Review of Solid Waste Resource Utilization for Brick-making

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Abstract. The utilization of solid waste resources is an essential strategy in the pursuit of sustainable development. Among the various techniques used for solid waste treatment, brick-making technology stands out as a key approach to facilitate the utilization of solid waste resources. This article provides a comprehensive review and summary of the recent research progress in the field of solid waste resource utilization for brick-making. It mainly focuses on the current state and technological advancements in brick-making using solid waste. Considering the influence of different external factors and variations in brick-making raw materials, this study employs the Citespace software to conduct co-word and clustering analysis, with "resource utilization" as the primary keyword. Furthermore, it introduces the brick-making technology utilizing sludge and red mud as raw materials, while also elaborating on advanced techniques and practical experiences in utilizing industrial and urban solid waste as raw materials. Additionally, the article presents an overview of the key development trends in this field and puts forward several recommendations for future research to aid designers in furthering their investigation.

1 Introduction

In our country, the annual quantity of accumulated solid waste far surpasses the processing capacity (Figur-e 1), encompassing a wide range of waste types. Conseq-uently, research on the utilization of resources from solidwaste has emerged as a critical approach to achieve sust-ainable development, with sintering and brick-making being regarded as pivotal methods to alleviate this iss-ue. As research progresses, the strategies for the utiliza-tion of solid waste in brick-making methods [1-4] are co-ntinuously evolving, leading to a constant emergence of research findings. Therefore, it is beneficial to summari-ze and synthesize the current achievements in order to foster profound advancements in this field.

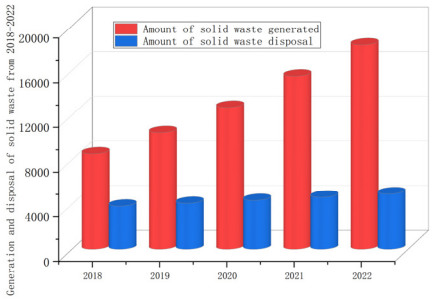

Fig. 1: Volume of Solid Waste Generation and Treatment in China from 2018 to 2022

Wang et al. [5] provided a comprehensive summary of the production and application of waste calcination, waste consolidation, and waste polymerization methods. The study results indicate that the application of solid waste resource utilization, in terms of economy, technol-ogy, and environment, is limited, and that there is a lack of relevant standards and public awareness. Xiao et al.[6] organized the utilization of solid waste regenerated materials as pavement base materials, including industrial, construction, and domestic waste materials, in pavement base layers. The research findings effectively address the issue of traditional landfill disposal and propose a holistic approach to the utilization of solid waste materials for sustainable resource management.

Despite the constantly growing achievements in solid waste resource utilization, there remains a dearth of comprehensive review literature. Existing review literature [5-8] is limited to certain aspects of discussion, such as waste brick-making [5] and construction waste [8]. Thus, it is necessary to comprehensively summarize and review the recent research accomplishments, aiming to promote further development and transformation of solid waste resource utilization technologies and facilitate indepth investigations. Drawing on the current research achievements and employing VOSviewer for keyword analysis (Figure 2), this paper offers a review and synthesis of the recent research progress, outlines the principal development trends in this field, and provides recommendations for future work based on the specific context of our country. These suggestions aim to assist designers in delving deeper into the relevant research.

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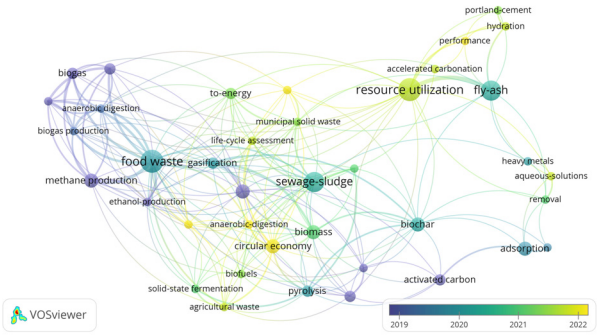

Fig.2 Based on VOSviewer keyword analysis

2 Research Status

Solid waste brick-making is a technology that tran-sforms industrial solid waste into construction materials. With the accelerated industrialization and continuous ur-banization, a large amount of solid waste is generated, which brings tremendous pressure and damage to the en-vironment. Therefore, further utilizing these solid waste resources and reducing their environmental harm is an inevitable trend for achieving sustainable development. Scholars in different periods [9-11] have conducted res-earch on the utilization of solid waste resources.

