WEP Warwick Evans Publishing

International Journal of Natural Resources and Environmental Studies

ISSN: 3006-2012 (Print), ISSN: 3006-0834 (Online) | Volume 5, Number 1, Year 2025
DOI: https://doi.org/10.62051/ijnres.v5n1.08
Journal homepage: https://wepub.org/index.php/IJNRES/index

Application of Solid Waste Artificial Substrate Improvement Technology in Mine Ecological Restoration

Na Wang[2, 3, *], Weiwei Chen[2, 3], Longfei Xia[1, 2, 3]

[1]Technology Innovation Center for Land Engineering and Human Settlements, Shaanxi Land Engineering Construction Group Co, Ltd and Xi'an Jiaotong University, Xi'an 710049, China;

[2]Institute of Land Engineering and Technology, Shaanxi Provincial Land Engineering Construction Group Co., Ltd., Xi'an 710075, China;

[3]Key Laboratory of Degraded and Unused Land Consolidation Engineering, the Ministry of Natural Resources, Xi'an 710075, China.

*Corresponding Author: Na0113@126.com

ABSTRACT

Soil degradation is one of the main challenges affecting the success of ecological restoration in mining areas. Mine soils often face issues such as nutrient depletion, acidification, and compaction, which hinder vegetation recovery and slow down the ecological restoration process. This paper reviews the basic composition of solid waste artificial substrates, compares the advantages and disadvantages of different types of solid waste and their applicable scopes, and discusses the application of solid waste artificial substrates in mine soil improvement. Furthermore, the development of solid waste artificial substrates is forecasted, aiming to provide solutions for the resource utilization of solid waste in mine ecological restoration.

KEYWORDS

Solid waste; Artificial substrate improvement; Mine ecological restoration; Soil improvement.

1. INT RODUCTION

The ecological damage caused by mining, especially soil degradation and vegetation loss, has become an urgent environmental issue globally. With the continuous extraction of mineral resources, many mining areas have suffered severe soil pollution and degradation, making vegetation restoration difficult and costly[1]. Traditional restoration methods face significant challenges. To reduce restoration costs and improve efficiency, the resource utilization of solid waste has garnered widespread attention from researchers in recent years. Solid waste (such as coal mine slag, smelting slag, construction waste, etc.) can be used as artificial substrate material for soil improvement in mining areas after proper treatment, enhancing the physical and chemical properties of the soil, thereby providing a more suitable environment for plant growth. Through solid waste amelioration technology, soil fertility, aeration, and water retention can be effectively improved, promoting the restoration of the mining area's ecosystem.

The application of solid waste artificial substrate improvement technology in mine ecological restoration not only achieves the resource utilization of waste but also effectively reduces the cost of mine restoration and promotes ecological recovery. Firstly, the disposal of solid waste is a common environmental challenge faced by mining regions. Traditional waste disposal methods often lead to secondary pollution, whereas resource utilization and amelioration of solid waste can effectively reduce the environmental burden of waste, aligning with the principles of circular economy and sustainable development[2]. Secondly, traditional methods of mine ecological restoration typically require large amounts of external resources (such as purchased soil, fertilizers, grass seeds, etc.), which are costly and complex[3]. In contrast, the resource utilization of solid waste can significantly reduce restoration costs. By transforming solid waste into artificial substrates, it not only reduces dependence on external resources during the restoration process but also improves soil quality and enhances its physical and chemical properties, allowing plants in the mining area to grow better and promoting the restoration of the mine ecosystem. Moreover, the application of solid waste artificial substrate improvement technology in mine ecological restoration helps accelerate the recovery of the ecological environment[4]. The substrates modified with solid waste can significantly improve soil fertility, aeration, and water retention, providing a better environment for plant growth and accelerating the rapid restoration of vegetation in mining areas. As vegetation recovers, the mining area's ecosystem gradually regains its functions, and biodiversity is restored. Therefore, studying the application of solid waste artificial substrate improvement technology in mine ecological restoration holds significant practical importance.

