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EFFECT OF WASTE NAPHTHALENE SLUDGE ON WORKABILITY AND STRENGTH OF MORTAR AND CONCRETE

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Abstract:

The increasing population and modern lifestyle demand have caused the increase in waste sludge production gradually at the same time causing environmental pollution. Thus, the idea of reusing this waste sludge emerges as an alternative way of reusing it to create a product instead of disposing it. The Naphthalene sludge, a by-product obtained from the production of superplasticizer, also known as concrete admixture, is used in this study as an additive in concrete. Concrete was produced with 0%, 1%, 2% and 3% additive of the naphthalene sludge and the workability and strength of mortar and concrete were studied to investigate the effect of the waste sludge on concrete. Samples for compressive strength test were prepared with fixed water-cement (w/c) ratio of 0.50 and cured for 7 and 28 days. The results showed an increase of concrete and mortar strength when the waste sludge addition is increased. 3% of Naphthalene sludge additive shows the highest concrete strength based on the 28 days strength and obtained the best workability among the control sample and the other 1% and 2% of additive. By adopting sustainable practices in waste management and innovation can mitigate adverse impacts while supporting global sustainability development goals (SDG) 2030.

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Introduction

In regard to the technological upswing having to cope with the modern lifestyle together with the increasing of population has caused a rise of waste being generated that comes from multiple sources leading to waste disposal crisis (Batayneh et al., 2007; Lim et al., 2018). This is an alarming issue which requires proper attention and remedies in align with having a reduction of waste generation in order to grant positive impacts towards the environment. Thus, the element sustainable development in the construction industry is introduced. Innovative and unconventional approaches are needed to achieve sustainable development in construction industry mainly the concrete industry (Hrabova et al., 2020).

Concrete is one of the materials that are being produced largely due to its demand, and it is placed second in the world as the most produced material (Bamigboye et al., 2022). Concrete is a mixture consisting of cement, water, fine and coarse aggregates (Bamigboye et al., 2022). Thus, the need to mine for those components are made to fulfil the ingredient of concrete. The concrete industry faces a myriad of challenges, with one significant issue in particular giving massive environmental impact associated with natural aggregates obtained through conventional mining processes, which also tend to be quite costly (Assi et al., 2018). Taking into account the impact it causes towards the environment and considering the cost needed to acquire these natural aggregates, new ways and methods are to be created to solve this dilemma.

Alternative aggregates that may be employed in concrete production while being environmentally friendly are potential options (Lehner et al., 2022). As reported by the global cement and concrete association, the global production figures for 2020 indicate the manufacture of 14 billion m^3 of concrete and 4.2 billion tons of cement. Cement, which is used as a crucial element in concrete, contributes significantly to the carbon footprint where the manufacturing process entails substantial utilization of raw materials and energy, leading to emissions of greenhouse gas (Teker et al., 2023). The consideration and implementation of reusing waste materials in mortar and concrete had been going on for a few decades now since sustainability element were emphasized on. Some common examples include fly ash, slag, recycled aggregates, silica fume, waste sludges and paper sludges. Sekar et al., (2023) mentioned the incorporation of industrial wastes like glass powder, eggshell powder, fly ash and rice husk into concrete, serving as partial replacements for cement, can contribute to a reduction in CO2 emissions. Naphthalene sludge is a by-product generated from the production of naphthalene-based compounds, commonly used as a superplasticizer to improve the concrete workability (Elsa, 2022; Xin et al., 2023) Workability is crucial for concrete placement and compaction processes (Yu et al., 2019; Anthony et al., 2020). Traditionally, disposal methods

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for naphthalene sludge have posed environmental challenges due to its chemical composition and potential hazards if not handled properly (Lim et al., 2018; Ju et al., 2021; Wu et al., 2021). This study aims to explore the potential benefits and impacts of using waste naphthalene sludge in concrete production, focusing on its effects on concrete properties such as workability, strength development, and overall performance.

Methodology

Sample Preparation

The waste Naphthalene sludge (NS) used in this study is generated from the production of concrete admixture from local concrete admixture company, Malaysia. It is originally in a sludge (in Figure 1) form which is later oven dried for 24 hours and then later crushed into powder which will be used in concrete to investigate its effects.

