Reducing Environment Pollution by Reusing of Alum Sludge Waste in Stone Mastic Asphalt Mixtures

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Abstract—**Globally, a huge quantity of alum sludge waste is produced as a by-product material from drinking water treatment plants that utilize aluminum salts as an essential coagulate and is the most generally produced water treatment remaining sludge around the world, which causes a serious environmental problem. Direct discarding of this substance has ecological effects. Hence, it is important to reuse this alum sludge waste material in such a manner to diminish its detrimental impacts on the environment. This research investigates the possibility of reusing alum sludge waste as a partial replacement of cement filler in stone mastic asphalt (SMA) paving mixtures. For this investigation, the alum sludge was used as a filler material in SMA mixtures in two modes; dried alum sludge at 110°C and burned alum sludge at 700°C. Different percentages of alum sludge were used as a replacement by the total weight of mineral filler at 0, 20, 40, 60, 80, and 100%. The results showed that using alum sludge as a substitution of filler in SMA mixtures reduces the performance of the mixtures in terms of Marshall properties and tensile strength for both dried and burned alum sludge compared with a standard mix. However, the performance of the mixtures containing burned alum sludge gave a better performance than the mixtures containing dried alum sludge.**

Index Terms—**Alum sludge; Alum sludge reuse; Burned alum sludge; Dried alum sludge; Environment pollution; Stone mastic asphalt.**

I. Introduction

The growth in population and urban expansion has resulted in a significant consumption of drinking water worldwide. Hence, the production of the residuals from water treatment plants is likely to increase with the growing population. From a technical perspective, nevertheless, the production of trustworthy and secure drinking water is often followed by producing water treatment residues and is called water treatment sludge (Zhao, et al., 2020). Since the water treatment plants include coagulation, flocculation, sedimentation, filtration and sterilization processes, during the "flocculation/coagulation" procedures known as water treatment residuals, a massive amount of residues as a by-product were created (Xu, et al., 2020). Alum sludge is the by-product material produced from drinking water treatment plants where aluminum salts are essential coagulating-flocculating chemicals (Yang, et al., 2006). Because of their performance and low expenses, aluminum salts are the main coagulating agents most widely used by water industries worldwide for water treatment processes (Gebbie, 2001). The environmental effects of alum sludge resulting from the water treatment process can also result in harm to human health. A part of these effects may appear instantly and others may require a longer time to affect, thusly, health impacts usually connected with natural contamination or environmental pollution that involves the utilization of chemicals or synthetic substances should be tested for the expected environmental pollution (Department of Environment, 2005). Therefore, water treatment sludge removal and the related expense besides the ecological effects are still global issues. Hence, the simple and unstudied removal techniques of water treatment sludge, such as discard in the sewer; discard in the common water body; discard in the lagoons and waste landfill; lead to unfavorable environmental effects (Turner, et al., 2019). As environmental and economic constraints restrict disposal choices, seeking appropriate alum sludge reuse options would also become imperative (Keeley, et al., 2014). Appropriate management of residual sludge is an environmentally and economically sustainable approach that remains a very serious concern. Recovery, recycle and reuse are a suitable solution for the disposal of water treatment sludge (Ahmad, et al., 2016).

To conform the disposal of waste requirements which have been stipulated by the authorities, researchers have been looking for alternative building materials as a replacement for conventional materials such as cement, bricks, ceramics, tiles, and aggregates so as to minimize the environmental effects of these wastes. In an attempt to close the distance between immense volumes of alum sludge and alleviate contamination, a series of studies aimed at beneficial reuse (Khalid, et al., 2014). Therefore, a study including the use of alum sludge in building and concrete work participates to reduce the potential pollution. Not only for being hard to get rid of growing volumes of alum sludge waste, but it also poses significant health risks. Therefore, efforts should be made to control the pollution resulting from the disposal of

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alum sludge by turning these undesirable wastes into usable raw materials for use in the construction field (Ahmad, et al., 2016). One of the opportunities to dispose of the alum sludge is to recycle it in the construction field. Every year, the construction sector consumes tremendous amounts of materials; accordingly, it can be considered an opportunity to reuse alum sludge in the manufacture of construction purposes and concrete production. Subsequently, to determine the highest percentage that could be used as a replacement for raw materials, further laboratory tests are needed. The growing issue of alum discharge into the environment will thus be mitigated if new solutions for disposal apart from landfill can be discovered (Khalid, et al., 2014).

