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Lopezite Enhanced Engineering Cementitious Sludge Ash Composite Using Emma Technique

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Abstract: According to the UN sustainable development goals, reducing and use of sludge is essential to maintain the sustainability by reproducing sludge into an industrial application product. Various types of sludge are produced from different sources from residential and industrial outlets. Sewage sludge is produced in large quantities where it is essential to be treated and to be reproduced into an applicative product. One such industrial product is the building component brick and composites made from sludge waste. The texture, porosity and compressive strength are important for such kind of sludge composite for building materials. Many studies have taken place to improve those parameters but by adding mineral admixtures into sludge components are very case in testing and proving. The objective of this study is to add a natural mineral component Lopezite to the sludge particle and to reduce the number of samples needed for trial mixes to reduce material quantity using Elkem Material Mix Analyzer (EMMA) which optimizes from nine samples to six samples with water content from 0.24 to 0.14. The EMMA is a particle packing technique which uses Modified Anderson and Andreason (MAA) theory and High range water reducing admixture (HRWRA) at water ratio of 0.16 with ideal dose. At the 28th day curing, the sample mix A08 recipe gave a compressive strength of 79 MPa for 70.6 mm x 70.6 mm x 70.6 mm cube of Lopezite added composite than the normal sludge composite of 42 MPa. Hence, this study proves that the Lopezite added sludge ash composite with EMMA technique gave good results and optimizes material quantity.

Keywords: Lopezite, Cementitious Material, Sewage Sludge, Sewage Sludge

1. Introduction

In the construction industry the engineered cementitious sludge ash composites has various application in the manufacturing of high strength concrete and building blocks whereas the Lopezite treated engineered cementitious sludge ash composite has even higher compressive strength and improved texture and porosity [1]. Lopezite mineral is most widely found in European countries like Italy where it is zeolite mineral used to improve the physical and chemical properties of cementitious composites. Engineered cementitious sludge ash (ECSA) can replace raw cement in partial replacement with concrete composites. Both the mixture of ECSA and Lopezite can improve the mechanical and durable properties of composite materials. The Elkem Material Mix Analyzer (EMMA) is used to optimize the material mix samples using Modified Anderson and Andreasen particle packing techniques [2]. In the present paper the steps for preparing Lopezite enhanced engineered sludge ash composite using EMMA was explained elaborately. EMMA software can calculate the optimal use of lopezite and ECSA sample mix recipes to reduce the quantity of raw materials and maintain sustainability. The first step includes the collection of raw materials such as cement, aggregate and sludge ash whereas the fly ash can be partially replaced by sludge ash [3]. The sample mix was prepared from the EMMA calculated mix proportion results which gives desired strength and high durable composites [4]. The engineered cementitious sludge ash values of specific gravity, particle packing distribution of different sieves were inputted in the EMMA software to find the optimistic sample mix with reduced water binder ratio from 0.24 to 0.14. The curing conditions of temperature and humidity can also be considered by EMMA software. In advance to the beginning of the production process, the raw cementitious materials were tested to meet the initial requirements of specification of the composite [5].

After the raw materials were selected and tested, the sample mix preparation can be done using EMMA and can be monitored to correct the proportions of each materials used. The prepared sample mix can be dropped to 70.6 mm x 70.6 mm x 70.6 mm mold for cube casting. After casting the raw composite must be cured for 7, 14 and 28 days to achieve good compressive strength and also the durability of the composite [6]. The sample mix was tested to ensure the required specification of the samples, and the analysis was done by EMMA [7]. At the final stage of testing the Lopezite enhanced engineered cementitious sludge ash composite was done to optimize the process of reducing the material quantity and to ensure the required specification of the composite. Lopezite mineral belongs to the monoclinic crystal structure where it typically forms as a crust of tubular and prismatic crystal with a pale yellow and dark orange colour [8]. In 1930 this mineral was discovered in Lopez mine in chile and named by a mineralogist Frank A.Lopez as Lopezite mineral [9]. Lopezite has a hardness of 2 to 2.6 and a specific gravity of 3.04. It has high concentrations of potassium dichromate ($K_2Cr_2O_7$), and has industrial applications like improving texture in concrete [10].

Numerous study areas have introduced sewage sludge bricks and composites; however, none of them have addressed how to increase the density and decrease the porosity of sludge composites [11]. In addition to improving density and texture, Lopezite, a sulfate mineral with potassium dichromate when treated with sludge and cementitious characteristics, is also a good binding agent that has not been covered in any research. No research has examined the particle size distribution and packing of sewage sludge ash utilizing the modified Andreassen and Andreassen approach employing EMMA. The fact that using sewage sludge as a building material did not improve density and decrease porosity in bricks that partially replaced cement with sewage sludge-added bricks was an intriguing observation [12]. An innovative method for enhancing density and texture is the use of lopezite, a mineral that contains potassium dichromate, as a binding agent. The EMMA is a particle packing technique which uses Modified Anderson and Andreason (MAA) theory and High range water reducing admixture (HRWRA) at water ratio of 0.16 with ideal dose. At the 28th day curing, the sample mix A08 recipe gave a compressive strength of 79 MPa for Lopezite added composite than the normal sludge composite of 42 MPa. Hence, this study proves that the Lopezite added sludge ash composite with EMMA technique gave good results and optimizes material quantity.