The cement used is an Ordinary Portland Cement (OPC) of CEM I 42.5N which complies with MS EN 197-1:2014 CEM I 42.5N standards which are stored in a proper container for good protection. The fine aggregate used was based on natural river sand that fulfills all the requirements of fine aggregate while the coarse aggregate used a crushed aggregate from quarry industry which were later washed to remove unwanted particles and then dried. Clean tap water that does not contain unwanted materials that might affect the hydration process are used.

Figure 1: Waste Naphthalene Sludge

Properties Determination

The chemical and physical properties of the waste naphthalene sludge were first determined using the XRD analysis to obtain the chemical composition (in Table 1 and Figure 2). The XRD analysis results show that the waste Naphthalene sludge in powder form only contains Disodium sulphate elements. This made the incorporation of this waste into concrete possible as it does not contain any unwanted elements such as heavy metals or elements that show toxic behaviour that may cause environmental issues in the future. This chemical composition test is the first test that was done before making any plans of using it in concrete. The particle size distribution (in Figure 3 and 4) to get fundamental materials characteristic in concrete.

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The particle size distribution and chemical properties of the waste Naphthalene sludge when compared to the OPC cement suggests that it is unable to be used as cement replacement as the size does not match of that OPC cement and the chemical properties is not similar too, thus the reason it is suggested to be used as an additive in concrete. Once the role has been decided as to make the waste sludge an additive in concrete, laboratory planning work was carried out. This includes material preparation which leads to mixing and batching, slump test was done to get the workability and later cast into concrete mould. The concrete cubes were later demoulded after 24 hours and then cured in the curing tank for 7 days and 28 days for compression test. Analysis of results are done after that to conclude the effects of this waste Naphthalene sludge in concrete.

Table 1: Chemical Composition of Waste NS and OPC

Chemical components weight, %	**OPC**	**NS**
C_3S	70%	-
C_2S	12%	-
C_3A	5%	-
C_4AF	10%	-
$NA_2 (SO_4)$ Disodium Sulphate	-	100

