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A STUDY ON THE UTILIZATION OF WASTEWATER TREATMENT SLUDGE IN THE CONSTRUCTION SECTOR

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ABSTRACT

Sewage sludge is a type of waste generated during the wastewater treatment process. If not properly disposed of, this waste can pose a risk to human health. This study explores the use of wastewater treatment sludge in the construction sector, with a focus on evaluating its impact on CO_2 emissions and its contribution to sustainability. The findings suggest that, following the calcination process, wastewater treatment sludge acquires pozzolanic properties, which enable its partial incorporation into cement and concrete production. Moreover, the incorporation of wastewater treatment sludge into cement and concrete will contribute to both the reduction of CO_2 emissions and the promotion of sustainability.

Keywords: Wastewater treatment sludge, CO_2 emissions, Sustainability.

ATIKSU ARITMA ÇAMURUNUN İNŞAAT SEKTÖRÜNDE KULLANIMI ÜZERİNE BİR ARAŞTIRMA

ÖZ

Kanalizasyon çamuru, atık su arıtma tesislerinde ayrıştırılan bir atık çeşididir. Bu atık malzeme düzgün bir şekilde bertaraf edilmezse insan sağlığına zarar verebilir. Atık su arıtma çamurunun inşaat sektöründe kullanımın araştırıldığı bu çalışmada, atık su arıtma çamurunun CO_2 emisyonuna etkisi ve sürdürülebilirliğe olan katkısının irdelenmesi amaçlanmıştır. Çalışmanın sonucunda, atık su arıtma çamurunun kalsinasyon süreci sonunda kül haline getirilmesi ile puzolanik özellik kazandığı ve çimento-beton üretiminde kısmen de olsa kullanılabileceği belirlenmiştir. Ayrıca atık su arıtma çamurunun çimento ve beton içerisinde değerlendirilmesiyle hem CO_2 emisyonlarının düşürülmesine hem de sürdürülebilirliğe katkı sağlanmış olunacaktır.

Anahtar kelimeler: Atık su arıtma çamuru, CO_2 emisyonu, Sürdürülebilirlik.

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1. Introduction

The increasing use of construction materials poses significant threats to natural resources and the environment [1]. It is well known that approximately 5-7% of CO_2 (carbon dioxide) emissions in the atmosphere are attributed to cement production [2]. In the case of widely consumed construction materials such as concrete and brick, attention should be focused on reducing consumption or finding substitute materials with lower greenhouse gas emissions per unit [1]. Consequently, researchers are actively exploring sustainable materials that can serve as alternatives to, or substitutes for, cement. Wastewater treatment sludge is one such alternative material. Wastewater treatment sludge can be directly used as a raw material in clinker production [3]. Additionally, ash generated from the incineration of wastewater treatment sludge can serve as a potential substitute for cement.