Ghazawi, et al. (2015) experimentally investigated the possibility of alum sludge being consumed in asphalt paving mixtures. Alum sludge was utilized as a replacement with different percentages by the total weight of mineral filler in the hot mix asphalt (HMA). It has been observed that with increasing amounts of sludge waste in the asphalt mixture, stability, flow, and air voids are increased, then decreased.

Sahar, et al. (2019) experimentally examined the influence of alum sludge on the performance of HMA concrete mixtures. Alum sludge was utilized as a fine aggregate substitute in HMA at various percentages by weight of fine aggregate. The results indicated that using alum sludge up to 50% as a partial replacement for fine aggregate in a HMA resulted in acceptable values complying with nearly all the standard specification requirements. The main objective of this paper is to investigate the possibility of reusing alum sludge as a replacement of cement filler in stone mastic asphalt (SMA) mixtures.

II. Materials Characterization

All materials used in this study are locally available and currently used in road construction in northern Iraq.

A. Aggregates

In this study, it was used an asphalt concrete mixture in which 19 mm maximum aggregate size has been selected according to the American Association of State Highway and Transportation Officials (AASHTO) Specifications (AASHTO, 2009). The coarse and fine aggregate used in this investigation was brought from Tanjero HMA plant, and these were originally brought from a quarry near Sulaymaniyah city and crushed at the asphalt plant by mechanical crusher. The aggregate gradation is shown in Table I according to AASHTO specification M 325-08. An ordinary Portland cement was used as a mineral filler.

B. Filler

An ordinary Portland cement was used as a mineral filler in the asphalt mixture, brought from the Al-Mas cement factory. It constitutes from 8% to 11% by the total weight of the asphalt mixture. In this study, 10% of mineral filler was used by the total weight of the asphalt mixture. The physical properties of the mineral filler are presented in Table II.

C. Asphalt Cement

In this study, one type of asphalt cement was used with penetration grade of 40-50 obtained from Baiji refinery, Iraq. The characteristics of asphalt cement are according to the American Society for Testing and Materials (ASTM). The physical properties of the asphalt samples are given in Table III.

D. Additive-sisal Fiber

Sisal fiber is one of the most commonly used natural fibers, it can be obtained from the sisal plant, and it is extremely easy to cultivate (Omar, et al., 2020). In this study, the sisal fibers were used as an additive stabilizer in the SMA mixes at a dosage of 0.3% by the total weight of the mixture as recommended by AASHTO M 325-08, (2009).

E. Alum Sludge

The alum sludge was collected from the Kanibe water treatment plant, located at the Kanibe area near Dukan, in northern Iraq. For the purpose of this study, the alum sludge was used as a filler material in SMA mixtures in two methods; the first one, was by drying the alum sludge at 110°C for 24 h, and the second method, was by burning the alum sludge at a high temperature of 700°C for 6 h then it was left to cool at room temperature before it was pulverized by Los Angeles abrasion machine, finally, a powder alum sludge passing through sieve No. 200 (75 μm) will be used

TABLE I
Selected Combined Gradation Of Aggreate And Filler According To Aashto Specifications

Sieve size (mm)	Specification range	Selected gradation
19	100	100
12.5	90-100	95
9.5	50-80	65
4.75	20-35	27
2.36	16-24	20
0.075	8-11	10

TABLE II
Physical Properties Of Portland Cement Filler

Properties	Unit	Value
Specific gravity	-	3.15
Passing Sieve No. 200	%	99

TABLE III
Physical Properties Of Asphalt Cement

Properties	Unit	Specifications	Test results	Specifications limits
Penetration at (25°C, 100 g, 5 s)	0.1 mm	ASTM D5	44	40–50
Specific gravity at 25°C	-	ASTM D70	1.03	-
Softening point (Ring and Ball)	°C	ASTM D36	54	-
Ductility (25°C, 5 cm/min)	cm	ASTM D113	112	> 100
Flash point	°C	ASTM D92	288	> 232
Fire point	°C	ASTM D92	319	-

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as a filler in the stone matrix asphalt mixture for both phases. Fig. 1 shows alum sludge after treatment.

