepared with dimensions 101.6 mm in diameter and 63.5 mm in height. In addition, the two loading strips of 12.7 mm wide and 63.5 mm long are made of steel to distribute the load the parallel way. The compressive load has been applied at constant rate of two 50.8 mm/min and the ultimate load at failure has been recorded as the specimen is loaded until failure, peak load has been measured according to the test (AASHTO-T322). Figure 6 indicates load configuration and failure plane for specimen in Indirect Tensile Strength test (ITS). The value of compressive peak load could be indirectly obtained from a sample by applying a tensile loading in the level plane. Then, according to Eq. 3, the ITS value could be determined:

$$\text{ITS} = \frac{2P}{\pi td}$$

Where:

P = The Peak load, expresses in N
t = The height of the expressed in mm
d = The diameter of the specimen (mm)

Figure 8 demonstrates the effect of using aluminum strips on IDT test comparing with IDT test for control mix. Using 1% of the Aluminum strips decreases the IDT value by about 100 kPa which is still within the acceptable limit. Regarding to the previous results, one could find little reduction in mechanical characteristics such as stability, ITS and other characteristics. These reductions could be attributed to two reasons. Firstly, a possible explanation for these results may be the huge dimensions of waste aluminum strips (5 mm width and 10 mm length). These values are so, high comparing with fiber. Therefore, minimizing these dimensions to 3×6 mm may give better results. Secondly, using these strips in surface layer may reduce from their influence of stability and IDT. Therefore, selecting other pavement layer such as binder and base may show good behavior.

CONCLUSION

The main important points obtained from this study could be summarized as: a huge amount of wasted Coco-Cola produced annually created environmental problems. Therefore, using such waste materials is one of sustainability index even with low percent of waste material. As the percentage of waste strips increases, most of the mechanical characteristics decrease. This could be attributed to the large dimensions of strips (1 and 2 cm) comparing with fiber dimensions which are ≤0.3 and 1 cm. The prefer percent value of waste strip is 1%. This value could satisfy the specifications of HMA when the stability of surface pavement >10kN.

RECOMMENDATIONS

According to the findings from this study, the recommendation is to minimize the dimension of strips to be 3 mm in width which may improve the performance of HMA with waste strips. This study would have been more relevant if it had used the waste aluminum strips with other pavement layers such as binder and base. Therefore, this study recommends of doing further study on such layers.

ACKNOWLEDGEMENTS

The researchers would like to thank AL-Qadisiya Lab staff for their incredible support in both achieving the tests and also in providing the raw materials which were used in this study.

REFERENCES

Ahmadinia, E., M. Zargar, M.R. Karim, M. Abdelaziz and E. Ahmadinia, 2012. Performance evaluation of utilization of waste Polyethylene Terephthalate (PET) in stone mastic asphalt. Constr. Build. Mater., 36: 984-989.

Ajam, H.K.K., 2013. Utilization of shredded tetra-pak in hot mix asphalt. Al Qadisiyah J. Eng. Sci., 6: 287-293.

Al-Saeedi, B.J.K. and H.A.E. Al-Jameel, 2018. Sustainable performance of Iraqi asphalt base course using recycled glass as aggregate replacement. J. Univ. Babylon Eng. Sci., 26: 63-80.

Anderson, D.A., J.P. Tarris and D. Brock, 1983. Dust collector fines and their influence on mixture design. J. Assoc. Asphalt Paving Technol., 51: 353-397.

Colbert, B.W. and Z. You, 2012. Properties of modified asphalt binders blended with electronic waste powders. J. Mater. Civil Eng., 24: 1261-1267.

Dong, Y. and Y. Tan, 2011. Mix design and performance of crumb rubber modified asphalt SMA. Proceedings of the GeoHunan International Conference 2011 on Pavements and Materials: Recent Advances in Design, Testing and Construction, June 9-11, 2011, American Society of Civil Engineer, Hunan, China, pp: 78-86.

Kaufman, J.G., 2000. Introduction to Aluminum Alloys and Tempers. ASM International, Russell Township, Ohio, ISBN:9780871706898, Pages: 258.

Moghaddam, T.B., M. Soltani and M.R. Karim, 2014. Evaluation of permanent deformation characteristics of unmodified and polyethylene terephthalate modified asphalt mixtures using dynamic creep test. Mater. Design, 53: 317-324.

Muwashee, R.S., H.A. Al-Jameel and Q.A. Jabal, 2018. Investigating the behavior of concrete and mortar reinforced with Aluminum waste strips. Intl. J. Eng. Technol., 7: 211-213.

Zulkati, A., W.Y. Diew and D.S. Delai, 2011. Effects of fillers on properties of asphalt-concrete mixture. J. Transp. Eng., 138: 902-910.