International Journal of Infrastructure Research and Management
Vol. 12 (1), June 2024, pp. 22 - 32

MECHANICAL PROPERTIES AND SUSTAINABILITY OF ALUM SLUDGE AS A PARTIAL REPLACEMENT OF FINE AGGREGATE

Sifat AKM, Norul Wahida Kamaruzaman, Tan Sheng Ying & Mahmoud Atef
Infrastructure University Kuala Lumpur, MALAYSIA

ABSTRACT

A substantial volume of alum sludge is generated globally during the water purification process for human consumption. The existing studies have highlighted that the conventional disposal methods pose significant environmental challenges, necessitating the exploration of more sustainable alternatives for alum sludge disposal. This research aims to investigate the workability and compressive strength behavior of traditional concrete by incorporating dry alum sludge as a replacement for fine aggregate (river sand). The alum sludge underwent treatment at 105 °C, was dried, crushed and sieved to achieve a fine particle. This treated alum sludge was then used to replace fine aggregate at varying percentages: 5, 10 and 15%. Specimens were prepared in cube forms (100×100×100mm) targeting a compressive strength of 25 MPa. The study aimed to understand the impact on the filler material properties, workability and strength of both fresh and hardened concrete. The compaction factor test and slump test results were employed to identify the fresh properties of the concrete. The compressive strength tests were conducted at 7, 14 and 28 days. The findings from the compressive strength tests indicated that a replacement of fine aggregate up to 10% was effective in achieving the targeted concrete strength. However, a reduction in workability was observed when the alum sludge filler was increased to 15%, while the 5% filler exhibited superior workability performance. This research contributes to altering certain aspects of concrete behavior by introducing the alum sludge as a replacement material for fine aggregate, thereby promoting environmental sustainability. The findings have sparked considerable debate in the field regarding concrete strength properties and behaviors, emphasizing the importance of exploring alternative materials for more eco-friendly construction practices.

Keywords:
Alum sludge, treated alum sludge, concrete mix, green concrete, sustainable concrete.

INTRODUCTION

As the global population continues to expand, projections indicate a doubling of water consumption by 2050. Meeting this heightened demand necessitates an increase in production by water treatment plants (WTPs), consequently leading to a surge in waste generation from treatment processes, commonly referred to as water treatment sludge (WTS). Globally, it is estimated that over 10,000 tons of sludge are generated daily. Management approaches for this waste vary among countries, often culminating in disposal in landfills, which poses significant environmental challenges. Consequently, there is a growing imperative to explore sustainable alternatives for WTS treatment and reuse, driving widespread interest among researchers. One promising avenue involves utilizing WTS as a raw material in other production processes, aligning with the principles of the circular economy. This strategy not only addresses environmental concerns but also contributes to mitigating the current challenges of natural resource scarcity (Mattoso et al., 2024).

The use of alum sludge in concrete has indeed gained significant attention among researchers. Alum sludge, which is a by-product of water treatment plants, offers potential benefits for enhancing certain properties of concrete. It is important to note that extensive research and testing are necessary to determine the optimal proportion of alum sludge in concrete mixtures to achieve the desired improvements in properties. (Ahmed et al., 2022) Investigated the mechanical characteristics of high-performance concrete incorporating alum sludge particles, with particle sizes such that 90% pass through sieve No. 200, serving as a substitute for cement at varying proportions 0, 5, 10, 15 and

20 % by mass. It may improve the mixture's workability and flow ability, making placement and compaction during construction simpler, which may increase the concrete's compressive strength. (Zhao & Zhang 2021). Factors such as the characteristics of the sludge, particle size distribution, and processing techniques need to be considered to ensure the best results which may have advantages for waste management and property improvement. Alum sludge can help to improve the characteristics of concrete when it is used in place of sand (Ching & Bashir 2021).

However, it is important to note that the proportion of alum sludge used as a sand replacement should be carefully determined through research and testing. In order to better understand how alum sludge affects the properties of concrete and to develop standards for its effective use, this research is actively investigating behavior of concrete incorporating alum sludge as fine aggregate. Also, the clay mineral content of alum sludge could potentially impact the workability of the concrete mix, particularly when used in significant quantities. This study also aims to explore the ideal alum sludge content that positively influences the workability performance of the concrete.