2. THE BASIC COMPOSITION OF SOLID WASTE ARTIFICIAL SUBSTRATE

The solid waste artificial substrate is a composite material used for soil improvement, made by rationally mixing various solid wastes (such as slag, construction waste, agricultural waste, etc.) with organic fertilizers, inorganic soil amendments, and other materials. Its main components include:

(1) **Slag and Smelting Waste**: Slag contains abundant minerals (such as calcium, magnesium, silicon, etc.), which can improve the soil structure, adjust the pH level of the soil, and provide essential mineral elements for plant growth.

(2) **Construction Waste and Industrial By-products**: These include discarded bricks, waste cement, waste plastics, etc. After treatment, these wastes can enhance soil aeration, looseness, and can be used to fill the gaps in the soil after mining, improving the physical structure of the soil.

(3) **Organic Waste**: This includes compost, agricultural and forestry waste, urban garbage, etc., which can increase the organic matter content of the soil, improve soil fertility, and enhance soil water retention capacity.

(4) **Inorganic Materials**: Such as expanded perlite and vermiculite, which have excellent drainage and aeration properties, helping to improve soil moisture management.

Table 1. Comparison of the Advantages and Disadvantages of Various Solid Waste Artificial Substrates

Types of Solid Waste	Advantages	Disadvantages	Scope of Use
Agricultural Waste	Rich in organic matter, it can effectively increase the organic matter content of the soil.	It may contain pathogenic microorganisms in the early stages and requires pretreatment.	Suitable for environments with poor soil and lack of organic matter in mining areas.
	Provides nutrients such as nitrogen, phosphorus, and potassium, promoting plant growth.	It may lead to excessive water retention in the soil, resulting in insufficient oxygen supply to the roots.	Suitable for the restoration of mining soils with poor water retention and low fertility.
	Improves soil structure, enhancing soil aeration and drainage.	Improper handling may lead to nutrient loss.	Suitable for improving mining soils using agricultural waste (such as straw, compost, farmland waste, etc.).
Construction Waste	Increases soil particle structure, improving soil aeration and drainage.	It may contain heavy metals or harmful substances and requires strict treatment.	Suitable for improving the poor drainage and aeration issues of mining soils.
	Increases soil mechanical strength and reduces soil compaction.	Substances in inorganic waste (such as cement, concrete) may have an inhibitory effect on plants.	Suitable for situations of soil acidification, salinization, or compaction in mining areas.
Industrial Waste (such as slag, waste cement, etc.)	It can improve the soil structure and increase porosity.	It may affect the soil's pH and requires careful control of the application rate.	Suitable for improving the structure and aeration of mining soils, ideal for areas with high slag content.
	Provides soil mineral nutrients, promoting root development in plants.	Some waste materials may cause soil heavy metal pollution, affecting plant growth.	Can be used for improving the physical structure of mining soils, especially for soil improvement with high mineral element content.
Organic Waste (such as compost, animal manure, etc.)	High organic matter content, significantly improving soil fertility.	It may produce odors or cause mosquito problems, requiring proper management.	Suitable for improving environments with insufficient organic matter in mining soils, promoting plant growth.
	Enhances soil biological activity, promoting the recovery of microbial communities.	It may lead to salt accumulation in the early stages, requiring careful attention to the ratio.	Suitable for the restoration of mining soils with poor water retention and severe nutrient loss.
Urban Waste (such as household waste, landscaping waste, etc.)	Rich in organic components, enhancing soil organic matter.	Requires sorting and processing to avoid contamination of the soil by harmful substances.	Suitable for resource recycling projects, especially land reclamation and soil restoration in mining areas.
	Improves soil permeability and water retention capacity.	Requires thorough composting or pretreatment to reduce pathogens and harmful substances.	Can be applied to urban mining, abandoned land reclamation, and areas with large amounts of urban waste.