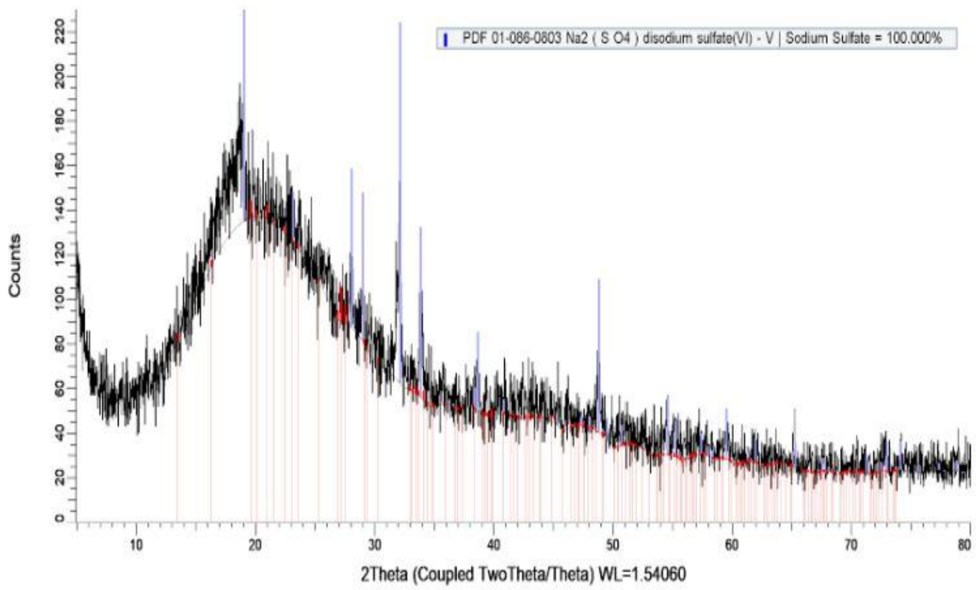

Figure 2: XRD Analysis on Chemical Composition of Waste Naphthalene Sludge

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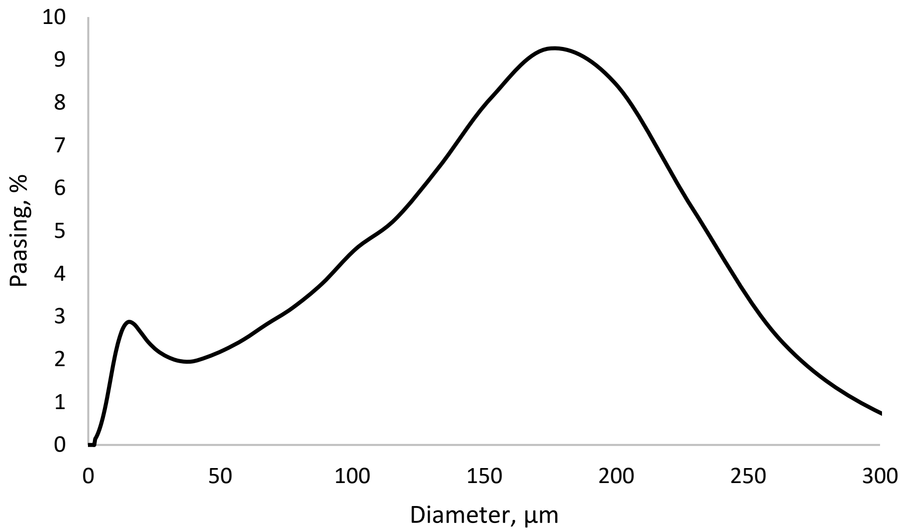

Figure 3: Particle Size Distribution of Waste Naphthalene Sludge

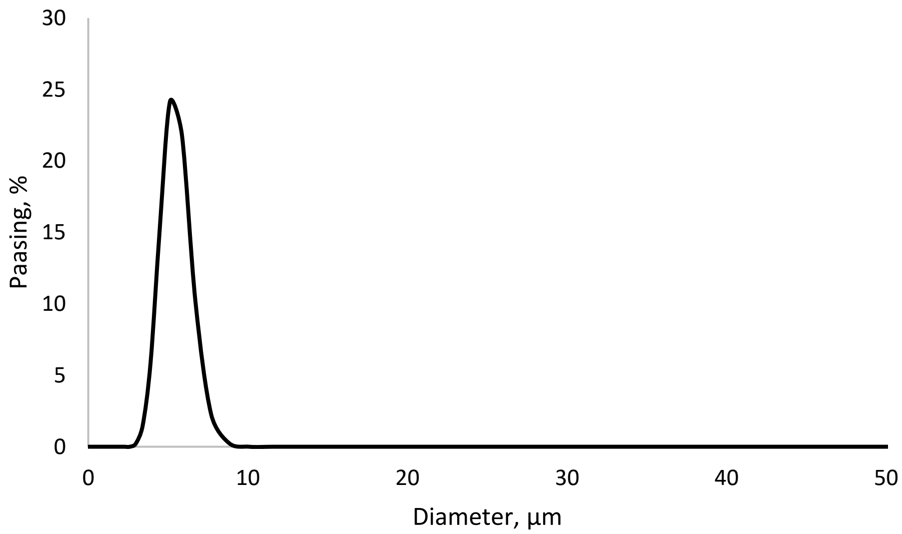

Figure 4: Particle Size Distribution of OPC Cement

Concrete Mix Design

The mix design (in Table 2 and 3) used was based on the Department of Environment, DOE method for normal concrete strength of 30 MPa. Water cement ratio of 0.5 is used in this study. The percentage of additives of waste naphthalene sludge are 0% as the control sample, 1%, 2% and 3% were batched respectively and obtained desirable workability (ASTM International, 2012)

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Table 2: Mix Design for Mortar Sample

OPC Cement	Water	Fine aggregate	Coarse aggregate	Naphthalene sludge, %
380kg/m^3	190kg/m^3	820kg/m^3	0	0%
380kg/m^3	190kg/m^3	820kg/m^3	0	1%
380kg/m^3	190kg/m^3	820kg/m^3	0	2%
380kg/m^3	190kg/m^3	820kg/m^3	0	3%