METHODOLOGY

Materials

This research is to determine the performance of the concrete that contains alum sludge (AS) that collected from the cake yard of a water treatment plant in Putrajaya, as shown in Figure 1. The river sand used in our study was sourced from the Kajang Quarry in Selangor. The river sand and the treated alum sludge were incorporated as fine aggregates, both falling within the particle size range bellow 2 mm. The course with the aggregate size maximum of 10mm, the cement used was ordinary Portland cement (OPC). Concrete cube samples were prepared and tested to determine various basic engineering properties. The concrete mix design involved a systematic analysis to select the appropriate ingredient proportions, aiming to produce modified concrete with desired strength and desired fresh properties when the cube is hardened. All tests conducted on the aggregate followed the standard and guidelines outlined in (BS EN 12620 2008).

Figure 1: The alum sludge is collected from cake yard, water treatment plant, Putrajaya

Preparation of materials

The sludge was collected and transported to the laboratory. Subsequently, it underwent an oven drying process at approximately 105 °C for 24 hours. After drying, the sludge was crushed and ground using a Los Angeles Abrasion test machine to achieve the desired fineness, which closely resembles the fineness of sand. To optimize the moisture content in the aggregate and eliminate any deleterious materials, the collected alum sludge must undergo treatment.

Experimental Programme

The experiments have been designed to assess various properties of alum sludge concrete (ASC), including particle grading, slump value, compacting factor and compressive strength. These tests aim to provide valuable insights into the characteristics and performance of ASC.

Concrete mix design

The mix design employed in this study followed the guidelines for normal concrete strength of 25 Mpa as per the British standard (BS 1881-108 1990). The replacement percentages ranged from 0, 5, 10 to 15 % and each mix was prepared separately. The control sample represented plain concrete without any alum sludge addition, as detailed in Table 1. The concrete curing process followed a conventional method, where different curing durations of 7, 14 and 28 days were implemented. For the assessment of compressive strength, concrete cube samples with dimensions of 100 mm were utilized. Additionally, for the evaluation of flexural strength, samples with dimensions of 100 mm x 100 mm x 500 mm were employed. These standardized sample sizes were chosen to ensure accurate and reliable testing of the concrete's strength properties. Proper curing of concrete cubes is essential to facilitate the correct hydration process. After the creation of the specimen cubes, they undergo a curing procedure involving submersion in water for varying durations, typically 7, 14 and 28 days. This curing process adheres to the guidelines outlined in (BS1881: Part III: 1983).

Table 1: Concrete mix proportion (Kg/m3)

Marking	W/C	Water	Cement	Coarse Agg.	Fine Agg.	Oven dried alum Sludge
C1	0.58	188.33	325	1200	736	0
CA5	0.58	188.33	325	1200	699	37
CA10	0.58	188.33	325	1200	662	74
CA15	0.58	188.33	325	1200	625	110

*Control sample (C) Oven dried alum sludge filler (A)

Particle Grading Test

The particle size distribution of aggregates and fillers will be determined by both representative and recovered samples will undergo sieve analysis following the guidelines of (BS 812) and (ASTM C136). This analysis focuses on measuring particle size distribution greater than 0.074 mm. The resulting particle size distribution curve will be presented for the representative soil sample. A total of 500 gm of fine aggregate will be weighed after recording the weights of the sieves and pan. The sieves will be assembled in ascending order, with larger openings on top and the No. 4 sieve at the top and the No. 200 sieve at the bottom. The fine aggregate will be placed in the top sieve and covered with a lid. The sieve stack will then be mechanically shaken for 10 minutes. After removing the sieve stack from the shaker, the weight of each sieve will be recorded.

Slump Value Test

The slump test is a widely used method for measuring the workability of concrete, both in laboratory settings and on-site. The apparatus required for conducting the test includes a metallic mould in the shape of a frustum of a cone, with specific dimensions. A steel tampering rod is also needed. In the field tests, the concrete sample should be obtained. The internal surface of the slump cone is thoroughly cleaned and dried before the test. The cone is placed on a smooth and rigid surface, secured with clamps, and filled with freshly prepared concrete in layers each compacted with 25 strokes of the tampering rod. The excess concrete is removed, and the cone is carefully lifted vertically without disturbing the concrete cone. The slump value is then recorded as a measure of the workability of the concrete.

