SSRG International Journal of Civil Engineering
ISSN: 2348-8352/ https://doi.org/10.14445/23488352/IJCE-V11I12P106

Volume 11 Issue 12, 64-68, December 2024

Review Article

Biomedical Waste Utilization in Soil Stabilization: Merging Waste Management and Sustainable Engineering

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Received: 10 October 2024 Revised: 13 November 2024 Accepted: 29 November 2024 Published: 26 December 2024

Abstract *- In today's rapidly advancing healthcare sector, the increasing generation of medical waste has become a critical environmental concern. If not properly managed, medical waste, including used syringes, nitrile gloves, bandages, plastics, face masks, expired medications, and more, poses significant environmental risks by contaminating soil, water bodies, and air. Traditional disposal methods, such as incineration, autoclaving, microwave, and chemical treatments, have limitations, with by-products like ash still requiring disposal. A potential solution is the innovative use of medical waste for soil stabilization, which strengthens and stabilizes weak soils and reduces the quantity of waste entering the environment, contributing to sustainability. This paper discusses stabilizing different soil types with various types of medical waste. To evaluate the engineering benefits of using medical waste in soil stabilization, the study is based on the following parameters: Optimum Moisture Content (OMC), Maximum Dry Density (MDD), Unconfined Compressive Strength (UCS), and California Bearing Ratio (CBR). This promotes sustainable construction practices while simultaneously addressing global waste management challenges, thus paving the way for an environmentally responsible solution to medical waste disposal.*

Keywords *- CBR, Expansive soils, Medical wastes, Soil stabilization, UCS.*

1. Introduction

Medical waste is the most critical aspect of healthcare operations, and it can be described as a product of waste materials from numerous healthcare facilities and related activities. It includes many products, such as disposed of syringes, contaminated dressings, expired medications, and radioactive substances, all of which can become significant health and environmental hazards if not properly managed. Medical waste includes infectious waste, such as used needles and tissues; hazardous waste, such as chemicals and pharmaceuticals; radioactive waste, such as radiopharmaceuticals; and general non-hazardous waste, such as packaging materials. Soil stabilization is the process through which the engineering qualities of soil are improved for use in building and other purposes. In order to ensure that constructions on or with soil have stability and durability, this procedure is critical to civil engineering and construction. Some common soil types that need stabilization due to their inherent properties are cohesive soils (Clay), which have small particles that can retain water and become highly plastic when wet. This makes them susceptible to swelling when wet and shrinking when dry, causing significant changes in volume. Granular Soils (Sand): Granular soils like sand are typically well-draining but may lack cohesion, making them prone to erosion and settling. Silt: Silt soils fall between clay and sand regarding particle size. They can be susceptible to erosion and compaction issues. Organic Soils (Peat and Muck): Soils like peat and muck contain significant organic matter. They have very poor load-bearing capacity and can compress over time. Expansive Soils: Expansive soils, like those containing a high percentage of montmorillonite clay minerals. These soils can cause structural damage to foundations and roads. Loess Soils: Loess soils are wind-deposited, fine-grained sediments susceptible to erosion.

Medical waste management has emerged as a major global challenge, especially following the unprecedented increase in healthcare waste during crises such as the COVID-19 pandemic. While there are numerous techniques for soil stabilization in civil engineering, the possibility of using treated medical waste as a soil stabilizing agent presents an unexplored frontier in sustainable construction. Despite the growing volume of research in waste management and soil stabilization, an enormous gap exists in this understanding: properly disinfected and treated medical waste could serve as a viable soil stabilizer while addressing waste disposal issues. This makes the need for innovative solutions to address the environmental and health risks associated with improper medical waste handling and the construction industry's need for cost-effective and sustainable soil stabilization methods more urgent.

This review examines the feasibility of including treated medical waste as a soil stabilizing agent in sustainable civil engineering applications. It discusses methodologies for safely utilizing medical waste by analyzing its environmental and engineering challenges and diverse soil conditions. These findings contribute to quicker, more environmentally responsible construction practices while providing an available solution to the widespread concern of medical waste.