III. Laboratory Specimen Preparation and Test Methods

A. Optimum Asphalt Content

Marshall specimens were prepared in accordance with the Marshall procedure specified in the ASTM D6926-10 with different percentages of asphalt cement varying from 4.5 to 7% at an increment of 0.5% mixed with aggregate, 0.3% sisal fibers, and 10% Portland cement filler according to the adopted gradation. The Marshall samples were left to cool at room temperature and thereafter extracted from the mold to conduct the test on the samples in accordance with the ASTM D6927-15 procedure. According to the Marshall test, the results showed that the optimum asphalt content is equal to 6.1%. The test results were represented in Figs. 2-5 which showed the Marshall properties of the SMA mixtures.

B. Effect of Alum Sludge Content

The influence of alum sludge on the performance of SMA was assessed by comparing the behavior of specimens having various percentages of alum sludge added to the asphalt mixture as a substitution of mineral filler at 0% as a reference, 20%, 40%, 60%, 80%, and 100% by total weight of filler. As compared with the conventional mixture, the results showed that when the alum sludge content in SMA increased, the Marshall stability values decreased, but they remained acceptable. Likewise, the Marshall flow were decreased when alum sludge content increased, but the accepted Marshall flow value can be obtained by replacing up to 40% of filler by alum sludge, whereas the air voids are increased when alum sludge amount increased. The results of the Marshall test for SMA mixtures are shown in Figs. 6-9.

Fig. 1. Alum sludge waste materials. (a) Alum sludge oven-dried at 110°C. (b) Alum sludge furnace-burned at 700°C.

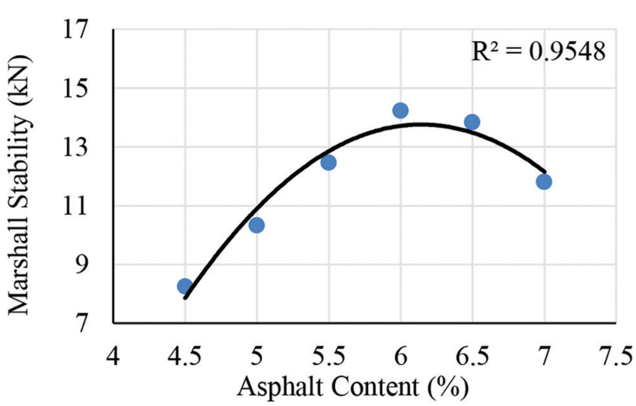

Fig. 2. Effect of asphalt content on Marshall stability of the mixtures.

The properties of SMA in terms of tensile strength per each alum sludge content can be examined by loading the Marshall specimen along a diametric plane with a compressive load at a constant rate acting parallel to and along the vertical diametrical plane of the specimen through two opposite loading strips. This loading method generates a relatively uniform tensile stress perpendicular to the direction of the applied load and along the vertical diametrical plane, ultimately causing the tested specimen to fail by splitting along the vertical diameter. The indirect tensile strength of a specimen is determined using the procedure stipulated

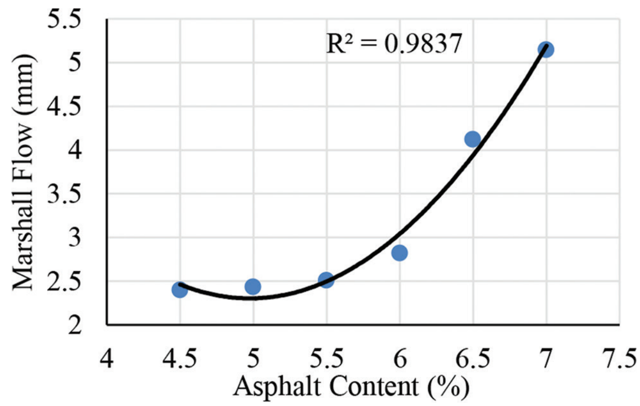

Fig. 3. Effect of asphalt content on Marshall Flow of the mixtures.

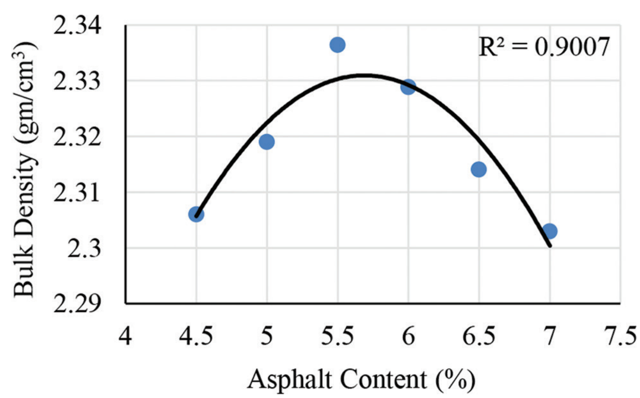

Fig. 4. Effect of asphalt content on bulk density of the mixtures.