Table 3. Mix Design for Concrete Sample

OPC Cement	Water	Fine aggregate	Coarse aggregate	Naphthalene sludge, %
380kg/m^3	190kg/m^3	820kg/m^3	965kg/m^3	0%
380kg/m^3	190kg/m^3	820kg/m^3	965kg/m^3	1%
380kg/m^3	190kg/m^3	820kg/m^3	965kg/m^3	2%
380kg/m^3	190kg/m^3	820kg/m^3	965kg/m^3	3%

Mechanical Testing and Sampling

After the mixing process of the concrete in the mixer, concrete cubes of 100 mm size were cast in cube molds that were applied oil which later put on the vibration table for compaction purpose to obtain compressive strength (ASTM International, 2009). 6 cubes of each sample were batched and cast and cured for 7 and 28 days (in Figure 5 and 6).

Figure 5: Casting of Concrete Cube Sample

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(a) (b)

Figure 6: Compression Strength Testing of (a) 50 mm Mortar Sample (b) 100 mm Concrete Cube Sample.

Results

Workability

Figure 7 and 8 shows the slump test and slump values for all the batched samples. The increased workability observed with higher percentages of waste naphthalene sludge additive, as demonstrated by the slump test results (in Figure 8), is noteworthy. Notably, the batch with a 3% additive showed the highest workability among all samples tested. This correlation between workability and waste sludge percentage suggests that the sludge, derived from superplasticizer production, retains some of the superplasticizing properties, which enhance the workability of fresh concrete. This finding aligns with expectations regarding the behavior of such additives improving the workability in concrete production (Xin et al., 2023). The phenomenon of improved workability with waste naphthalene sludge additive can be attributed to several factors such as absorption capacity, surface area and fineness. Firstly, the sludge, derived from the production of superplasticizers, is inherently rich in chemical compounds that possess water-reducing and dispersing properties.

These properties are essential in concrete mixtures as they facilitate better particle dispersion, reduce water content without compromising hydration, and improve the overall cohesiveness of the mix (Lim et al., 2023; Wang et al., 2022). The superplasticizers are commonly used in concrete production to achieve high workability without increasing water content significantly. Therefore, the presence of residual superplasticizing properties in the waste naphthalene sludge aligns with the observed enhancement in workability. This retention of superplasticizing effects in the sludge is crucial for sustainable practices, as it signifies the potential for reusing industrial by-products effectively in construction applications (Ju et al., 2021; Wang et al., 2023).

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Figure 7: Slump Test on Fresh Concrete

