Influence of using alum sludge as an aggregate on hot mix Asphalt

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Abstract: Alum sludge (AS) is one of the final products from water treatment processes. Handling and disposal of alum sludge has become one of the major economic and environmental concerns. An experimental investigation was examined to study the possible utilization of alum sludge as aggregate substitute in asphalt mixtures for pavement construction applications. Five asphalt mixtures containing various contents of the AS, 0% (reference mix), 30%, 50%, 70% and 100%, as a replacement to the fine aggregate were prepared in this study. The results conducted that alum sludge is a suitable material for producing asphalt mixes that contains of AS ranging from 30% to 50% as partial replacement for fine aggregates to achieve almost all the standard requirements for aggregates in asphalt mixtures.

Keywords: Alum sludge, Mechanical Properties, Marshall, Stability, Flow.

1. Introduction

The hot-mix asphalt (HMA) mixtures are complex material consisted of asphalt binder and mineral aggregates. The asphalt binder is used as birdlime in asphalt pavement [1], whilst the aggregate acts as the structural frame work. HMA contains 90–95% by weight and 75% up to 85% by volume of mineral aggregates [2]. The asphalt mixtures contain high percentages of aggregates; thus, use types of aggregates are needed for the construction and maintain roads. Use of waste material as replacement of aggregates in the pavement making lead to prevent the accumulation of these wastes, environmental pollution and as well as reduce primary production costs [3]. The sludge is one of the important water treatment plants in the water industry. In fact, sludge-treated water sludge (alum sludge) is an unavoidable by-product obtained as a result of water treatment, such as coagulation, flocculation, clarification and filtration, where the use of aluminum sulfate as the primary coagulant [4-10]. It became the disposal of sludge alum (AS) resulting from drinking water treatment plants gradually a threat to the environment and requires complex and expensive handling and disposal procedures [11-18]. Generally, alum sludge contains useful chemical compounds such as silicon dioxide (SiO2) and aluminum oxide (Al2O3), which are the main components of cement [19].

In European countries, the sludge management method comprises the several stages such as sludge gathering and storage, pumping to thickening area, thickening, storage of thickened sludge, pumping to dehydration area, dehydration, atomization, and final storage. In contrast, the discharge of sludge directly into the nearby stream. This traditional practice of the performance of sludge directly to a nearby stream became less acceptable because this discharge could violate the permitted current standards [20].
This has been identified globally as the most feasible alternatives to solve the sludge discharge problem including several reuse options such as soil barriers, reduction of nutrients in the soil laden spin-off and run in brick making, in the ceramics industry, the pavement and structural improvement in the soil, cement and adhesives industry, lightweight aggregate. Sludge used as supplementary cementitious material and fine aggregate substitute in preparation of cement mortar and concrete. Bearing in mind that the calcination conditions i.e., temperature and duration affect the microstructure and the pozzolanic properties of industrial solid wastes and as a result control the mechanical properties of pozzolanic cements [21]. Previous studies were investigated to study the potential of using sludge and sludge ash in the production of building and construction materials, artificial aggregate, cement, and ceramics production. Typical examples of the direct use of sludge ash from wastewater treatment plants are as filler in concrete. Owaid et al. 2014; Owaid et al. 2016 [22, 23] showed that the incorporation of alum sludge as a partial replacement to ordinary Portland cement in concrete is an effective means for improving the fresh state and hardened properties of high performance concrete (HPC).

2. Materials and experimental works

2.1 Materials

2.1.1 Asphalt binder

An asphalt binder of (40 - 50) penetration grade brought from Al Hilla refinery, Iraq, and it was used in this study. The physical properties and related standards are summarized in Table 1, which meet the requirements of the specifications [24].

| Test               | No. Standards | Requirements | Results |
|--------------------|---------------|--------------|---------|
| Penetration        | ASTM D5       | 40-50        | 49      |
| Flash Point        | ASTM D92      | ≥260         | 237     |
| Ductility          | ASTM 113      | ≥100         | 102     |
| Specific Gravity   | ASTM D70      | -            | -       |
| Softening Point    | ASTM D36      | ≥46          | 47.5    |

2.1.2 Aggregates

The source of the fine and coarse aggregates used in this study were obtained from Al-Najaf city. The graduation of aggregates is very important in hot mix design to check its suitability for hot mix asphalt. Table 2 shows the physical properties of the aggregates. Gradation of aggregates, is provided in Table 3. The gradation curves of the mixture design are shown in Figure 1.
Table 2. Physical properties of Aggregates.