Compacting Factor Value

The fresh concrete was delicately placed into the upper hopper using a hand scoop, ensuring it reached the brim of the hopper. Subsequently, the trap-door was opened, allowing the concrete to flow into the lower hopper. In cases where the concrete stacked up in the hoppers, a rod could be gently pushed from the top to assist the process. Once the concrete came to rest, the cylinder needed to be uncovered, and the trap door of the lower hopper opened to allow the concrete to fall into the cylinder. Following this, any excess concrete was removed using a trowel. The weight of the cylinder with the concrete was then recorded as W1.

Next, the cylinder was emptied and refilled with the same concrete mix, layer by layer, approximately 5 cm deep. Each layer was compacted by ramming to achieve full compaction. The top surface was leveled before recording the weight of the fully compacted concrete in the cylinder as W2. Subsequently, the weight of the empty cylinder was recorded as W.

The compaction factor is defined as the ratio of the weight of partially compacted concrete to the weight of fully compacted concrete.

Compressive Strength

The surface of the concrete sample was thoroughly cleaned before positioning it in the compression machine. Subsequently, the sample was centrally aligned on the base plate of the machine. The load was applied gradually at a rate of 140 kg/cm2/min until the sample reached failure. The maximum load and the mode of failure were carefully recorded.

RESULT AND DISCUSSION

Particle Grading

The particle size distribution of alum sludge closely resembled that of a fine aggregate, as shown in Figure 2. Consequently, these particles hold the potential to significantly augment the aggregate's strength by filling gaps between the coarse aggregates. Alongside evaluating the particle grading of the raw materials, tests were conducted on the fresh concrete to assess its workability, including the slump value test and compacting factor test.

The particle shapes, sizes, and quantity of fine aggregate play pivotal roles in determining both the workability and strength of concrete. The fine modulus of the locally sourced natural sand in Malaysia was determined 2.84 and alum sludge fine modulus 2.52. Additionally, specific gravity and moisture content were measured at 2.67 and 0.86 for sand, and 2.33 and 30 % for alum sludge respectively. Coarse aggregate comprised crushed stone chips with a maximum size of 10mm for the proposed concrete mix design method. Specific gravity and moisture content of the coarse aggregate were determined in accordance with (ASTM C127) standards. The grading curve of the coarse aggregate was established following (ASTM C33) guidelines. Table 2 presents the physical properties of the fine aggregates utilized in the study.

Table 2: Physical Properties of Aggregate

Physical properties	Fine aggregate	Alum sludge
Specific gravity	2.67	2.33
Fineness modulus	2.84	2.52
Moisture content	0.63 %	30 %

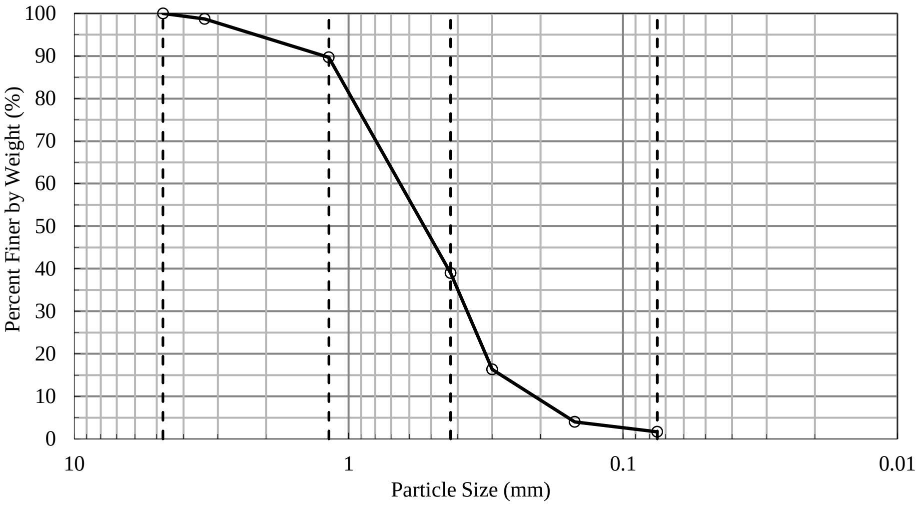

Figure 2: The particle size analysis of alum sludge

Slump test

Figure 3 represents the comprehensive analyses of slump test results provides valuable insights into the influence of alum sludge replacement on concrete workability. The findings reveal that a 100 % substitution of alum sludge leads to a significant decrease in slump, with recorded values ranging from 0 to 4 mm, indicating extremely poor workability. This highlights the challenges associated with entirely replacing sand with alum sludge in concrete mixtures.

