



An Overview of Coal Gangue Resource Utilisation: A Brief Study

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

As a major solid waste, coal gangue not only occupies land but also pollutes groundwater and air, and even triggers geological disasters. Therefore, comprehensive resource utilization of coal gangue has received increasing attention. This paper analyzes research progress in backfilling treatment, extraction of valuable elements, improvement of agricultural production, development of sound-absorbing and noise-reducing ceramsite, manufacturing of building materials, and subgrade filling. It is proposed that efforts should be intensified in strengthening top-level design, enhancing pretreatment of coal gangue, extending industrial chains, fostering talent cultivation, and improving industrial policies to create an environment for harmless disposal and resource utilization of coal gangue.

Keywords: *Coal gangue; solid waste; resource utilization pathways.*

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1. INTRODUCTION

Coal gangue, a primary by-product of coal mining and washing, is mostly composed of mudstone or limestone with low carbon content and high hardness, making it difficult to burn alone and resulting in low utilization rates. Currently, coal gangue is mainly disposed of through open-air stacking, which causes issues such as farmland occupation, groundwater and air pollution, and geological hazards. As a critical solid waste requiring urgent disposal in mining areas, coal gangue accounts for over 40% of total mine solid waste emissions, becoming a focus of attention in the coal industry and society. With the advancement of modernization, large-scale operations, and intelligentization in coal mining, along with increasing exploitation of coal seams under harsh conditions, coal gangue emissions have been rising annually. In recent years, driven by the "dual carbon" strategic goals, coal gangue has been listed as a key bulk solid waste in the "14th Five-Year Plan" and its comprehensive disposal has gained greater emphasis. Statistics show that the cumulative stockpile of coal gangue in China exceeds 7 billion tons, occupying approximately 1.5 million hectares of land, with an annual increment of over 800 million tons (Li, 2024). In February 2024, the General Office of the State Council issued the Opinions on Accelerating the Construction of a Waste Recycling System (Guobanfa [2024] No. 7), specifying that by 2025, the annual utilization of bulk solid wastes such as tailings, fly ash, coal gangue, smelting slag, industrial by-product gypsum, construction waste, and straw should reach 4 billion tons, and the comprehensive utilization rate of newly generated bulk solid waste should reach 60% (Lan, 2024). Therefore, research on the comprehensive utilization of coal gangue holds significant social, environmental, and economic implications. This paper aims to summarize the latest developments in high-value utilization of coal gangue at home and abroad, providing references for its application in China.

2. PROPERTIES OF COAL GANGUE

2.1 Physical Properties

Coal gangue is a gray-black rock symbiotically occurring with coal seams (Luo, 2016). It has a lower carbon content than coal but higher hardness: sandstone-dominated gangue typically has a Mohs hardness of 4–5, while shale-dominated gangue ranges from 2–3. Classified as sedimentary rock, coal gangue is a mixture of

various minerals (Liu, 2013). Additionally, its moisture content is 20–25%, plasticity index 2.5–3.5, refractoriness 1250–1350°C, and viscosity approximately 1.1 (Sun et al., 2016).

2.2 Chemical Properties

Coal gangue is primarily composed of inorganic matter, with only trace organic components. Inorganic matter mainly includes minerals and water, often transformed into oxides, and contains trace rare metals (e.g., Ti, V, Co) (Zuo et al., 2014). Organic matter in coal gangue is mainly coal-derived, increasing with coal content, and includes elements such as C, H, O, N, and S. Higher carbon content generally results in higher calorific value. Due to its reactive substances, coal gangue can hydrolyze under certain conditions to form a plate structure. Its chemical properties are neutral or weakly alkaline, but some high-moisture gangue may become strongly acidic due to hydrolysis of reactive substances (Li et al., 2017).

3. CURRENT STATUS OF COAL GANGUE RESOURCE UTILIZATION

Current resource utilization of coal gangue focuses on its potential value and economic benefits. Domestic research institutions, enterprises, and universities have conducted extensive studies, primarily in filling mining, chemical products, agriculture, adsorption materials, and building materials.