2. Experiment and testing

The composition of sewage sludge can vary depending on the source and the treatment process, but in general it contains organic and inorganic components. Organic components are nothing, but human and animal waste and it includes proteins, carbohydrates, and lipids. The inorganic components consist of a variety of minerals and elements, including phosphorus, nitrogen, calcium, magnesium, iron, and heavy metals. Sewage sludge also contains microorganisms such as bacteria and parasites, which are pathogenic and require treatment before disposal [13].

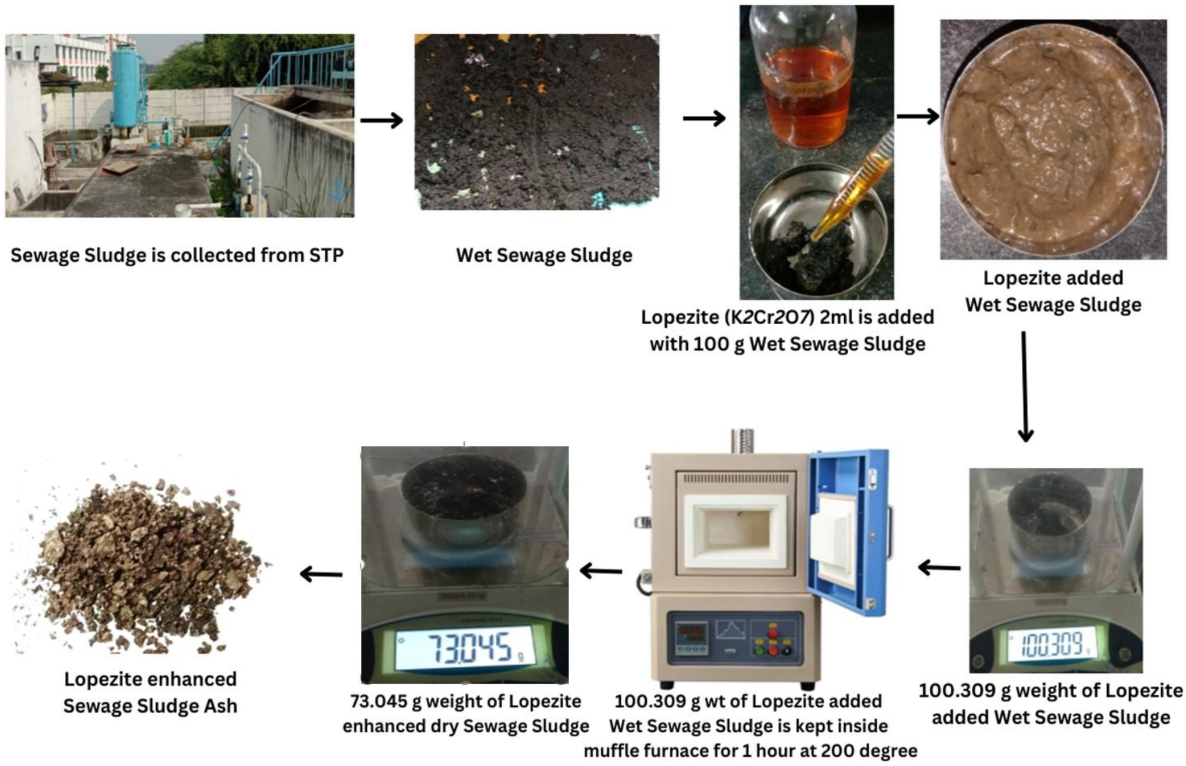


Figure 1. The Process of Making Lopezite enhanced Sewage sludge ash

Table 1. The composition of the sewage sample taken

Organic matter: 50%	Water: 35%	Nitrogen: 1.8%
Phosphorus: 0.9%	Potassium: 0.7%	Calcium: 4.6%
Magnesium: 0.4%	Sulfur: 0.2%	Iron: 3,000 ppm
Zinc: 300 ppm	Copper: 90 ppm	Nickel: 30 ppm
Lead: 12 ppm	Cadmium: 3 ppm	Chromium: 16 ppm

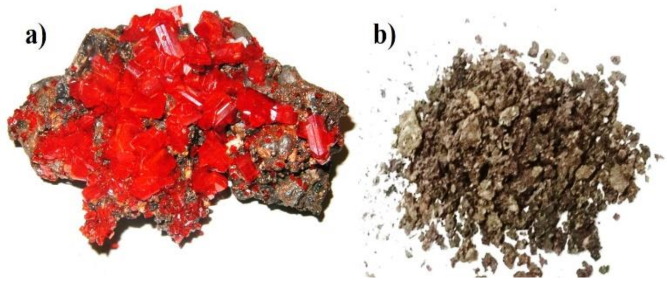


Figure 2. a) Lopezite mineral **b)** Dried Sewage Sludge after treated with Lopezite (K2Cr2O7)