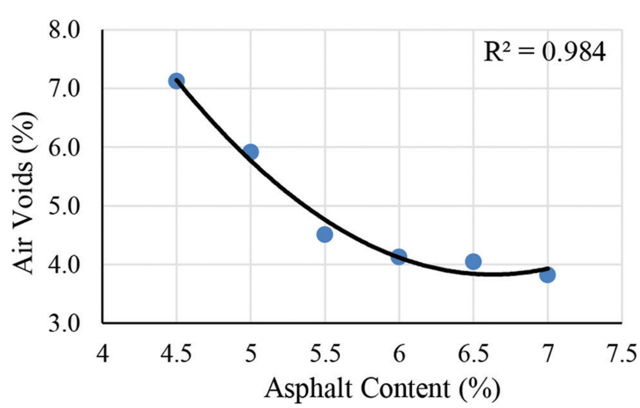

Fig. 5. Effect of asphalt content on air voids of the mixtures.

in ASTM D 6931. The tensile strength ratio depending on the result of indirect tensile strength in two scenarios; conditioned and unconditioned, and represented in Figs. 10 and 11. The results showed that when the percentage of replaced cement filler by alum sludge increased, the indirect tensile strength decreased; similarly, the tensile strength ratios were decreased as the percentage of replaced cement filler by alum sludge increased and indicated that the mixtures are more sensitive to moisture damage as a result of the presence of water in the mixture. However, the tensile strength ratios are still acceptable according to the moisture susceptibility requirement by AASHTO T 283/ASTM D4867 standard specifications.

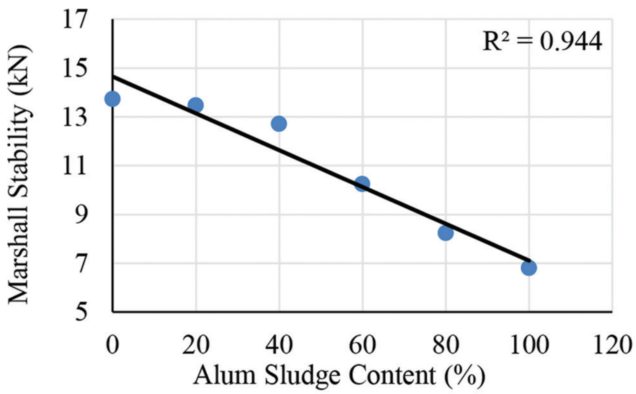

Fig. 6. Effect of alum sludge content on Marshall stability of the mixtures.

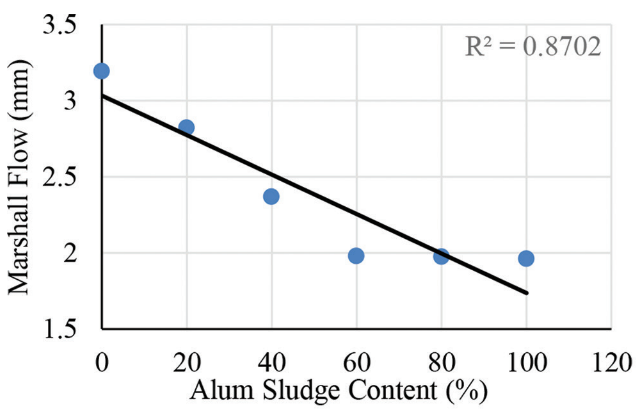

Fig. 7. Effect of alum sludge content on Marshall flow of the mixtures.

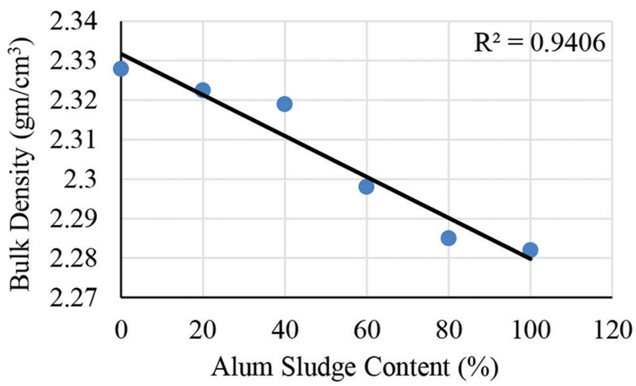

Fig. 8. Effect of alum sludge content on bulk density of the mixtures.