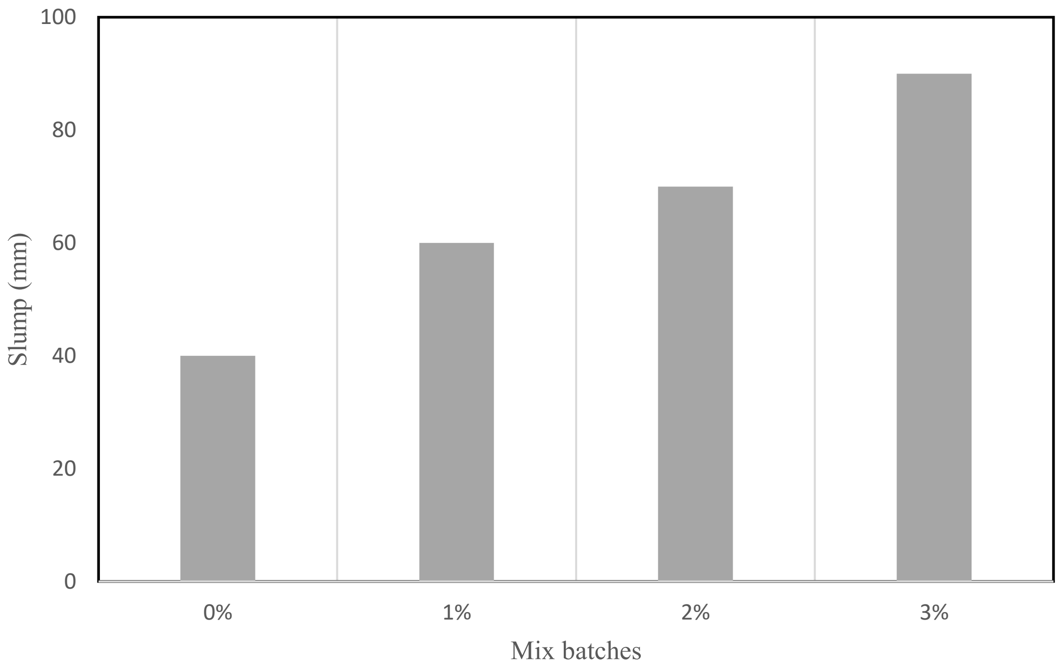

Figure 8: Slump Test on All Mix Batches

Compressive Strength

The compressive strength of construction materials like mortar and concrete is not only a fundamental property but also a critical indicator of their suitability for structural applications. In this study, the compressive strength assessments were conducted at key intervals of 7 days and 28 days after curing. These time points are significant in the construction industry as they

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reflect the early-age and mature-stage strengths of the materials, respectively, providing valuable insights into their performance over time.

As shown in Figure 9 and Figure 10, both mortar and concrete achieved consistent and notable increase in compressive strength as the percentage of waste naphthalene sludge additive is incrementally increased in both mortar and concrete samples. This trend underscores the positive influence of the additive on the mechanical properties of the materials, leading to enhanced strength parameters. Understanding the early-age strength development is crucial in construction projects as it directly impacts the initial load-bearing capacity of structures. Concrete typically exhibits about 65% of its characteristic strength by the 7th day of curing. In this study, based on a concrete grade of 30 MPa, the expected strength at 7 days would be around 24.7 MPa. It is noteworthy that except for the 1% batch, all other batches surpassed this 65% strength threshold at 7 days, highlighting the effectiveness of the waste naphthalene sludge additive in promoting early-age strength development. However, it is equally important to analyze the longer-term performance of the materials. At 28 days, concrete is expected to achieve its desired strength, typically reaching or exceeding its characteristic strength.

In this study, none of the concrete batches achieved the expected strength on the 28 days, indicating potential challenges or discrepancies in the curing and testing procedures. Factors such as variations in workmanship, errors during material preparation, suboptimal environmental conditions during curing, or even variations in material quality could contribute to these discrepancies. Despite not reaching the desired characteristic strength at 28 days, the 3% waste naphthalene sludge additive consistently exhibited the highest average strength compared to the control and lower percentage (1% and 2%) additive batches. This finding reinforces the additive's positive impact on long-term strength development, suggesting that with further optimization and refinement, achieving the desired strength levels within the specified curing period is feasible (Anthony et al., 2020; Chen et al., 2016).