3. APPLICATION OF SOLID WASTE ARTIFICIAL SUBSTRATE IN MINING SOIL IMPROVEMENT

3.1. The Role of Slag and Smelting Waste in Soil pH Regulation

The application of solid wastes such as slag and smelting waste can effectively regulate soil pH. In many mining areas, due to prolonged mining activities, the soil often becomes highly acidic and nutrient-poor. By adding slag to mining soils, the alkaline components in the slag can neutralize the soil's acidity and adjust the pH value, gradually bringing it to a neutral range suitable for plant growth. For example, certain metal smelting plant wastes are rich in lime components, which can significantly raise the soil's pH, thereby improving nutrient absorption and root growth conditions in the soil[5-6].

The alkaline oxides in slag and smelting waste (such as calcium oxide, CaO, and magnesium oxide, MgO) react with the acidic substances in the soil, producing hydrates and releasing hydroxide ions (OH^-). These hydroxide ions neutralize the hydrogen ions (H^+) in the soil, effectively increasing the soil pH.

The reaction is as follows:

$$CaO+H_2O \rightarrow Ca(OH)_2$$

$$Ca(OH)_2+2H^+ \rightarrow Ca^{2+}+2H_2O$$

This reaction significantly reduces the concentration of H+in the soil, thereby increasing the soil pH and achieving the goal of neutralizing the acidity.

3.2. Application of Construction Waste in Soil Structure Improvement in Mining Areas

Mining activities often lead to land exposure, loose soil structure, and poor water retention capacity. Construction waste (such as discarded bricks, waste cement, waste concrete, etc.), when crushed and mixed with other ameliorative materials (such as organic fertilizers, expanded perlite, etc.), can form a soil improvement substrate suitable for plant growth. While providing physical support to the soil, construction waste increases soil aeration and looseness, helping to improve soil drainage and preventing plant roots from being damaged due to waterlogging or lack of moisture.

3.3. The Role of Organic Waste in Supplementing Soil Organic Matter in Mining Areas

Mining activities and the accumulation of associated waste often lead to a significant decline in soil organic matter content in mining areas, resulting in soil degradation, poor plant growth, and severely hindering the progress of ecological restoration. Soil organic matter is not only a vital source of soil fertility but also directly affects key biological and physicochemical properties of the soil, such as its structure, aeration, water retention, and microbial activity. Therefore, supplementing and restoring soil organic matter is one of the core aspects of mining soil improvement and ecological restoration[7].In recent years, organic waste (such as agricultural waste, urban household waste, industrial organic waste, etc.) has been widely researched and applied for supplementing organic matter in mining soils due to its rich content of organic materials, nitrogen, phosphorus, potassium, and other plant nutrients. In mining soil restoration, the appropriate addition of organic waste can not only increase soil organic matter content but also improve the soil's physicochemical and biological properties, promote plant growth, and restore the ecological environment. Mining soils are typically deficient in organic matter, leading to poor water retention and root growth. Organic waste, such as compost, agricultural and forestry waste, and urban garbage, is rich in organic matter and can effectively increase the organic content in soil. By adding these organic wastes to mining soils, not only can soil water retention, fertility, and microbial activity be improved, but the structural stability of the soil can also be enhanced, aiding root growth and nutrient absorption by plants. For example, the application of compost in mining soils can increase the humus content, improving soil water retention and aeration. In a metal mining area in Liaoning Province, researchers conducted experiments on organic waste improvement in mining soils, using composted agricultural waste (such as straw and livestock manure) as an amendment. The results showed that after adding organic waste, the organic matter content in the mining area's soil significantly increased, soil water retention and aeration were improved, and plant growth showed significant improvement[8]. After two years, vegetation coverage in the mining area increased by 35%, and soil fertility was restored by over 30%.