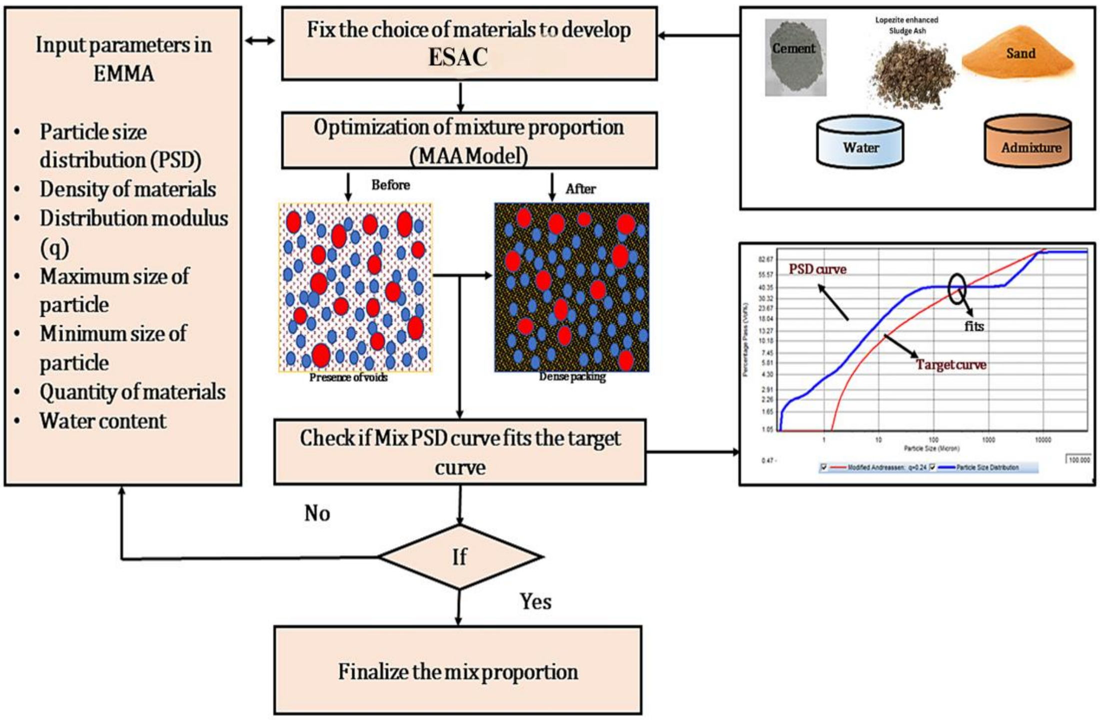


Figure 3. Flowchart on mix design method for the development of ESAC

Due to the potential health and environmental risks associated with sewage sludge, a strict regulation governing its treatment and disposal is needed. Many wastewater treatment plants are following advanced treatment processes to reduce the number of contaminants in sewage sludge and makes it safer for reuse and disposal. In this study the sewage sample was tested and its compositions are given in Table 1.

Figure 1 shows the process of making Lopezite enhanced sewage sludge ash [14]. The sewage sludge was then dried for 7 days and treated with lopezite mineral precipitate ($K_2Cr_2O_7$). Initially, 100 grams of dried sewage sludge was tested with 2 ml of potassium dichromate ($K_2Cr_2O_7$) and kept in a muffle furnace at 200 ° C for 1 hour. Then the tested sample was taken, and its weight was 73 g. Also, the sample was completely dried and textured because of potassium dichromate. Figure 2 shows the sample model of dried sewage sludge.

The balanced chemical equation for this reaction is as follows [32]:

$$K_2Cr_2O_7 + \longrightarrow CaO\ K_2CrO_4 + CaCrO_4$$

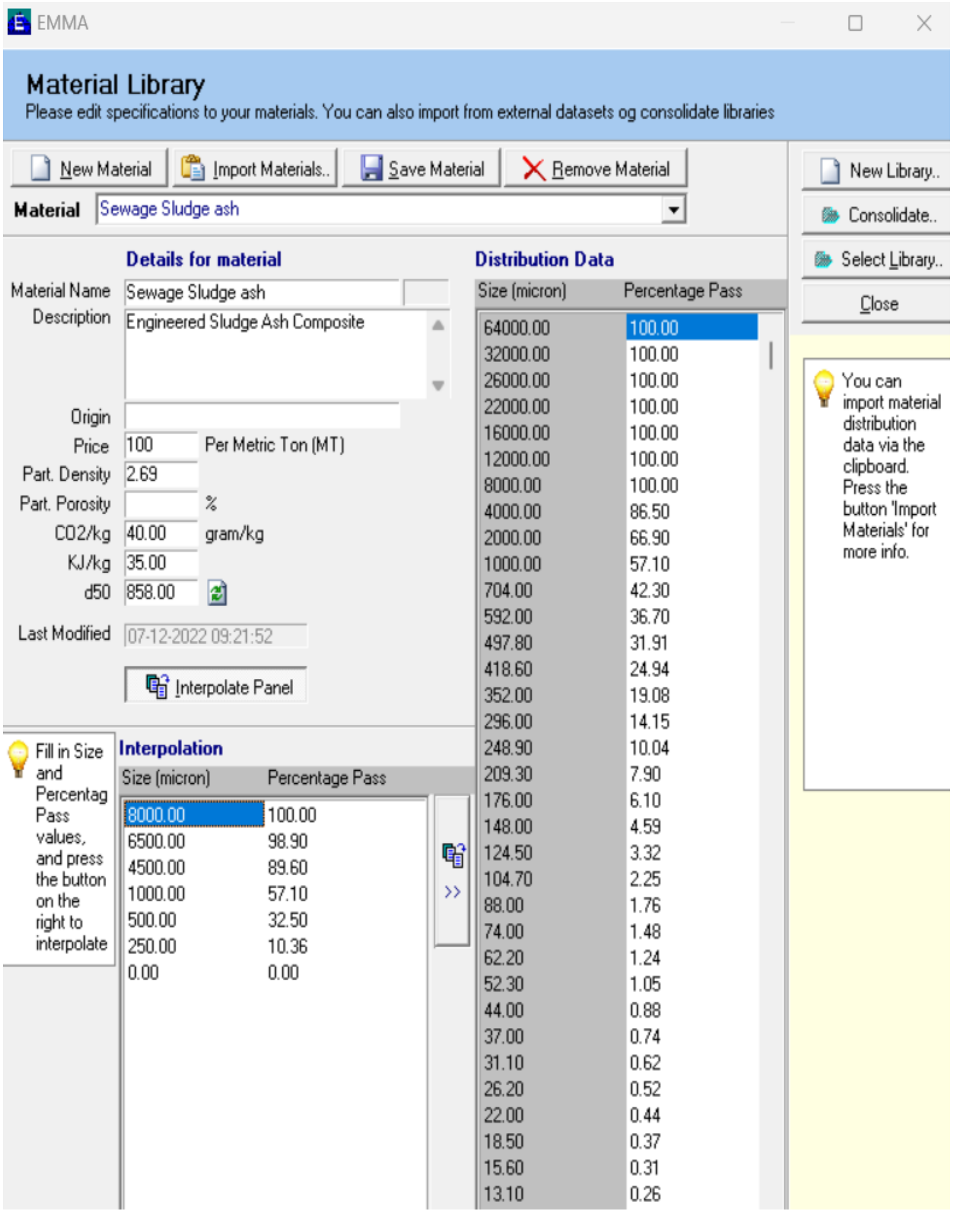


Figure 4. Pass percentage added for sewage sludge ash in material library

In this reaction, potassium dichromate (K_2Cr_2O7) is reduced to potassium chromate (K_2CrO_4), while calcium oxide (CaO) is oxidized to calcium chromate ($CaCrO_4$). Note that this reaction is typically not used in any practical application. Potassium dichromate is a strong oxidizing agent and calcium oxide is a basic oxide, so they are unlikely to come into contact with each other in a chemical process.

Figure 3 shows the flowchart on mix design method for the development of ESAC [15]. Now, this treated sample was powdered and was called sewage sludge ash, and it was subjected to addition to the material property for cube testing in EMMA. To feed the material property in the Elkem Material Mix Analyzer, a Sieve analysis was performed for all components of the mixture, such as sewage sludge ash, cement, and sand. The pass percentage was noted and entered the EMMA.

Figure 4 shows the percentage of pass added for sewage sludge ash in the material library [16].

After entering the pass percentage data in the materials library, the recipe details such as the amount and density of the sewage sludge ash material, the High Range Water Reducing Admixture (HRWRA), sand and cement were entered for the proportions of the mix. The composition matrix was generated from EMMA to identify the mix ratio under various pass percentages.

Figure 5 shows the mixing procedure and step by step process of fabrication of ESAC. The mixture was grouped into 6 categories G1 to G6 and 24 IDs of the mixture were created as 24 cubes to be cast to test compressive strength and named A01 to A24. The size of the cube to be tested is 70.6 mm x 70.6 mm x 70.6 mm [17]. Table 2 shows the properties of the mixture of various test samples from A01 to A24. Mix IDs A01 to A06 come under the Group 1 category.

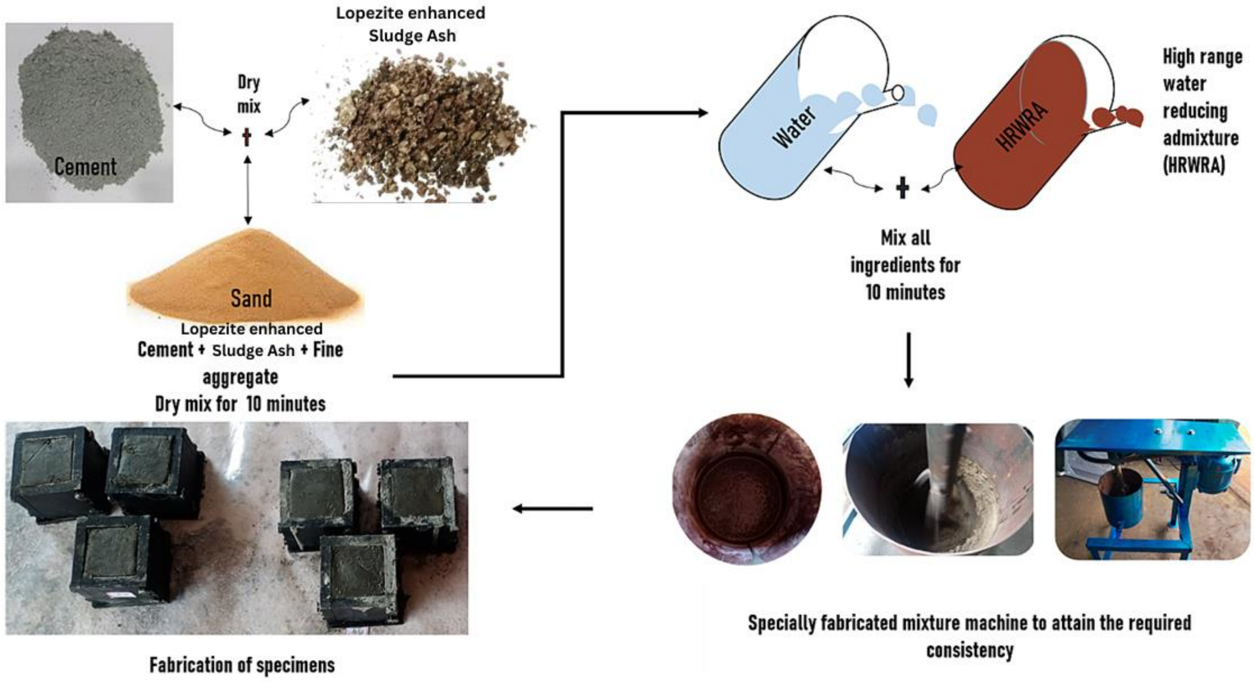


Figure 5. Mixing procedure and step by step process of fabrication of ESAC

Table 2. Mix properties of various testing samples of ESAC (Group 1-6)