C. Effect of Alum Sludge burning

To investigate the effect of burning alum sludge on the performance of SMA mixtures, the material was subjected to a high temperature of 700°C for 6 h then cooled at room

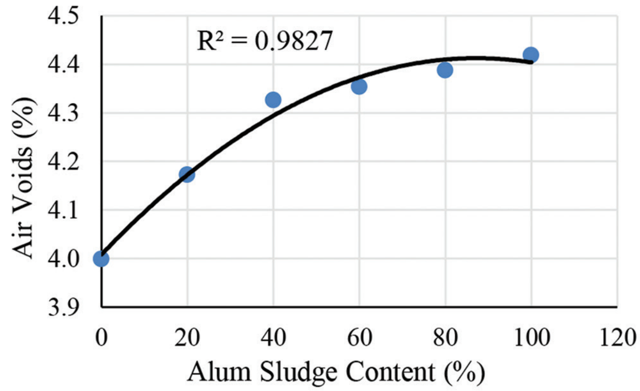

Fig. 9. Effect of alum sludge content on air voids of the mixtures.

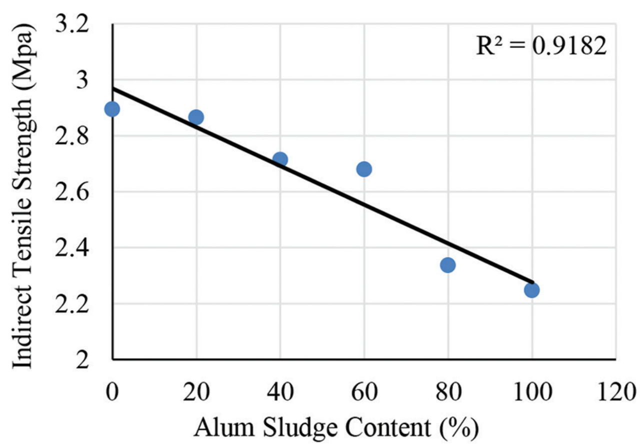

Fig. 10. Effect of alum sludge content on indirect tensile strength (unconditioned).

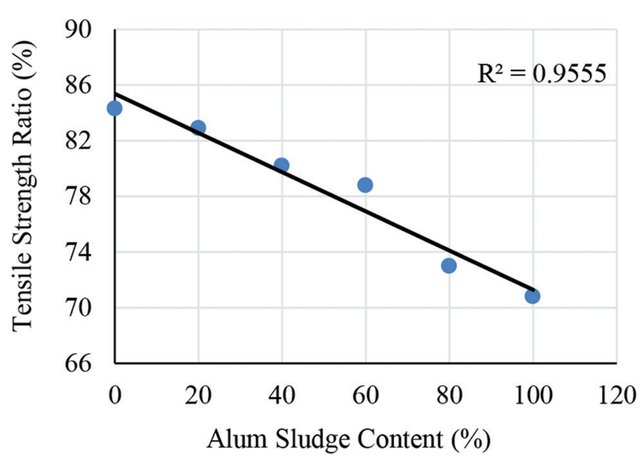

Fig. 11. Effect of alum sludge content on index of retained strength.

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temperature before being pulverized by a rotary steel ball mill and sieved on a sieve No.200 (75 µm) to be utilized as a filler in SMA mixtures. The performance of SMA was evaluated by comparing the behavior of specimens containing different percentages of burned alum sludge added to the asphalt mixture as a replacement of mineral filler at 20%, 40%, 60%, 80%, and 100% by total weight of filler. The results showed that as the replacement percentage of burned alum sludge in SMA mixtures increased, the Marshall stability, bulk density and the Marshall flow are slightly increased as compared with the mixtures containing the same percentage of dried alum sludge, whereas the air voids are decreased when the burned alum sludge amount increased in the SMA mixtures. The results of the Marshall test for the SMA mixtures are shown in Figs. 12-15.