3.1 Backfilling Treatment

Backfilling mining requires crushing surface or underground gangue into appropriate particle sizes and transporting it to goafs via conveyors for in-situ utilization. To achieve this, systems including surface crushing, storage, and transportation systems, as well as underground return-gangue transportation systems, are essential. Shanxi Coking Coal Dongqu Mine adopted underground filling technology, achieving a monthly face advance of 45 meters, reducing gangue by 100,000 tons per month, and minimizing ecological impact while maximizing resource utilization. Based on an annual output of 350,000 tons and gangue filling of 500,000 tons, the annual cost increased by approximately 63.9 million yuan, with a unit cost increase of 159.75 yuan/ton. However, it saved 9.9 million yuan in surface disposal fees and reduced resource taxes by 3.57 million yuan, creating a new model for high-quality mine development aligned with green coal mining policies (Lan, 2024).

3.2 Extraction of Valuable Elements

Aluminum-based chemical raw materials can be economically extracted from coal gangue. Ji et al., (2023) reduced alumina extraction costs by activating red mud-coal gangue mixed slag with calcium carbonate and sodium carbonate, leveraging sodium carbonate recycling and residual alkali in red mud. Most Chinese coal gangue is high-sulfur, containing iron mainly as pyrite, which can be enriched via gravity and flotation. Oxidative roasting of coal slag produces iron-based products (e.g., iron oxide red/yellow) (Tian et al., 2025; Kang et al., 2023). Activated silicates in gangue can yield silica-based products such as precipitated silica, water glass, and silicon carbide. Precipitated silica (white carbon black), a white amorphous powder with high dispersibility, is widely used in electric power, metallurgy, and chemicals. Xing et al., (2020) prepared white carbon black with 89% purity from quartz-based gangue via calcination, impurity removal, and alkali boiling/melting. Pressurized acid leaching-carbon thermal reduction achieved 97.76% silica in gangue residues. Additionally, trace rare metals (e.g., Li, Ga, Ti) in gangue provide low-cost raw materials for aerospace, military, and computing industries (Ma et al., 2021). Acid leaching is the primary technology for extracting these elements (Wang, 2023).

3.3 Mineral Fertilizer

Coal mining causes land subsidence, soil degradation, and nutrient loss. Coal gangue, with its porosity and water retention, can be modified physically, chemically, or biologically to improve plant growth and accelerate soil formation. Liu et al., (2025) isolated *Bacillus aerius*, a thermophilic bacterium that enhances gangue dissolution, releasing nutrients (available K, P, alkaline-hydrolyzable N, and humic substances). Adding *B. aerius* and gangue significantly increased alfalfa germination and growth.

3.4 Development of Sound-Absorbing Ceramsite

Sound-absorbing panels and barriers use cost-effective ceramsite. Traditional raw materials (shale, clay) are non-renewable and restricted by environmental policies. Coal gangue and Bayer red mud have been used in metal recovery and ceramics. Zhu et al., (2023) prepared high-performance, eco-friendly ceramsite using waste stone powder, gangue, and red mud via disc pelletization and sintering. The ceramsite met

physical and radioactive standards, with an average sound absorption coefficient of 0.50, offering a new high-value utilization pathway.

3.5 Manufacturing of Building Materials

Coal gangue, similar to clay in chemical composition, provides SiO_2 and Al_2O_3 for cement clinker production. Calcined gangue ash, blended with cement raw meal, reduces energy consumption and storage issues. Feng et al., (2023) studied gangue and ultra-fine composite powder in concrete for roadbed paving. Adding 30% composite powder maintained strength while increasing 后期 (long-term) compressive strength. Steel fiber-reinforced gangue concrete improved mechanical properties and crack resistance, with increases of 39.2% in splitting tensile strength, 29.5% in compressive strength, and 12.3% in elastic modulus.

3.6 Subgrade Filling

Processed coal gangue can be used for subgrade filling. In a 160-km expressway project, 40% of subgrade filling used gangue, saving 5% of total costs. Tests showed low weathering, Mohs hardness 6, alkali reactivity below standards, low sulfide corrosion risk, and adequate bearing capacity (average compressive strength meeting minimum requirements), demonstrating good shear strength and frost resistance.

4. CONCLUSION

China is in a critical stage of building an environmentally friendly and resource-efficient society, necessitating intensified research on coal gangue utilization. Despite growing environmental awareness and technological advancements, coal gangue utilization remains in its infancy, characterized by unordered development and insufficient attention to environmental impacts. Challenges include low-scale operations, inadequate R&D investment, and poor economic returns, reducing corporate incentives. Future efforts should focus on top-level design, pretreatment optimization, industrial chain extension, talent cultivation, and policy improvement to facilitate harmless disposal and resource utilization of coal gangue.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image

generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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