Mix ID	Sieve (µ)	Sewage Sludge Ash (Kg/m³)	Cement (Kg/m³)	Fine Aggregate (Kg/m³)	HRWRA (%)	Cementitious Paste Volume (CPV %)
G1						
A01	64000	80.60	11.16	14.64	1.3	52
A02	32000	80.60	11.16	14.64	2.4	45
A03	26000	80.60	11.16	14.64	3.2	49
A04	22000	80.60	11.16	14.64	4.1	52
A05	16000	80.60	11.16	14.64	4.7	40
A06	12000	80.60	11.16	14.64	5.6	40
G2						
A07	8000	80.60	11.16	14.64	1.57	40
A08	4000	69.72	11.16	14.64	2	30
A09	2000	53.92	11.16	14.64	2.61	40
A10	1000	46.02	11.16	13.62	3.88	40
G3						
A11	704	34.09	11.16	9.55	4.28	50
A12	592	29.58	11.16	7.88	5.34	40
A13	497.80	25.72	11.16	7.25	1.49	30
A14	418.60	20.10	11.16	6.72	1.8	50
G4						
A15	352	15.38	11.16	6.13	2.9	50
A16	296	11.40	11.16	5.64	3.2	30
A17	248.90	8.09	11.16	5.23	4.3	60
A18	209.30	6.37	11.16	4.88	1.3	50
G5						
A19	176	4.92	11.16	4.49	2.9	30
A20	148	3.70	11.16	4.16	4.67	30
A21	124.50	2.68	11.16	3.89	0.9	40
G6						
A22	104.7	1.81	11.16	3.66	1.9	40
A23	88	1.42	11.12	3.14	3.4	30
A24	74	1.19	10.97	2.94	1.6	40

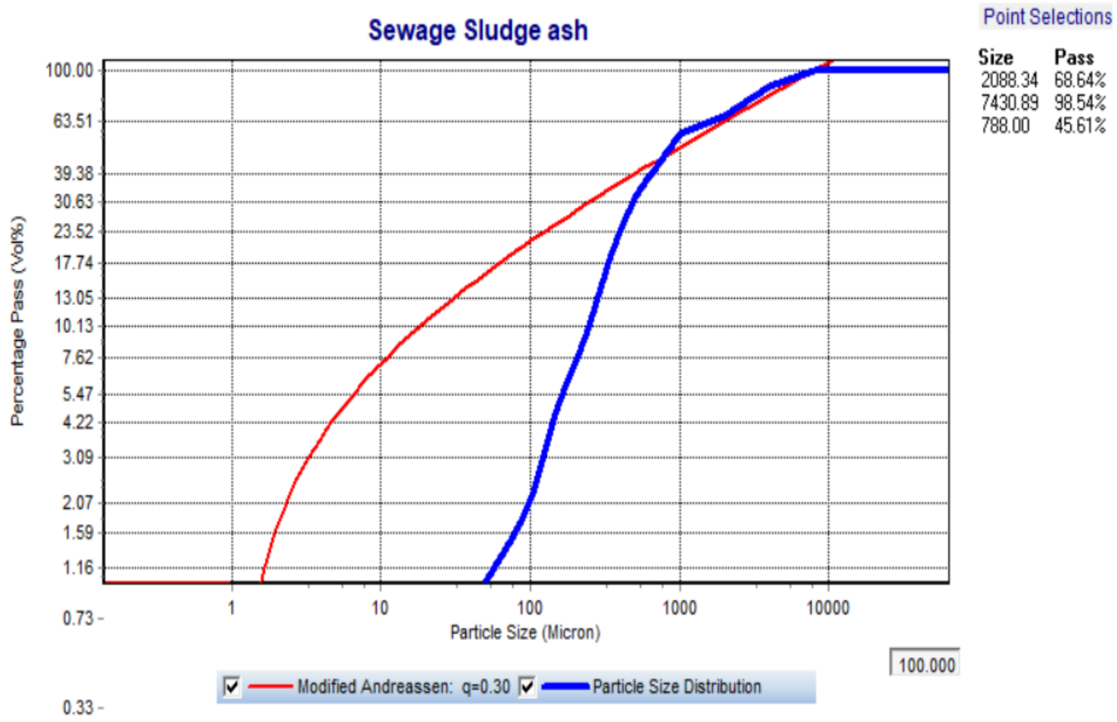


Figure 6. Optimization of the proportion of the mixture using particle packing theory