To evaluate the effect of the burned alum sludge on the moisture susceptibility of the SMA mixtures, the tensile strength test was conducted on two sets of specimens conditioned and unconditioned in accordance to ASTM D 4867. The results indicated that when the percentage of replaced cement filler by burned alum sludge increased, the indirect tensile strength decreased as compared with the standard mix. Likewise, the tensile strength ratios were decreased when the percentage of replaced cement filler by burned alum sludge increased. However, the mixture with the replacement of burned alum sludge have showed a slight better performance as compared with those mixtures containing dried alum sludge at the same percentage. This can be attributed to the burning of organic matter content in alum sludge, which caused an increase in the bulk density, and eventually improved the performance of the mixture. Fig. 16 shows the failure mode of the indirect tensile test.

The results of the indirect tensile test and tensile strength ratio for the SMA mixtures are shown in Figs. 17 and 18.

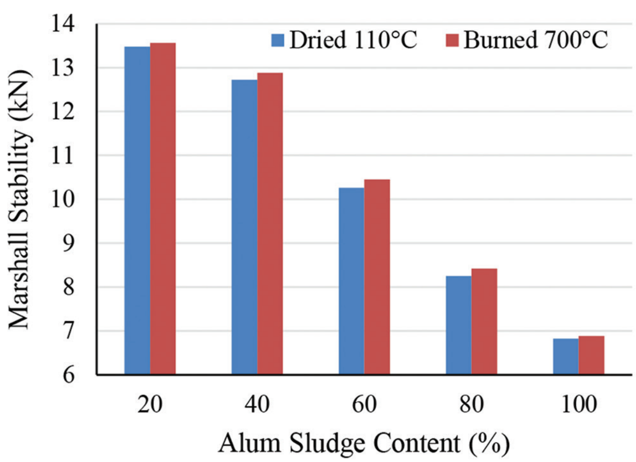

Fig. 12. Effect of alum sludge burning on Marshall stability of the mixtures.

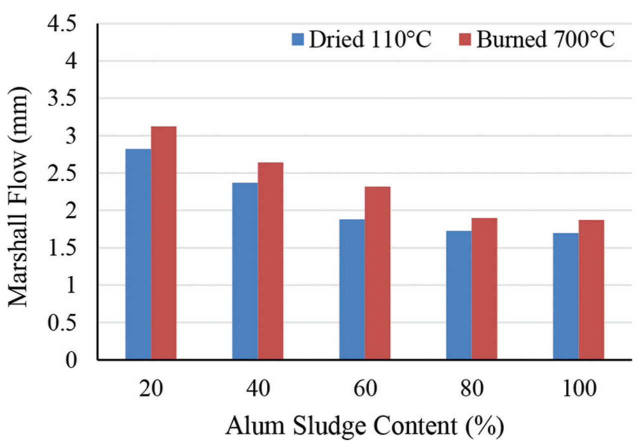

Fig. 13. Effect of alum sludge burning on Marshall flow of the mixtures.

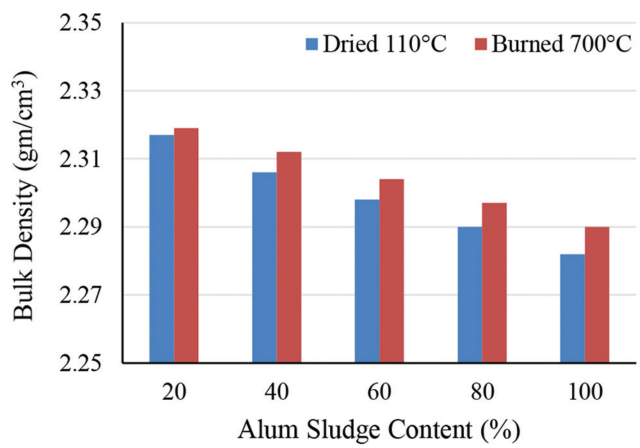

Fig. 14. Effect of alum sludge burning on bulk density of the mixtures.