There are several significant studies in the literature regarding the use of wastewater treatment sludge in the construction industry. Pinarli and Kaymal [4] replaced 5%, 10%, 15%, and 20% of the cement weight with sewage sludge ash. Their findings indicated that an increase in the replacement ratio resulted in longer initial and final setting times. They also noted that the effects on Le Chatelier expansion and the specific surface area of the mortar were negligible. While the compressive strength decreased with the addition of sludge ash, a 10% replacement ratio still resulted in compressive and flexural strengths within the acceptable limits at 28 days. In their study, Lin et al. [5] added up to 3% nano-SiO_2 additive to mortar mixtures composed of Portland cement, sewage sludge ash, and fly ash. They found that the nano-SiO_2 additive improved the hydration of the mortar, thereby enhancing early strength development. Donatello and Chesseman [6] conducted a study on the recycling and recovery methods of sewage sludge ash. Their research concluded that approximately 1.7 million tons of sewage sludge ash are produced annually worldwide, a figure expected to rise in the future. They highlighted that utilizing this material as a raw material in applications such as cement mortars, concrete, sintered bricks, tiles, glass-ceramics, and paving stone production is the most effective disposal method. Chakraborty et al. [7] identified that the use of 70% sewage sludge ash, combined with 20% unslaked lime, 10% blast furnace slag, and an alkali activator (NaOH), is an effective technique for developing sustainable construction materials and improving waste management. Vouk et al. [8] conducted a study in which they obtained sewage sludge ash at three different combustion temperatures (800, 900, and 1000 °C). They found that the combustion temperature did not affect the fresh mortar properties, and the optimal combustion temperature for mechanical properties was 900 °C. Additionally, they stated that substituting up to 20% of cement with sewage sludge ash was a suitable value for their study. Oliva et al. [9] investigated the effects of different temperatures and calcination durations on the partial replacement of cement with sewage sludge ash in Portland and blended cements. They found that lower burning temperatures combined with longer calcination durations increased the specific surface area of the sewage sludge ash, positively influencing the mechanical performance of concrete through hydraulic and pozzolanic activity. Krejcirikova, Rode, et al. [10] found that as the amount of sewage sludge ash replaced with cement increased, the 28-day compressive strengths of the hardened mortars decreased. They also observed that replacing 30% of the cement with sewage sludge ash resulted in a 15% reduction in thermal conductivity, and as the cement-to-ash ratio decreased, the water vapor permeability increased. Zhou et al. [11] investigated the effects of adding sewage sludge ash to lime and Portland cement by incorporating 10%, 20%, and 30% by weight of sewage sludge ash. They produced lime, cement pastes containing sewage sludge ash, and observed that the lime pastes with sewage sludge ash exhibited higher reactivity and heat generation compared to the cement pastes. The study concluded that in lime-based systems, the development of strength was primarily governed by the formation of crystalline phases, including brucite and calcium phosphate hydrates. Additionally, they recommended the substitution of 30% lime for sewage sludge ash in the production of controlled low-strength materials. Cong et al. [12] suggested that to reduce the adverse effects of sewage sludge ash on cement hydration, drying and grinding the sewage sludge to a powder form and heating it in a microwave oven for 15 minutes was more beneficial than subjecting it to the same pre-treatment followed by calcination at 500 °C for 2 hours. Gu et al. [13] in their study found that using sulfate-rich sewage sludge ash as a cement replacement material negatively impacted workability, compressive strength, and flexural strength, delayed setting times, reduced autogenous shrinkage, and resulted in a longer drying shrinkage and greater expansion of the cement paste. However, they concluded that replacing up to 5% of cement with sulfate-rich sewage sludge ash did not cause significant detrimental effects on the properties of the cement paste. This substitution led to a 4.98% reduction in CO_2 emissions and a 25.42% reduction in cost. D. Pang et al. [14] investigated the physicochemical properties of different types of sludge. Based on their study, they concluded that utilizing wastewater treatment sludge as a substitute for raw materials

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and as an alternative fuel could lead to a reduction in carbon emissions of approximately 25 million tons annually. Huang et al. [15] produced glass ceramics by using waste glass and sewage sludge ash together. They reported that the resulting new product exhibited successful compressive strength and water absorption performance, as well as the ability to stabilize heavy metal leaching. Alrefaei et al. [16] improved the early-age performance of silico-alumino-phosphate geopolymer by using sewage sludge ash.

2. Material and Method

Wastewater from the sewage system is initially screened to remove large debris. In the second stage, heavy contaminants settle at the bottom, resulting in the formation of sludge. In the third stage, an aeration process is applied to eliminate bacteria [17]. Finally, the sludge is dried and compacted; making it suitable for utilization. Figure 1 presents an image of the dried wastewater treatment sludge.

Figure 1. Image of dried wastewater treatment sludge

The incineration of sewage sludge results in the production of a large amount (70% by mass and 90% by volume) of odorless, cellular, porous, and lightweight sewage sludge ash, which helps address an environmental issue [4,11,18]. The SEM image of sewage sludge ash [19] is presented in Figure 2, and its chemical properties [20] are provided in Table 1.