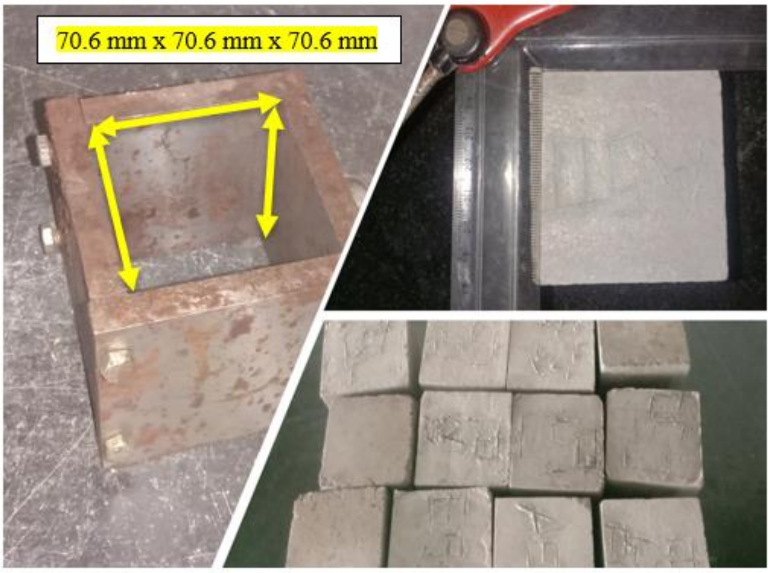


Figure 7. 70.6 mm x 70.6 mm x 70.6 mm cube mould and casted specimens

A07 to A10 fall under Group 2 category. A11 to A14 come under the Group 3 category. A15 to A18 under the group 4 category. A19 to A21 fall under Group 5 category and A22 to A24 comes under Group 6 category.

Now, the material and water amounts were added to the EMMA recipe box. Where the quantity of water was 0.22% and the quantity of material was a 100% mixture of sewage sludge ash, high-range water reduction additive (HRWRA), sand and cement. The modified Andreasen q-value was entered as 0.30 for a good calculation matrix. The modified Andreasen graph shows that there was a good mix under the pass percentage of 68.64%, 98.54% and 45.61%. The Andreassen modified graph for the sewage ash composite of the A08 mix recipe with the particle size distribution. Figure 6 shows the optimization of the proportion of the mixture using particle packing theory for recipe A08.

All these 24 cubes were cast and cured for 7 days, 14 days, and 28 days based on the mix proportions of particle packing. Figure 7 shows the 70.6 mm x 70.6 mm x 70.6 mm cube mold and casted specimens.

3. Result and Discussion

3.1. Workability

The flow table analysis was performed for the mix recipes of the A01 to A24 mix. Where the flow value changes with each mix recipe under a different water binder ratio. Under the A01 to A06 mix group 1 recipe the water binder ratio was 0.14 where the flow value ranges from 185 to 215mm for a high dose of HRWRA admixture of up to 5%. Under the A07 to A10 mix Group 2 recipe the water binder ratio was 0.16 and in the A08 mix recipe A08, the optimal dosage of HRWRA was 2.68%. In the recipe of Group 3 from A11 to A14 mix the water binder ratio was 0.18. Group 4 recipe from A15 to A18 mix, the water binder ratio was 0.20. In group 5 recipe of A19 to A21 mixes the water binder ratio was 0.22. Group 6 recipe from A22 to A24 mixed, the water binder ratio was 0.24. Figure 8 shows the compressive strength of the A08 mix recipe that has 79 MPa. The compressive strength of sludge-based baking-free brick made from sewage sludge with high moisture content reached 13.7 MPa under wet-heat cycle curing when the sludge content was less than 30% [18].

Figure 8. Compressive strength of the A08 mix recipe having 79 MPa.