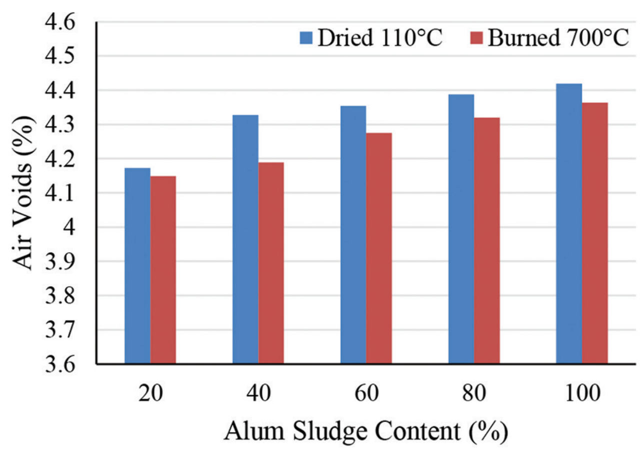

Fig. 15. Effect of alum sludge burning on air voids of the mixtures.

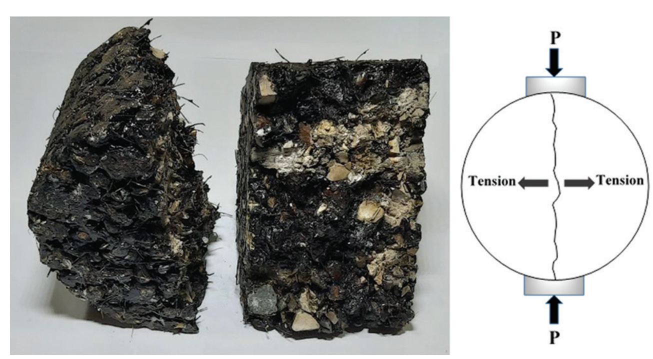

Fig. 16. Failure mode of indirect tensile test.

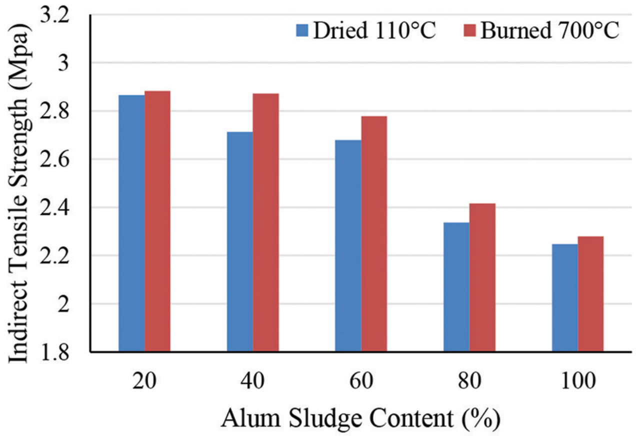

Fig. 17. Effect of alum sludge burning on indirect tensile strength (unconditioned).

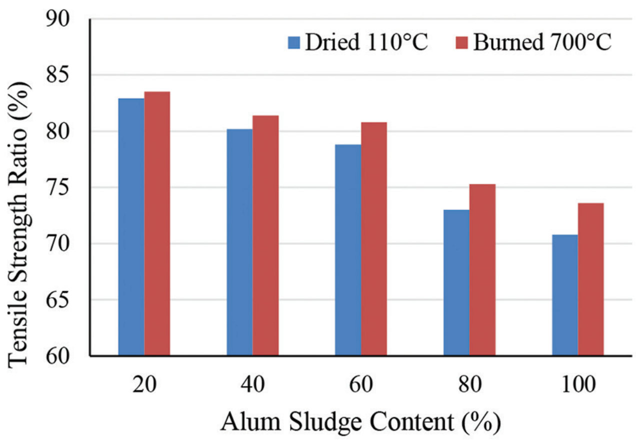

Fig. 18. Effect of alum sludge burning on index of retained strength.

IV. Conclusion

From the laboratory investigation, it can be seen that the replacing of the cement filler with alum sludge in the SMA mixtures reduces the performance of both Marshall properties and tensile strength as compared with the standard mixture of SMA. The main conclusions are drawn as the following:

1. The Marshall stability and Marshall flow values decreased when the cement filler was replaced with dried alum sludge in the SMA mixes, nevertheless, up to 40% of replacement, the results were acceptable in accordance with the standard specifications
2. The mixtures containing the burned alum sludge as a substitution of cement filler up to 60 % have satisfied all the properties required for asphalt mixtures for the Marshall properties in accordance with the standard specification
3. In SMA mixtures, when the percentage of replaced cement filler by alum sludge increased, the indirect tensile strength and tensile strength ratio decreased as compared with the standard mix by 22% and 16%, respectively, for dried alum sludge, while for the burned alum sludge decreased by 21% and 12.7%, respectively. However, the results are still acceptable in accordance with the standard specifications.