3.4. Optimization of Water Retention and Drainage Capacity of Solid Waste Artificial Substrate

In mining soil improvement, water management is a critical issue. Solid waste artificial substrates can improve water resource management in mining areas by increasing the soil's water retention capacity. By properly blending materials such as expanded perlite and vermiculite, it is possible to ensure soil aeration while also enhancing water retention. This is particularly important for areas in mining regions that experience prolonged drought or excessive moisture during the rainy season. Studies have shown that amended mining soils can effectively improve water retention capacity, reduce water loss, and ensure plant growth requirements under various climate conditions.

The particle structure of solid waste is a key factor in optimizing both water retention and drainage capacity. Inorganic wastes such as slag, waste concrete, and discarded bricks have a large specific surface area and abundant microporous structures. These tiny pores not only store water but also ensure good drainage. The pore structure in the waste materials plays a dual role in both water retention and permeability, enabling effective moisture retention and discharge, and preventing excessive water accumulation or loss[9]. Solid waste with high porosity can store more water, but excessive porosity may lead to poor drainage. Appropriate porosity allows water to be stored in the substrate and released to plants when needed. Organic wastes (such as compost, straw, etc.) can increase the soil's specific surface area, thereby enhancing its water adsorption capacity. Water can remain on the surface of these organic materials for a longer period, reducing evaporation loss. The addition of solid waste, especially larger particle materials such as waste bricks and waste cement, can improve soil structure by enhancing soil aggregation. Aggregated soil particles create more micropore spaces, allowing for the proper distribution of water and air within the soil[10]. This mechanism helps to maintain moderate water retention and ensure effective drainage, avoiding waterlogging or drought conditions. By optimizing the particle size distribution of solid waste, it is possible to enhance soil water-air channels, promoting water infiltration and gas exchange, thus providing a more favorable growth environment for plant roots.

3.5. Plant Growth Promotion by Solid Waste Artificial Substrate

Mining soils typically lack macronutrients (such as nitrogen, phosphorus, and potassium) and micronutrients (such as zinc, copper, and iron) that are essential for plant growth, which directly limits plant development and ecological restoration. Solid waste, particularly organic waste (such as agricultural waste and animal manure), is rich in essential nutrients like nitrogen, phosphorus, and potassium. After composting, fermentation, and other treatments, these wastes release a large amount of nutrients that plants can absorb. For example, animal manure, straw, and urban waste contain abundant nitrogen, phosphorus, and potassium elements. When added to the soil, these elements are converted by microorganisms into forms that plants can directly absorb, promoting root growth and development. Additionally, the organic matter in solid waste, after decomposition in the soil, produces humus that can effectively enhance soil fertility and provide a stable nutrient supply to plants over the long term.

Soil microorganisms are an essential support system for plant growth, as they participate in processes such as organic matter decomposition, nutrient transformation, and disease suppression. Mining soils often lack organic matter, leading to a poor microbial community and low biological activity, which weakens the functions of the soil ecosystem. Organic matter in solid waste provides a rich carbon source for soil microorganisms, promoting the recovery and diversity of microbial communities. Studies have shown that solid waste (such as compost and humus) can significantly increase the number and activity of beneficial microorganisms (such as nitrogen-fixing bacteria and decomposers) in the soil. These microorganisms break down organic materials and release nutrients that plants can absorb. At the same time, microbial metabolic products (such as organic acids and amino acids) can improve soil pH, enhance nutrient utilization efficiency, and further promote plant growth[11].

Mining soils often face harsh environmental conditions such as water scarcity, salinization, and acidification, which place significant stress on plant growth. Solid waste, especially organic waste rich in humus, can improve soil moisture retention and alleviate soil salinization, thereby enhancing plant resistance. For example, humus can improve soil pH, maintaining it within a range suitable for plants; meanwhile, water-soluble substances in organic waste can regulate soil permeability, enhancing plant root absorption of water and helping plants grow better in dry or saline-alkali soils.