However, as the replacement rate increases to 15%, the slump begins to low because cohesion of alum sludge. This reduction is attributed to the physical and chemical properties of alum sludge exceeding the optimal water/cement ratio, resulting in decreased workability. The observed slump test results Table 3, ranging from 30 mm (0% replacement) to 40 mm (15% replacement), offer valuable insights into the relationship between alum sludge replacement and concrete workability. While complete replacement negatively impacts workability, partial replacement initially improves it before reaching a threshold beyond which workability diminishes.

Table 3: The results of slump test

Control mix	30mm
5% alum	35mm
10% alum	50mm
15% alum	40mm

Figure 3: The slump test of different percentages of alum sludge

Compaction factor test

The compaction factor test as shown in Figure 4 plays a pivotal role in assessing concrete workability, shedding light on how easily freshly mixed concrete can be compacted. Results from the test are categorized as high, moderate or low compaction factors, providing valuable insights. The interpretation of these results is crucial for refining concrete mixes to meet specific project requirements. Striking a balance between workability and strength is essential for the successful execution of concrete construction projects, ensuring both durability and structural integrity. Adjustments to mix proportions, additives or the overall mix design process may be contemplated based on the observed compaction factor.

In Table 4, the compaction factor test results reveal that the 10% and 15% replacements exhibit a high compaction factor. This signifies excellent workability, suggesting easy placement and compaction. Additionally, it is noteworthy that such mixes are suitable for intricate shapes and structures, promising a smooth surface finish and efficient construction practices. These findings underscore the significance of the compaction factor in guiding decisions regarding concrete mix optimization for superior performance in construction projects.

Figure 4: Compaction factor test

Table 4: The results of compaction factor test

Control mix	0.84	Low
5% alum	0.90	Medium
10% alum	0.93	High
15% alum	0.96	High

Compressive Strength Test

In Figure 5, the compressive strength of all concrete mixes exhibits a consistent upward trend concerning curing age. Specifically as shown in Figure 6, at a 5% partial replacement of sand, the compressive strength of the concrete specimens reached 20 MPa, 25.45 MPa and 27.18 MPa after 7 days, 14 days and 28 days of curing, respectively.

However, a contrasting trend is observed at 15 % replacement, where the compressive strength is notably lower compared to the earlier results. The decline in strength at 15 % replacement of alum sludge is likely attributed to a potential deterioration in bond between particles. As the percentage of alum sludge replacement increases, the surface area of contact between alum sludge grows. Despite the constant sand content in the concrete, the additional bonding required is lacking, leading to a reduction in compressive strength.

Remarkably, at a 15 % replacement rate, a significant enhancement in compressive strength is evident. This suggests that this particular replacement percentage fosters a favorable balance between the surface texture of particles and the bonding with cement paste, resulting in improved compressive strength.

Figure 5: Compressive strength test

Figure 6: The compressive strength test result.

Flexural strength test

The flexural strength assessment of hardened concrete test specimens will involve applying a constant moment in the central zone while loading at two (or three) points. Upon extraction from water, specimens will be promptly analyzed while still wet. The test begins by precisely centering the specimen's longitudinal axis within the apparatus. In the case of molded specimens, the loading direction must be perpendicular to the direction of mold filling. Load application commences only after ensuring that all supporting and loading rollers are uniformly in contact with the test specimen as shown in Figure 7. For high-strength concretes, higher loading rates will be applied, while lower loading rates will be used for concretes with lower strengths. Once the loading rate is set, it should be maintained until failure occurs. The breaking load, signifying the maximum weight recorded on the scale at the point of failure, is then determined.