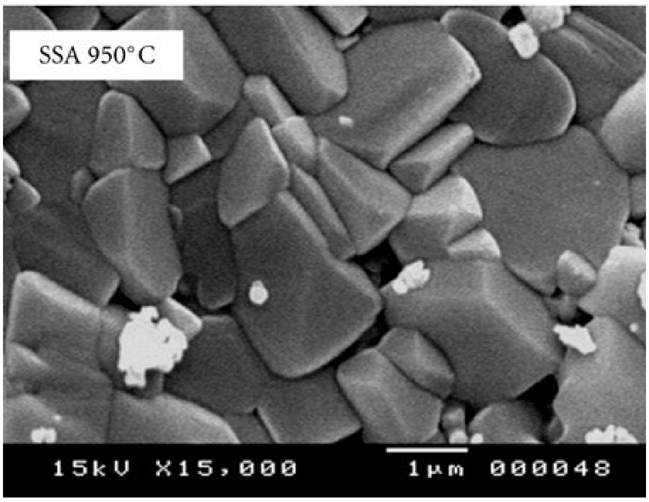

Figure 2. SEM image of sewage sludge ash

Table 1. Chemical composition of sewage sludge ash

Component	Al_2O_3	SiO_2	P_2O_5	Fe_2O_3	CaO	K_2O	Na_2O	MgO	TiO_2	SO_3
%	31.74	26.71	16.71	6.80	13.08	0.69	0.47	1.08	0.45	2.27

The particle size distribution of sewage sludge ash is similar to that of cement particles [9]. Moreover, the composition of silicon, calcium, aluminum, iron, and other elements in wastewater treatment sludge ash is similar to the composition of raw materials used for cement production [14].

Information on several significant studies regarding the use of wastewater treatment sludge ash as a cement replacement material is provided in Table 2.

Table 2. Information on some notable studies

Cement Type	Replacement ratio (%)	Calcination temperature (°C)	Paste / Mortar / Concrete/ Geopolymer	Reference
OPC	5-20	800	Mortar	[21]
CEM I 42,5 R	5-10	850	Concrete	[22]
Clinker	0-30	850-900	Mortar	[23]
OPC	0-40	800	Mortar	[24]
OPC	0-30	900	Concrete	[25]
CEM I	0-50	-	Paste	[26]
OPC	0-20	900	Concrete	[27]
OPC	0-20	Microwaved high temp.	Concrete	[28]
OPC	25-50	850	Mortar	[29]
CEM I 52,5 N	10-30	850	Mortar	[10]
CEM I 42,5 R	10-30	700	Mortar	[30]
OPC	0-30	-	Mortar	[31]
CEM I 42,5 R	10-20	-	Mortar	[32]
-	50	550-850	Geopolymer	[33]
CEM I 52,5 R	25-50	850	Mortar	[34]
CEM I 52,5	0-60	-	Mortar	[35]

Examining Table 2 reveals that a temperature range of 550-900°C is sufficient for wastewater treatment sludge to acquire pozzolanic properties through incineration. Additionally, it is noted that a microwave oven has been utilized for the calcination process. Although replacement ratios between 0-60% have been investigated, the optimal ratio is approximately 10% [23,35]. This phenomenon can be attributed to the ability of sewage sludge ash to effectively fill micro-voids up to a proportion of 10% [36].

3. Results and Discussion

Due to its high content of nitrogen (N), phosphorus (P), and potassium (K), sewage sludge is considered one of the most suitable materials for application to agricultural land. However, the disposal of sewage sludge on agricultural land is limited due to its potential to increase methane gas emissions and cause outbreaks of diseases such as foot-and-mouth disease [6]. In contrast, the use of wastewater treatment sludge ash in the cement and concrete industries contributes to reducing greenhouse gas emissions and preserving non-renewable natural resources [37]. Therefore, the most appropriate disposal method is to incinerate the sludge, converting it into ash, which can subsequently be utilized in cement and concrete production. In this context, the use of wastewater treatment sludge ash in concrete and cement results in:

- Environmental pollution is mitigated, supporting waste management efforts and promoting sustainability
- The durability of concrete in sulfate and acidic environments is improved.
- Due to its pozzolanic properties, the long-term strength of concrete increases.
- The workability of fresh concrete improves.
- The unit weight of concrete decreases.

Along with the positive aspects of using sewage sludge ash in concrete and cement, it is also important to consider the potential negative aspects. Specifically, research focused on improving its adverse effects on mechanical performance is necessary. Such studies will make the use of sewage sludge ash in concrete and cement production more efficient. As a result, utilizing sewage sludge ash will contribute to sustainability in the construction sector.

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