4. OUTLOOK

As the environmental impact of mining activities becomes increasingly significant, mine ecological restoration has become one of the key environmental protection tasks. Mining soils, due to long-term exposure to harsh conditions, often exhibit characteristics such as infertility, lack of organic matter, and imbalanced pH, which lead to difficulties in vegetation restoration and severe degradation of ecosystem functions. Traditional soil restoration methods, although improving soil quality to some extent, face challenges due to high costs, low efficiency, and the difficulty of achieving lasting effects. Therefore, there is an urgent need to explore more economical and sustainable restoration technologies. Solid waste artificial substrate improvement technology, as an innovative restoration method, is receiving increasing attention due to its advantages of resource utilization, eco-friendliness, and low cost.

(1) With the continuous advancement of waste resource utilization technologies, the pretreatment processes of solid waste will be further optimized, including more efficient composting, fermentation, and biodegradation technologies. These improvements will greatly enhance the fertility and stability of waste-based substrates, strengthening their role in soil improvement. At the same time, based on the specific problems of different mining soils, the types and proportions of solid waste will be more precisely tailored to create customized restoration solutions. For example, by accurately analyzing the pH, nutrient status, and moisture conditions of mining soils, suitable solid waste combinations can be selected to achieve the best soil improvement results.

(2) By regulating the rhizosphere microbial communities, solid waste substrates can improve the soil microbial environment, promote the proliferation and decomposition of beneficial microorganisms, which will further optimize the soil structure and promote plant growth. In the future, technologies such as remote sensing and artificial intelligence can be integrated to monitor and manage mine soils and plant growth in real time, achieving precise ecological restoration control and enhancing the efficiency and effectiveness of restoration efforts.

FUNDINGS

This work was supported by the Technology Innovation Center for Land Engineering and Human Settlements, Shaanxi Land Engineering Construction Group Co., Ltd. and Xi’an Jiaotong University (2024WHZ0244); the Young Talent Fund of Association for Science and Technology in Shaanxi, China(20240517); the Scientific Research Item of Shaanxi Provincial Land Engineering Construction Group (DJNY2024-25).

REFERENCES

[1] Li Jianhua, Wang Mingli, & Zhang Xiaohui. Research progress on soil remediation technology in mining areas. Ecology and Environmental Sciences, 2019,28(3), 315-321.

[2] Wang Jianhua, Chen Hongbin, & Zhou Jianguo. Study on the integration of solid waste resource utilization and mine ecological restoration. Resource Science, 2020,42(1), 85-93.

[3] Zhang Hua, Li Na, & Liu Wei. Utilization of solid waste in mine ecological restoration and its effects. Acta Pedologica Sinica, 2021,58(5), 1247-1254.

[4] Liu Wei, Wang Wenjun, & Zhao Pengfei. Research on mining ecological restoration technology based on solid waste. Journal of China University of Mining & Technology, 2020,49(6), 1132-1141.

[5] Li Li. The role of slag and smelting waste in regulating soil pH and their application in mine ecological restoration. Mine Environmental Protection, 2021,40(5), 42-47.

[6] Zhang Pengfei, Wang Tao, & Liu Haibo. Study on the role of smelting waste in mine soil improvement. Environmental Science and Technology, 2020,37(9), 120-125.

[7] Liu Haibo, Zhang Pengfei, & Wang Tao. Application of organic waste in mine soil improvement. Mine Environmental Protection, 2020,39(4), 53-58.

[8] Zhang Ming, Gao Peng. Application and practice of organic waste in mine soil improvement. Environmental Protection, 2021,44(7), 56-60.

[9] Wang Tao, Liu Haibo. Impact of organic waste on soil moisture retention. Transactions of the Chinese Society of Agricultural Engineering, 2021,37(10), 25-30.

[10] Xu Xiao Jie, Chen Jianhua. The role of solid waste in soil structure and water management. Ecology and Environmental Sciences, 2020,41(6), 1128-1135.

[11] Chen Jianhua, Xu Xiao Jie. The regulatory role of organic waste on soil pH and microbial community. Journal of Agricultural Environmental Sciences, 2021,39(3), 563-570.