2. Sterilization of Medical Wastes

Medical waste can be sterilized by various methods like incineration, autoclaving (steam sterilization), chemical disinfection, etc., to render it safe before final disposal or reuse. Some of the common and feasible medical wastes used by the researchers were face masks, nitrile gloves, Bio-Medical waste incinerator ash, syringe powder, etc. (Kishore 2021) sterilized the non-hazardous ground waste at a temperature of 93.3 degrees Celsius and mixed with black cotton soil to stabilize it. (Zhu 2022) suggested that an interlaced approach was crucial to minimize the waste generated during the COVID-19 pandemic. This is why they used disposable nitrile gloves during their investigation. Isolation with dry heat was done to sterilize and disinfect the gloves. After being left for 96 hours in a sealed container, the gloves were washed with soap and hot water and then sun-dried. Another promising waste disposal method is using biomedical waste incinerator ash from an incinerator center in Adami, Ethiopia (Tseganeh 2021).

3. Type and Proportion of Wastes

The size and the number of wastes used for stabilizing soil play a remarkable role in the properties of stabilized soil (Singh 2021). (Purohit 2018) Mixed syringe powder of 2%, 4%, 6% and 8% into the black cotton soil reduced the plasticity index and enhanced its properties. Similarly (Kishore 2021) added syringe powder and medicine wrappers in the proportions of 3%, 5%, 7% and 9%. Only the syringe powder addition done by (Purohit 2018) suggested an optimum value of 4%, while a mixture of syringe powder and medicine wrappers (Kishore 2021) concluded with an optimum content between 5 and 7%. When it comes to non-powder wastes like gloves, face masks, plastics, etc., the size of the additive also plays a crucial role. (Wang 2022) cut the nitrile gloves and protective clothing into 1.5, 3, 3.5 cm long and 0.5 cm wide, respectively.

Further, the researchers mixed both the wastes in different proportions, gloves in 0.5%, 1%, and 1.5%, while protective clothing in 0.25%, 0.5%, 0.75% and 1% to stabilize the silty sand. (Rehman 2021) worked on stabilizing the fat clay using the face mask (4%, 8%,12% and 16%) as fibre reinforcement and silica fume (0.3%, 0.6%, 0.9% and 1.2%) as the cementitious additive. (Zhu 2022) used 1cm wide and 2cm long strips of shredded nitrile gloves to stabilize the black cotton soil. Adding gloves to the soil resulted in enhanced flexibility as well as ductility of the soil. (Abdullah 2021) shredded healthy personnel protective clothing of maximum size 0.5 cm width and 2 cm length with a percentage of 0.5%, 1% and 1.5% to stabilize the silty sand of Najran.

4. Environmental Impact Analysis

Using medical waste in soil stabilization has posed many environmental and health-related problems due to the likelihood of toxic leachates in the surrounding ecosystem. Medical wastes contain hazardous contents such as heavy metals, pathogens, and organic compounds. These contents may eventually contaminate the groundwater by dissolving in the soil over time. The leachates change the chemistry of the soil, making its fertility and microbial diversity lose their importance in maintaining the ecological balance. Long-term exposure to such contaminants in groundwater can significantly affect human and wildlife health through toxicity, bioaccumulation of harmful metals, and the spread of antibiotic-resistant bacteria. Moreover, POPs in medical wastes may interfere with endocrine systems in both terrestrial and aquatic organisms. Appropriate pre-treatment methods, integrated risk analyses, and harsh regulations have to be imposed in order to diminish this risk for the proper consumption of medical waste in the field of geo-technology (Zhu 2022), (Kishore 2021), (Tseganeh 2021), (Wang 2022), (Rehman 2021).

5. Analysis of the Findings from the Literature Review

5.1. Compaction Characteristics

Adding a stabilizer to the soil leads to variation in the compaction results, i.e., OMC and MDD. Stabilization can sometimes increase the OMC, making it easier to achieve proper compaction, especially for low-plasticity soils. In some cases, stabilization may reduce OMC, which can help reduce susceptibility to swelling and shrinkage in expansive soils. Stabilization should generally increase MDD, indicating improved compaction characteristics, reduced settlement, and increased load-bearing capacity. In rare cases, stabilization might lower MDD. (Kishore 2021) found that with the rise in Biomedical waste powder, the OMC kept decreasing while MDD increased to 9% of the additive and then stopped increasing. This contrasts with (Tseganeh 2021), where adding biomedical incinerator ash increased the OMC and decreased the MDD. The increase in water content was due to replacing clayey soil with ash, a finer and pozzolanic reaction.