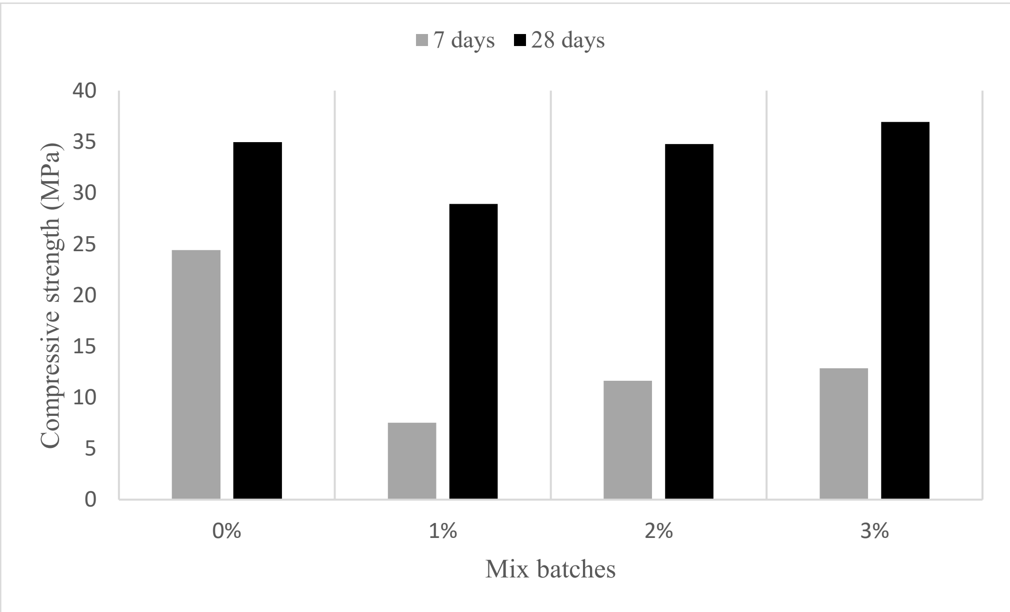

Figure 9: Compressive Strength of Mortar Samples for 7-day and 28-day

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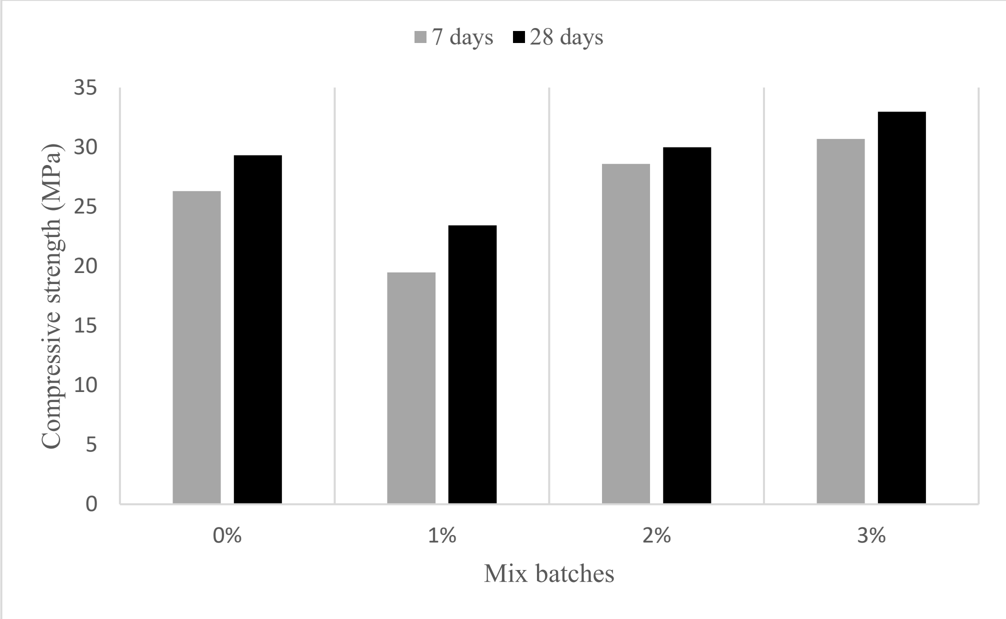

Figure 10: Compressive Strength of Concrete Samples for 7-day and 28-day

Conclusions

The addition of waste naphthalene sludge also shows an increase in workability in align with the increase of percentage used. The 3% of waste naphthalene sludge addition recorded a slump value of 90 mm which is the highest compared to the control sample which is 40 mm while 1% and 2% shows slump value of 60 mm and 70 mm respectively.

XRD analysis on the chemical composition of the waste naphthalene sludge shows that it contains 100% of disodium sulphate which is an inorganic compound and does not contain any other elements and free of any toxic or dangerous chemical content. While the particle size distribution of the waste sludge shows that it is finer than cement which later was decided to be made use as an additive in concrete instead of partial replacements of cement or sand.

Based on the compressive strength for both mortar and concrete, 3% of addition of waste naphthalene sludge also shows the highest compressive strength compared to control and the other 1% and 2%. There is a potential use for this waste sludge as it shows positive outcome in terms of workability and compressive strength in this research. Further research should be conducted using this waste sludge to conduct on the splitting tensile strength and flexural strength to investigate its capabilities fully.

Furthermore, considering the sustainability aspects of construction materials is increasingly important in modern engineering practices. Waste-derived additives such as naphthalene sludge offer not only technical benefits but also contribute to sustainable practices by repurposing industrial by-products. This aligns with global initiatives towards circular economy principles and resource efficiency in construction contributes to SDG 12- Responsible Consumption and Production by reducing waste generation and promoting circular economy principles.

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