| Test                                      | No. specification | Results  |
|-------------------------------------------|-------------------|----------|
| Coarse aggregate                          |                   |          |
| Bulk specific gravity (g/cm³)             | ASTM C 127        | 2.632    |
| SSD specific gravity (g/cm³)              |                   | 2.64     |
| Apparent specific gravity (g/cm³)         |                   | 2.663    |
| Fine aggregates                           |                   |          |
| Bulk specific gravity (g/cm³)             | ASTM C 128        | 2.637    |
| SSD specific gravity (g/cm³)              |                   | 2.645    |
| Apparent specific gravity (g/cm³)         |                   | 2.662    |
| Abrasion loss (%) (LOS Angeles)           | ASTM C 131        | 24.1     |
| Flat and elongated particles (%)          | ASTM D 4791       | 17.1     |

Table 3. Graduation of Aggregates and Specifications.

| Sieve SIZE | % Passing | Specification |
|------------|-----------|---------------|
| 19         | 100       | 100           |
| 12.5       | 90        | 90-100        |
| 9.5        | 87        | 76-90         |
| 4.75       | 60        | 44-74         |
| 2.36       | 40        | 25-58         |
| 0.3        | 18        | 5-21          |
| 0.075      | 5         | 4-10          |

Figure 1. Grading curves of aggregates and specification limits.
2.1.3 Mineral filler

The physical properties and chemical compositions of mineral filler are presented in Tables (4) and (5), respectively.

### Table 4. Physical properties of Mineral Filler

| Test items          | Results |
|---------------------|---------|
| Specific gravity    | 2.706   |
| Sieve Size (mm)     |         |
| No.30(0.6)          | 100     |
| No.50(0.3)          | 100     |
| No.200(0.075)       | 97.5    |

### Table 5. Chemical Compositions of Mineral Filler

| Chemical Compositions | CaO  | SiO₂ | Al₂O₃ | Fe₂O₃ | SO₃  | MgO  |
|-----------------------|------|------|-------|-------|------|------|
| Results               | 62.74| 22.68| 5.06  | 3.24  | 2.2  | 2.36 |

2.1.4 Waste material (alum sludge)

The waste materials used in this study was alum sludge (AS) that was collected at Al Hilla city water treatment plant, then oven-dried at 105 °C for 24 h as shown in Figure 2. The dried AS was crushed and sieved the graduation same of requirements for fine aggregate which that used in this study. The physical characteristics of AS was light brown. X-ray fluorescence (XRF) was used to analyse the chemical composition of alum sludge as seen in Table (6).

![Figure 2](image-url)
Table 6. Chemical composition of waste material (alum sludge).

| Chemical Analysis, (%) | CaO | SiO₂ | Al₂O₃ | Fe₂O₃ | MgO | SO₃ | K₂O | Na₂O |
|------------------------|-----|------|-------|-------|-----|-----|-----|------|
| Waste material (alum sludge) | 0.42 | 41.38 | 33.03 | 3.84 | 0.31 | 0.27 | 1.53 | 0.14 |

2.2 Mix Design

The gradation was adopted according to the aggregate conditions, and the details were shown in Figure 1. According to the hot mix asphalt (HMA) mixture gradation design in relevant specifications [24]. Marshall Gradation Design Method was utilized to determine the asphalt-aggregate ratio. For the results, reveal that the optimal asphalt-aggregate ratio was 4.8%.

2.2.1 Marshall test

Marshall test was conducted to study the mechanical character of prepared asphalt mixtures with a loading rate of 50 mm/min at 60 °C, and the Marshall stability and Flow value were determined according to ASTM D1559 [25].

2.2.2 Indirect Tensile Strength Test

The indirect tensile strength test is used to measure the creep compliance and strength of asphalt mixture. The specimen is loaded until failure-peak load is measured throughout the test, (AASHTO, 2005).

3. Result and Discussion

3.1. Marshall Properties

The results of all Marshall Stability tests are summarized in Table 7. All results shown for each specimen are the average value of three tests. It was found that it can be concluded that there is possible replacing (30-50)% of fine aggregate by alum sludge at hot asphalt concrete mixtures.