However, density was reduced due to the lower ash density than the soil. By increasing the shredded nitrile gloves content, the OMC and MDD decreased. This was said to be due to the low water absorption and low specific gravity of shredded nitrile gloves compared to expansive clay (Zhu 2022). While (Abdullah 2021) saw a reduction in MDD and an increase in OMC due to the addition of percentages of healthy personal protective material with the waste materials that possess low water absorption capacity and low specific gravity. (Rehman 2021) stated that there was a slight increase in the OMC when silica fume and face masks were added. With silica fume from 0% to 12% and face mask from 0 to 1.2%, the OMC increased by approximately 8 and 9%, respectively, while there was a reduction in the MDD.

5.2. Unconfined Compressive Strength

Soil stabilization can significantly impact the strength of the soil. Almost all the researchers who worked on soil stabilization using biomedical waste performed the UCS test. When the syringe powder was mixed with the black cotton soil, the maximum compressive strength was attained at 4% syringe powder, which increased the strength by approximately 100% compared to the unmixed soil (Purohit 2018). Similarly (Kishore 2021) also obtained the maximum UCS value at 5% biomedical waste ash (syringes and medicine wrappers), after which it decreased.

The addition of healthy personal protective clothing in the Najran's soil proved effective, where the optimum value of the UCS was obtained, and the change in the UCS value concerning different proportions of the additive. (Abdullah 2021) observed the maximum rise in UCS value with the addition of 0.5% (Tseganeh 2021) and found the optimum UCS value with the addition of 9% bio medical incinerator ash.

To further enhance the strength, they added hydrated lime in a proportion of 2% and 3% to the uncured as well as a 7 7-day cured mixture of expansive soil and 9% ash. The UCS was increased by 13.5% and 16.7% when mixed with 2% and 3% hydrated lime, respectively. Singh (2021) established that with the addition of 18% of Paris's waste plaster, the unconfined compressive strength attained its peak value of 2.84 kg/cm2. It was established that clayey soil amended with waste plaster of Paris increased the shear strength of the soil. (Gaikwad 2023) added RBI grade-81 and a single-use face mask to black cotton soil to improve its compressive strength. The black cotton soil mixed with 2% RBI Grade-81 was observed to have the highest UCS value. Meanwhile, 0.8% had the maximum UCS value for the face masks. For the mixture of both the additives, 8% RBI Grade-81 and 0.8% face mask had the highest UCS value.

Adding 1% shredded nitrile gloves to the clayey soil enhanced its properties, such as ductility and flexibility, due to its high tensile strength. However, higher inclusions reduced the ductility and flexibility, as shredded gloves started stacking on top of one another (Zhu 2022). (Zhu 2022) The fibres of the gloves act as a reinforcement to bind the soil together, decreasing the intensity of cracks compared to plain clayey soil. These shredded gloves created a bridging effect due to which only small cracks can be witnessed in the mixture soil. The addition of Plaster of Paris kiln dust to the dispersive clayey soil had a huge enhancement in the strength of the soil, increasing the UCS value by 875% with the addition of 3% Plaster of Paris kiln dust after 60 days (Fatima 2013).

5.3. California Bearing Ratio

CBR test is a fundamental part of pavement design and evaluation. It helps engineers assess the capacity of the soil to bear any load on top of it, which is crucial for designing and constructing roads, highways, airports, etc. The unsoaked CBR values increased when 1% shredded nitrile gloves were added to the soil. This was because of the texture of the gloves, which gave rise to internal friction (Zhu, 2022). 1% of shredded nitrile gloves reduced the subgrade thickness by about 8%, which will aid in the reduction of the construction cost and contribute to sustainable road construction.

Similarly, (Abdullah 2021) also added healthy personal protective material to the soil sample of Najran. There was an increase in the CBR value from 23% to 30% when 0.5% of the stabilizer was added. A decline was noticed when it reached 1%, in which CBR decreased from 30% to 8%. Meanwhile, the addition of powder substances like biomedical ash up to 7% led to an increase in CBR value, after which it gradually started decreasing (Kishore 2021). (Tseganeh 2021) also investigated the addition of biomedical waste incinerator ash in expansive soil and found an increase in the CBR value by 121.74% when the soil was mixed with 9% ash. They found that soil stabilized with 9 % biomedical waste ash and amended with 2% and 3% lime as a subgrade material was suitable for road construction. (Singh 2021) proposed that incorporating 18% waste Plaster of Paris and 6% groundnut shell into the clayey soil provides the highest soaked CBR value in the range of 3.82 and 11.52.