Test results outlined in Figure 8, revealed that the flexural strength values of concrete incorporating alum sludge exhibit a notable deterioration ranging from 5 % to 15 % when compared to the control concrete. Specifically, at a 5 % partial replacement of alum sludge, the flexural strength was measured at 2 MPa, 2.2 MPa and 2.7 MPa after 7, 14 and 28 days, respectively. This signifies a significant decrease of 15 % in flexural strength compared to the control mix.

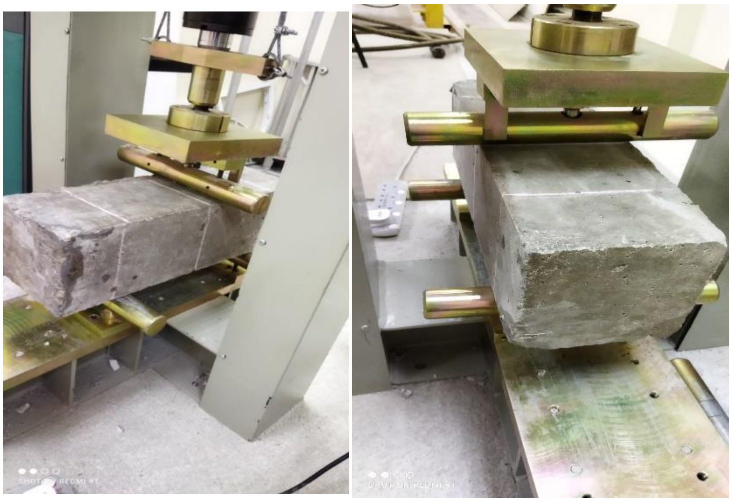

Figure 7: Arrangement of two-point loading.

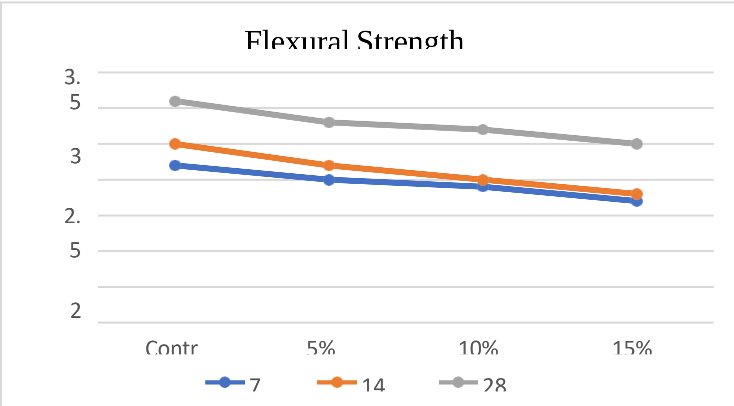

Figure 8: Flexural strength test result.

CONCLUSION

The purpose of this research is to explore the characteristics of concrete incorporating oven-dried alum sludge as a partial substitute for fine aggregate. The outcomes of this investigation conclude that the inclusion of alum sludge enhances the properties of concrete when used as a replacement for fine aggregate. The overarching goal of this study was to assess the viability of alum sludge as a partial substitute for sand in concrete mixtures. The research encompassed the formulation of concrete mixes containing alum sludge and the evaluation of concrete properties in both the fresh and hardened states. The properties under examination included mix workability, compressive strength and flexural strength. The study highlights the complex interplay between alum sludge replacement and concrete performance. While partial replacement of alum sludge shows promise in enhancing workability and even compressive strength up to a certain threshold, there are diminishing returns beyond this point.

Additionally, the flexural strength of concrete decreases with increasing alum sludge content. These findings underscore the importance of carefully balancing sustainability objectives with concrete performance requirements. A nuanced approach to alum sludge utilization is necessary, considering factors such as workability, strength, and overall performance. Future research should focus on optimizing alum sludge incorporation in concrete mixtures to maximize sustainability benefits while maintaining structural integrity and durability. Overall, this study contributes valuable insights into the potential of alum sludge as a partial replacement for sand in concrete mixes, guiding sustainable practices in the construction industry.