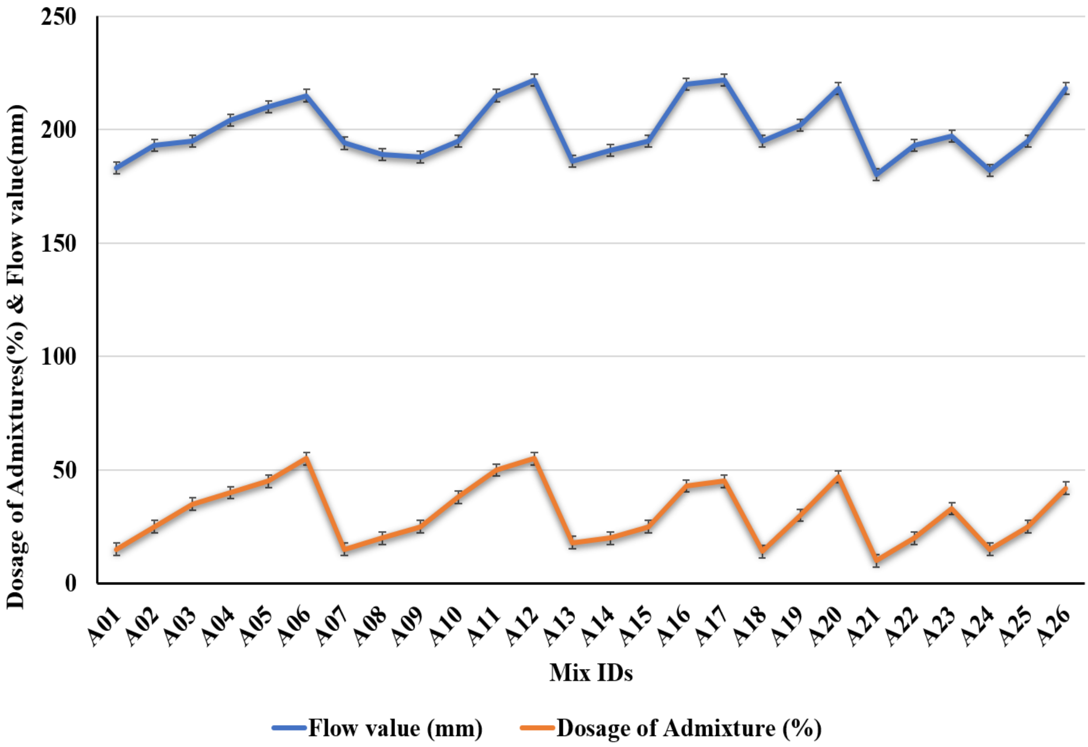


Figure 9. Comparison of Flow value and Dosage of Admixtures for Various Mix IDs

In comparison to reference values of 0% additive, of 25.10 g/(cm^2.min$^{0.5}$) and 6.17 MPa, recycled wastewater treatment plant sludge produced a higher capillary water absorption coefficient of 47.15 g/(cm^2.min$^{0.5}$) and a lower compressive strength of 3.95 MPa when added to ecological lightweight earth bricks. The composition of cinder and sewage sludge into lake sediment decreased the linear drying shrinkage of adobe, but it also increased water adsorption and decreased compressive strength. This was demonstrated by the fabrication, microstructure, and properties of bricks fired from these materials [19]. An examination of the pore structure and crystalline phase of thermal insulation bricks containing a significant amount of municipal sewage sludge is carried out. The bricks' strength and durability will deteriorate as a result of the excessive MSS content. Microstructure and mechanical characteristics of porous ceramics with a high concentration of sewage sludge and high strength. Because of the liquid phase formation, porous ceramics had a smooth surface, a typical void structure, and excellent mechanical properties. Figure 10 shows the comparison of flow value and dosage of admixtures for various mix ID’s.