5.4. Scanning Electron Microscope (SEM)

A SEM test is a technique that has been scientifically proven to provide high-resolution surface images of any sample using an electron-focused beam. It provides such an examination in great detail about composition and topography. Because SEM has been used in analyzing many samples from magnification 10 times up to 100,000 times, it is used for applications in diverse scientific disciplines such as materials science, biology, geology, and nanotechnology, among many others. Untreated expansive soil particles have low bonding ability and interlock significantly, much less. Thus, it resulted in a layered structure, as shown by (Tseganeh 2021).

Adding lime and ash from burning biomedical waste to soil increased the bonding. This was mainly because the positively charged additives would attract the negatively charged ions of the soil. (Tseganeh 2021) also stated that the amendment led to the formation of homogeneous particles due to the formation of cementitious compounds. (Zhu 2022) stated that the plain clay soil consists of large pores, which reduces its strength, and when water is added, it is absorbed into these pores, making it more unsuitable for construction work. It was observed by (Zhu 2022) that when the shredded nitrile gloves were amended with the soil, the clay particles attracted towards the small pieces of gloves, enhancing the bond. The rough texture of the gloves also helped increase the overall strength of the soil.

6. Critical Summary

Based on all the literature reviewed, the following conclusions can be made:

1) With the increase in the global population, the proper treatment and disposal of bio-medical wastes have become the need of the hour. Especially due to the

unfortunate phase of the COVID-19 pandemic, increasing waste by almost double the previously generated amount. Biomedical waste, when used as an additive for stabilizing soil in the right manner, will not only strengthen the soil but also help reduce the amount of medical waste produced daily at an enormous rate.

2) The amount of waste to be incorporated in the parent soil was found to be an essential factor to obtain the maximum benefit. Studies showed that powdered biomedical wastes like incinerator ash, syringe powder, etc, required a higher proportion (usually 5%-10%). In contrast, wastes like gloves, clothing materials, and face masks required a lesser percentage (usually 0.5- 1.5%) as the increase in proportion may stack the additives on top of each other, reducing strength.
3) When shredded and amended with the soil, waste materials such as nitrile gloves helped increase their ductility and flexibility due to their stretchable property. It also increased the UCS and CBR value due to its rough texture, making it suitable for road construction as a subgrade component.
4) Ash and syringe powder from burned medical wastes improved the strength of clayey soil and reduced its ductility. The structures flocculated by bond formation between negatively charged clay surfaces and cations in the ash were thought to be the origin of this result. Therefore, it may substitute expensive additives such as fly ash, cement, and silica fume to a considerable extent, thus making the process cost-effective and environment-friendly.
5) The swelling potential of the clay is a very important factor affecting its strength and stability. More than a 50% reduction in the free-swell index was observed with the amendment of bio-medical waste ash.
6) The size of the waste additives had a huge role in altering the characteristics of the soil when it comes to non-powdered waste. The most preferred sizes were 0.5-1 cm wide and 1-3 cm long for wastes like nitrile gloves, face masks, protective clothing, etc.
7) Adding a slight amount of lime with other additives led to the formation of a cementitious compound, resulting in a homogenous unit.
8) The SEM analysis done by various researchers proved that additives in the soil led to flocculation in the soil mass, increasing the bonding and strength of the soil.

These points verify that biomedical waste as a soil stabilizer can be very effective and a massive step towards the cleanliness and sustainability of the environment when amended with the soil in the correct proportion. However, most of the works in this field were found to be based on clayey soil. Therefore, further research can be done by considering other types of weak soils, like silty sand, peat, loess, etc., to have a broader perspective on the subject.

Acknowledgement

First, we would like to thank the International Journal of Civil Engineering (IJCE) for the opportunity to publish our review. In addition, we would also like to express our sincerest thanks to all the authors whose work has been reviewed for this study for allowing us to use their work. Further, we thank our mentor, Dr Ajanta Kalita, for her helpful and wise advice while executing this project. We wish to express our sincere gratitude to all committee members for their precious time and energy spent reading the article.

Funding

The authors declare that no funds, grants, or other support were obtained to prepare this paper.

Author Contributions

All the authors contributed to the successful completion of this work. Dr Ajanta Kalita and Ms Pem Yangchin spearheaded the review paper's conceptualization, outlining the review's scope, objectives, and structure. Mr Jeelek Rigia completed the final draft for the review paper before submission. Dr Ajanta Kalita assisted in finalizing the submission and ensuring that it met academic standards and formatting guidelines before submission.

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