Table 7. Marshall Stability test results for Mixtures with different alum sludge content.

| Fine aggregate sand % | alum sludge % | stability (kN) | flow (mm) | % Air voids | Density (gm/cm³) |
|-----------------------|---------------|---------------|-----------|-------------|-----------------|
| 100%                  | 0%            | 8             | 4.1       | 4           | 2.16            |
| 70%                   | 30%           | 8.1           | 2.6       | 3.8         | 2.10            |
| 50%                   | 50%           | 8             | 2.7       | 4.2         | 2.13            |
| 30%                   | 70%           | 7.5           | 2.3       | 4.5         | 2.08            |
| 0%                    | 100%          | 7             | 2.3       | 4.5         | 2.0             |
**Figure 3.** Results of Marshall Stability of different asphalt mixtures.

**Figure 4.** Flow of different asphalt mixtures.

**Figure 5.** Results of Air Voids of different asphalt mixtures.
3.2. Indirect Tensile Strength Test results

The effects of replacing fine aggregate with AS in asphalt mixtures are presented in Table 8. The results revealed that the indirect tensile strength increased with an increase in AS content for all mixes up to 50%. Beyond this replacement level, the tensile strength shows a decline.

Table 8. The ITST Results of conditioning and un conditioning samples

| Mixture           | P Max load (KN) | ITST   |
|-------------------|-----------------|--------|
| Alum Sludge (0%)  | 24.9            | 2.480  |
| Alum Sludge (30%) | 26.9            | 2.707  |
| Alum Sludge (50%) | 28.92           | 2.865  |
| Alum Sludge (70%) | 23.88           | 2.377  |
| Alum Sludge (100%)| 23.6            | 2.349  |

4. Conclusions

The mixtures of the alum sludge and conventional aggregates from natural sources has satisfied all the properties required for asphalt mixtures and produced expected mix design properties in accordance with the standard specification requirements at (30-50)% replacing aggregate. For ITST test results, it indicated that replacement of alum sludge by weight of fine aggregate lead to improve the asphalt mixtures using up to 50%, but they decreased with a further increase in alum sludge contents because of the waste material effect on the mixture density.

References

[1] White TD, Haddock JE, Rismantojo E. 2006. Aggregate tests for hot-mix asphalt mixtures used in pavements. NCHRP report 557.
[2] Topal A, Sengoz B. 2005. Determination of fine aggregate angularity in relation with the resistance to rutting of hot-mix asphalt. Constriction& Building Material 19:155–63.
[3] C. Sullivan, M.Tyrer, C.R.Cheeseman and N.J.D.Graham.2010.Disposal of water treatment wastes containing arsenic---areview,Sci.TotalEnviron.4081770–1778.
[4] K. S. Hashim, A. Shaw, R. Al Khaddar, M. Ortoneda Pedrola, and D. Phipps, "Defluoridation of drinking water using a new flow column-electrocoagulation reactor (FCER) - Experimental, statistical, and economic approach," J Environ Manage, vol. 197, pp. 80-88, Jul 15 2017.
[5] K. S. Hashim, A. Shaw, R. Al Khaddar, M. O. Pedrola, and D. Phipps, "Iron removal, energy consumption and operating cost of electrocoagulation of drinking water using a new flow column reactor," *Journal of Environmental Management*, vol. 189, pp. 98-108, 2017.

[6] K. S. Hashim, A. Shaw, R. Al Khaddar, M. O. Pedrola, and D. Phipps, "Energy efficient electrocoagulation using a new flow column reactor to remove nitrate from drinking water - Experimental, statistical, and economic approach," *J Environ Manage*, vol. 196, pp. 224-233, Jul 01 2017.

[7] K. S. Hashim, N. H. Al-Saati, A. H. Hussein, and Z. N. Al-Saati, "An Investigation into The Level of Heavy Metals Leaching from Canal-Dreged Sediment: A Case Study Metals Leaching from Dreged Sediment," presented at the 1st International Conference on Materials Engineering & Science, Istanbul Aydin University (IAU), Turkey, 2018.

[8] N. H. Al-Saati et al., "Statistical modelling of turbidity removal applied to non-toxic natural coagulants in water treatment: a case study," *Desalination and Water Treatment*, vol. 150, pp. 406-412, 2019.