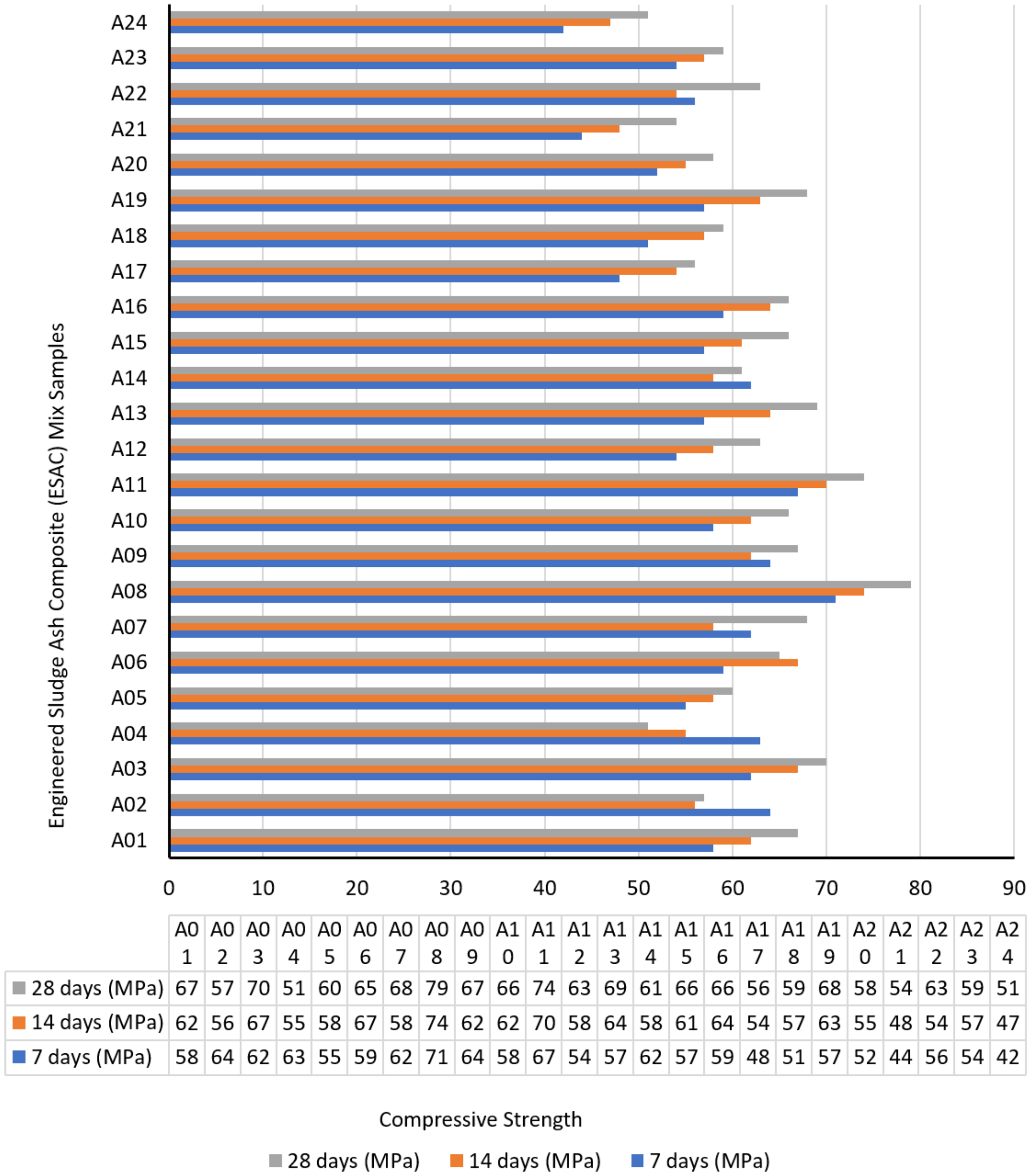
3.2. Compressive Strength

Table 3 shows the compressive strength of the ESAC specimen of mix IDs from A01 to A24 for 7 days, 14 days, and 28 days. Under the Group-1 recipe of A01 to A06, the maximum compressive strength was achieved at A03 of 70 MPa for 28 days. And under the A07 to A10 Group-2 recipe, the maximum compressive strength was achieved at A08 of 79 MPa for 28 days. Under the Group-3 recipe from A11 to A14, the maximum compressive strength was achieved at A11 of 74 MPa for 28 days. Under the Group-4 recipe from A15 to A18, the maximum compressive strength was achieved at A15 and A16 of 66 MPa for 28 days.

Under the Group-5 recipe from A19 to A21, the maximum compressive strength was achieved at A19 of 68 MPa for 28 days. Under the Group-6 recipe of A22 to A24, the maximum compressive strength was achieved at A03 of 63 MPa for 28 days. Therefore, the overall compressive strength was gained by the A08 recipe which has 79 MPa for 28 days. The combined effects of anhydrous Na_2CO_3 and amorphous porous materials on the performance of bricks containing a high amount of municipal sewage sludge [20-21].

Table 3. Compressive Strength of ESAC Samples

Mix ID	7 days (MPa)	14 days (MPa)	28 days (MPa)
A01	58	62	67
A02	64	56	57
A03	62	67	70
A04	63	55	51
A05	55	58	60
A06	59	67	65
A07	62	58	68
A08	71	74	79
A09	64	62	67
A10	58	62	66
A11	67	70	74
A12	54	58	63
A13	57	64	69
A14	62	58	61
A15	57	61	66
A16	59	64	66
A17	48	54	56
A18	51	57	59
A19	57	63	68
A20	52	55	58
A21	44	48	54
A22	56	54	63
A23	54	57	59
A24	42	47	51



	A01	A02	A03	A04	A05	A06	A07	A08	A09	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22	A23	A24
28 days (MPa)	67	57	70	51	60	65	68	79	67	66	74	63	69	61	66	66	56	59	68	58	54	63	59	51
14 days (MPa)	62	56	67	55	58	67	58	74	62	62	70	58	64	58	61	64	54	57	63	55	48	54	57	47
7 days (MPa)	58	64	62	63	55	59	62	71	64	58	67	54	57	62	57	59	48	51	57	52	44	56	54	42

Figure 10. Graphical representation of Compressive strength of ESAC Mix Samples under 7 days, 14 days and 28 days.

Because of the porous structure that results from a significant amount of organic evaporation at high temperatures in MSS, it can be used as bricks for thermal insulation. Figure 10 shows the graphical representation of Compressive strength of ESAC Mix Samples under 7 days, 14 days and 28 days.

4. Conclusion

In order to improve traditional design approaches, this proposed study investigates the important strategies in particle packing theories, namely the MAA model. The packing density is a key factor in influencing a number of ESAC performance factors. The application of EMMA is examined to maximize binder ratios, guaranteeing the efficient selection of granular materials according to moisture content and particle size. Finally, the effect of the distribution modulus (q) on ESAC's compressive strength and workability is evaluated. The sewage sludge was treated with potassium dichromate, a mineral component of lopezite, which gives good texture to the building material. Hence, this study reduces the number of trial mixes required for optimization. Six trial mixes with varying water binder ratios ranging from 0.24 to 0.14 were prepared and optimization was carried out using Elkem Materials Mixture Analyzer (EMMA). The MAA theory was used to consider the solid particle packing effect, and the ratio of water and high-resolution water reduction admixture (HRWRA) was determined on the basis of the flowability test of ESAC. The study found that the optimal dose of HRWRA was 2.68% with a water binder ratio of 0.16. The A08 mix recipe was found to exhibit an improved compressive strength of up to 79 MPa at 28 days.

The results of the study indicate that the MAA theory and particle packing concept can be effective in optimizing the proportions of the ESAC and reduce the number of trial mixes required for optimization. The results demonstrate that the altered design approach produces more unique ESAC with enhancement of Lopezite mineral. To obtain the optimal PSD that meets the target curve for dense particle packing of ESAC, the suggested binder system with q values ranging from 0.22 to 0.23 is recommended. Consequently, ESAC has a higher compressive strength due to the combined effects of a lower water binder ratio, a minimal inter-particle spacing, and a better reactivity of supplemental cementitious ingredients. It has been noted that the me-chemical impacts of heterogeneity in ESAC are lessened when the coarse aggregate is removed. Based on the obtained results, microstructural investigation should be conducted in the future stage to examine the efficacy of employing the packing density model to enhance ESAC performance. Here, the idea of filler technology is to be integrated with fibers, nanomaterials, and waste reutilization in order to improve the ESAC's performance in addition to increasing the particle density of the paste and aggregate phases. In order to promote the concrete's environmental sustainability, the new updated ESAC will reduce the cement content.

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Authors Contribution Statement

Both the authors equally contributed to the Conceptualization, Methodology, Investigation, Validation, Formal analysis, Data Curation, Writing - Original Draft and Writing - Review & Editing. The final manuscript has been read and approved by all authors.

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Competing Interests

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Has this article screened for similarity?

Yes

Data Availability

The data supporting the findings of this study can be obtained from the corresponding author upon reasonable request.

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