Finally, despite alum sludge decreasing the performance of asphalt mixtures in terms of Marshall properties and tensile strength, it can be used up to 40% as a partial replacement of Portland cement filler in the SMA mixtures, and because there was a slight difference in results for dried and burned alum sludge; it is recommended to reuse the alum sludge in a dried state to be more economic by saving the energy. Eventually, that will help in the safe and environmentally adequate disposal of alum sludge, besides that can contribute to keeping resources of construction materials.

References

Ahmad, T., Ahmad, K. and Alam, M., 2016. Sustainable management of water treatment sludge through 3 ‘R’ concept. *Journal of Cleaner Production*, 124, pp.1-13.

American Association of State Highway and Transportation Officials (AASHTO), 2009. *Standard Specification for Stone Matrix Asphalt* (*SMA*), *No. M325-08*, American Association of State Highway and Transportation Officials, Washington, DC.

American Association of State Highway and Transportation Officials, 2021. *Standard Method of Test for Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage*, American Association of State Highway and Transportation Officials, No. 283, Washington, DC.

ASTM D4867-04. *Standard Practice for Effect of Moistureon Asphalt Concrete Paving Mixtures*.

ASTM D6926-10. *Standard Practice for Preparation of Bituminous Specimens Using Marshall Apparatus.*

ASTM D6927-15. *Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures.*

ASTM D6931-12. *Standard Test Method for Indirect Tensile (IDT) Strength of Bituminous Mixtures*.

Department of Environment, 2005. *Guidelines for the Application of Special Management of Scheduled Waste*. Environmental Quality Act (Scheduled Waste) Regulation, Department of Environment, Ministry of Natural Resources and Environment, Malaysia.

Gebbie, P., 2001. Using Polyaluminium Coagulants in Water Treatment. In: *64th Annual Water Industry Engineers and Operators' Conference All Seasons International Hotel, Bendigo*, 5 and 6 September, 2001.

Ghazawi, Z., Khedaywi, T. and Gouneem, A., 2015. Pollution Reduction and Reuse of Sludge Waste in Asphalt Paving Mixtures. In: *Proceedings of the 4th International Conference on Energy Systems, Environment, Entrepreneurship and Innovation* (ICESEEI' 15) Dubai, United Arab Emirates February 22-24, pp.395-400.

Keeley, J., Jarvis, P. and Judd, S.J., 2014. Coagulant recovery from water treatment residuals: A review of applicable technologies. *Critical Reviews in Environmental Science and Technology*, 44(24), pp.12-25.

Khalid, M.B., Faris, G.F. and Isam, M.A., 2014. Reuse of alum sludge in construction materials and concrete works: a general overview. *Infrastructure University Kuala Lumpur Research Journal*, 2(1), pp.20-30.

Mahmood, O.T. and Ahmed, S.A., 2020. Influence of natural fibers on the performance of hot mix asphalt for the wearing course of pavement. *ARO The Scientific Journal of Koya University*, 8(2), p.10710.

Sahar A.A., Hayder A.O., Tameem M.H. and Kareem, H., 2019. Influence of Using Alum Sludge as an Aggregate on Hot Mix Asphalt. In: *International Conference on Civil and Environmental Engineering Technologies. IOP Conference Series Materials Science and Engineering*, Vol. 584.

Turner, T., Wheeler, R., Stone, A. and Oliver, I., 2019. Potential alternative reuse pathways for water treatment residuals: Remaining barriers and questions a review. *Water Air Soil Pollution*, 230, p.227.

Xu, D., Lee, L.Y., Lim, F.Y., Lyu, Z., Zhu, H., Ong, S.L. and Hu, J., 2020. Water treatment residual: A critical review of its applications on pollutant removal from storm water runoff and future perspectives. *The Journal of Environmental Management*, 259, p.109649.

Yang, Y., Tomlinson, D., Kennedy, S. and Zhao, Y.Q., 2006a. Dewatered alum sludge: A potential adsorbent for phosphorus removal. *Water Science and Technology*, 54(5), pp.207-213.

Zhao, Y.Q., Liu, R.B., Awe, O.W., Yang, Y. and Shen, C., 2018. Acceptability of land application of alum-based water treatment residuals an explicit and comprehensive review. *The Chemical Engineering Journal*, 353, pp.717-726.