[9] D. Al-Jumeily, K. Hashim, R. Alkaddar, M. Al-Tufaily, and J. Lunn, "Sustainable and Environmental Friendly Ancient Reed Houses (Inspired by the Past to Motivate the Future)," in *2018 11th International Conference on Developments in eSystems Engineering (DeSE)*, 2018, pp. 214-219: IEEE.

[10] A. Shaw, K. S. Hashim, R. Alkhaddar, M. O. Pedrola, and D. Phipps, "Influence of electrodes spacing on internal temperature of electrocoagulation (EC) cells during the removal (Fe II) from drinking water," in *The 3rd BUiD Annual Doctoral Research Conference*, The British University in Dubai, 2017.

[11] K. S. Hashim, A. Shaw, R. Alkhaddar, and M. O. Pedrola, "Controlling of Water Temperature during the Electrocoagulation Process Using an Innovative Flow Columns - Electrocoagulation Reactor," *International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering*, vol. 9, no. 8, pp. 869-872, 2015.

[12] K. S. Hashim, A. Shaw, R. Alkhaddar, M. O. Pedrola, and D. Phipps, "Effect of the supporting electrolyte concentration on energy consumption and defluoridation of drinking water in the electrocoagulation (EC) method," in *The 2nd BUiD Doctoral Research Conference*, The British University in Dubai, 2016.

[13] M. Abdulredha, R. Al Khaddar, D. Jordan, P. Kot, A. Abdulridha, and K. Hashim, "Estimating solid waste generation by hospitality industry during major festivals: A quantification model based on multiple regression," *Waste Manag*, vol. 77, pp. 388-400, Jul 2018.

[14] M. Abdulredha, A. Rafid, D. Jordan, and K. Hashim, "The development of a waste management system in Kerbala during major pilgrimage events: determination of solid waste composition," *Procedia Engineering*, vol. 196, pp. 779-784, 2017.

[15] A. W. Alattabi, C. Harris, R. Alkhaddar, A. Alzeyadi, and K. Hashim, "Treatment of Residential Complexes' Wastewater using Environmentally Friendly Technology," *Procedia Engineering*, vol. 196, pp. 792-799, 2017.

[16] A. W. Alattabi, C. B. Harris, R. M. Alkhaddar, K. S. Hashim, M. Ortoneda-Pedrola, and D. Phipps, "Improving sludge settleability by introducing an innovative, two-stage settling sequencing batch reactor," *Journal of Water Process Engineering*, vol. 20, pp. 207-216, 2017.

[17] I. A. Idowu et al., "An analyses of the status of landfill classification systems in developing countries: Sub Saharan Africa landfill experiences," *Waste Management*, vol. 87, pp. 761-771, 2019.

[18] K. S. Hashim et al., "Removal of phosphate from River water using a new baffle plates electrochemical reactor," *MethodsX*, vol. 5, pp. 1413-1418, 2018.

[19] A. B. M. A. Kaish, a, Khalid Mohammed Breesem and Manal Mohsen Abood,. 2018.Influence of Pre-treated Alum Sludge on Properties of High-Strength Self-compacting Concrete, journal of Cleaner Production.

[20] M. Arabani and A.R. Azarhoosh .2012. The effect of recycled concrete aggregate and steel slag on the dynamic properties of asphalt mixtures, *Construction and Building Materials*, 35 (1–7).
[21] A.Tantawy.2015. Characterization and pozzolanic properties of calcined alum sludge, *Materials Research Bulletin*, Volume 61, January, Pages 415-421.

[22] H.M Owaid, R Hamid, MR Taha. 2014. Strength-ultrasonic pulse velocity relationship of thermally activated alum sludge multiple blended high performance concretes. Key engineering materials 594, 521-526

[23] H.M Owaid, R Hamid, MR Taha. 2016. Variation of ultrasonic pulse velocity of multiple-blended binders concretes incorporating thermally activated alum sludge ash. KSCE Journal of Civil Engineering 21 (4), 1235-1246.

[24] P.R. China, Ministry of Communications.2005. Technical Specification for Construction of Highway Asphalt Pavements, China Communications Press. ASTM. ASTM D1559–89, Standard Test Method for Resistance to Plastic Flow of Bituminous Mixtures using Marshall Apparatus, Annual Book of ASTM Standards USA, 1995.

[25] ASTM. ASTM D1559–89, Standard Test Method for Resistance to Plastic Flow of Bituminous Mixtures using Marshall Apparatus, Annual Book of ASTM Standards USA, 1995.