AUTHORS BIOGRAPHY

Sifat AKM, is a Master of Civil Engineering (by Research) candidate in the Faculty of Engineering Science and Technology, Infrastructure of Infrastructure University Kuala Lumpur. His research supervisor was Norul Wahida Kamaruzaman, Ts., PhD. *Email: akmsifat123@gmail.com*

Norul Wahida Kamaruzaman, Ts., PhD is a lecturer in the Civil Engineering & Construction Department of Infrastructure University Kuala Lumpur. She received her M.Eng in Construction from the University Malaysia Pahang in 2013 and her PhD in Engineering Technology in 2019 from the same university. *Email: wahida@iukl.edu.my*

Tan Sheng Ying is a Bachelor of Civil Engineering (Hons) graduate in the Faculty of Engineering Science and Technology, Infrastructure of Infrastructure University Kuala Lumpur. *Email: shengying2000@gmail.com*

Mahmoud Atef is a Bachelor of Civil Engineering (Hons) graduate in the Faculty of Engineering Science and Technology, Infrastructure of Infrastructure University Kuala Lumpur. *Email: mahmoudatef99@gmail.com*

REFERENCES

ASTM-C293. (2002). Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading). West Conshocken, PA, USA: ASTM International

ASTM D854. (2014). Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer. Annual Book of ASTM Standards

BS EN 12390: Part 7. (2000). Testing hardened concrete. Density of hardened concrete. British Standards Institution, London.

BS EN 12390: Part 3. (2000). Testing hardened concrete. Compressive strength of test specimens. British Standards Institution, London

BS 8500: Part 1. (2006). Concrete – Complementary British Standard to BS EN 206 – 1 – Part 2: Specification for Constituent Materials and Concrete. British Standards Institution, London.

BS 1377: Part 2. (1990). Methods of test for soils for civil engineering purposes. Classification tests. British Standards Institution, London

BS 1881:part 102: (1983). Method for Determination of Slump. British Standards.

BS 1881:part 103: (1983). Method for Determination of Slump. British Standards.BS EN 12390: Part 7. (2000). Testing hardened concrete. Density of hardened concrete. British Standards Institution, London.

BS EN 12390: Part 3. (2000). Testing hardened concrete. Compressive strength of test specimens. British Standards Institution, London

ASTM-C293. (2002). Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading). West Conshocken, PA, USA: ASTM International

Ahmed, F. R., Muhammad, M. A., & Ibrahim, R. K. (2022, June). Effect of alum sludge on concrete strength and two-way shear capacity of flat slabs. In Structures (Vol. 40, pp. 991-1001). Elsevier.

Mattoso, A. P., Cunha, S., Aguiar, J., Duarte, A., & Lemos, H. (2024). Valorization of Water Treatment Sludge for Applications in the Construction Industry: A Review. Materials, 17(8), 1824.

He, X., Zhao, X., Zhang, W., Ren, B., & Zhao, Y. (2022). Developing a novel alum sludge-based floating treatment wetland for natural water restoration. Water, 14(15), 2433.

Ching, C. Y., Bashir, M. J., Aun, N. C., & Aldahdooh, M. A. A. (2021). Sustainable production of concrete with treated alum sludge. Construction and Building Materials, 282, 122703.

Norhaiza Nordin, Muhammad Zulhelmi Husaini Zahri Afandi (2023). Finite Element Analysis of Reinforced Concrete BeamColumn Connection with Kinked Rebar Configuration Under Lateral Cyclic Loading Using Abaqus. International Journal of Infrastructure Research and Management Vol. 11 (1), June 2023, pp. 11 – 24

Norul Wahida Kamaruzaman, Nurazim Ibrahim, Halfaoui Abdel Rahman, Ibrahim Sowaileh (2023). The Chemical Properties of Granite and Beranang Laterite Aggregate by Using Sem-Edx. International Journal of Infrastructure Research and Management Vol. 11 (1), June 2023, pp. 88 - 95

Peng Wei, Siti Nur Aliaa Roslan and Mohd Nizam Shakimon (2023). Analysis Of Countermeasures for Risk Management of Construction Engineering.International Journal of Infrastructure Research and Management Vol. 11 (1), June 2023, pp. 77 - 87

Sandanayake, M., Bouras, Y., Haigh, R., & Vrcelj, Z. (2020). Current sustainable trends of using waste materials in concrete—a decade review. Sustainability, 12(22), 9622.

Zhao, W., Xie, H., Li, J., Zhang, L., & Zhao, Y. (2021). Application of alum sludge in wastewater treatment processes:“science” of reuse and reclamation pathways. Processes, 9(4), 612.