At the end of the twentieth century, Jing [10] analyzed the basic conditions of making bricks from waste, such as moisture content, waste ratio, chemical composition of organic and inorganic substances, and describedthe process of making bricks from waste. The characteris-tics of waste brick-making were briefly summarized and compared with the most commonly used incineration method, providing a way out for waste brick-making. At the beginning of the twenty-first century, Chen et al. [11] analyzed the composition of raw materials for solid waste brick-making and conducted comparative exper-iments on the three processes of brick molding, natural drying, and high-temperature firing. They studied the pr-eparation of bricks by mixing dried sludge with solid waste and tested the properties of molded bricks. After the experiments, all factors met the cor-responding stand-ards, providing a way for the treatment of solid waste re-sources.

Sewage sludge, as the main raw material for solid waste brick-making, deserves exploration in terms of the products prepared. Fan et al. [12] found in their study on the blended preparation of shale and sewage sludge that appropriate blending of shale can improve the plasticity and other performance of the finished products, with he-avy metal content lower than the control indicators. Yang [13] studied a series of factors influencing the performance of chromium-containing sludge-fired bricks, obtained the best raw material ratio and process parameters through leaching experiments and detoxification experiments, providing data support for the harmless treatment and resource utilization of chromium-containing sludge, and providing ideas for the preparation ratio of energysaving bricks. Chinese scholars [14] prepared sintered bricks using red mud and fly ash as raw materials in 2023. Through orthogonal experiments, parameter analysis, performance testing, and analysis mechanism of SEM and XDR, they provided a research foundation and technical reference for environmentally friendly waste-free sintered bri-cks.

For waste brick-making today, most of our research focuses on energy-saving methods, while research on cost-saving and expanding production lines still needs improvement.

3 Research Trends

Due to the different brick-making materials used by different researchers and the influence of various environmental factors, key co-word analysis and keyword cluster analysis on the utilization of solid waste resources were conducted using CiteSpace software (Figures 3 and 4), revealing an increasing trend towards subdividing raw materials for waste brick-making (Figure 5).For example, there is increasing research on waste brick-making technologies using sludge and red mud as raw materials [2,4,11-13,15-17], as well as technologies using urban solid waste and industrial solid waste for brick-making [3,6,8,10,14,25-28]. In addition, the waste brick-making basedon resource utilization has significant potential and adva-ntages as a new waste treatment and resource utilization technology. By effectively utilizing and transforming so-lid waste resources, it is possible to reduce environmental pollution, achieve the circular utilization of resources, and promote sustainable development.

Fig.3 Citespace keyword co-occurrence analysis

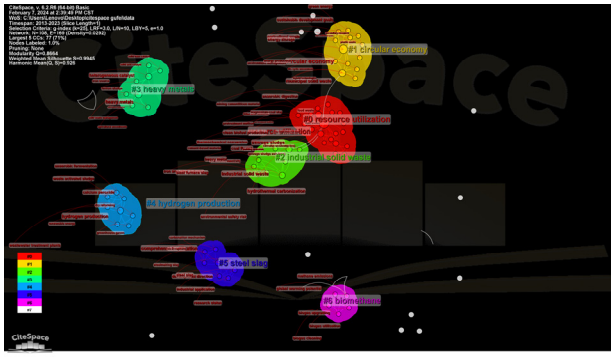

Fig.4 Citespace keyword clustering analysis

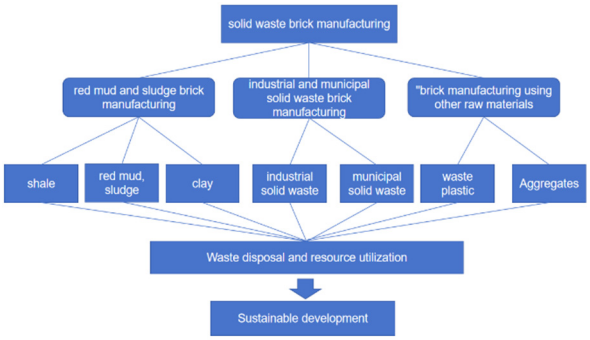

Fig.5 Subdivision of raw materials for solid waste brick-making.

3.1 Solid Waste Brick Making with Sludge and Red Mud

Sludge and red mud from sewage and other sources have long been recognized and discussed as important components of solid waste. In recent years, extensive research has been conducted on these materials, with a focus on their resource utilization, making it a current research priority in society [15,16]. As show in figure 6.

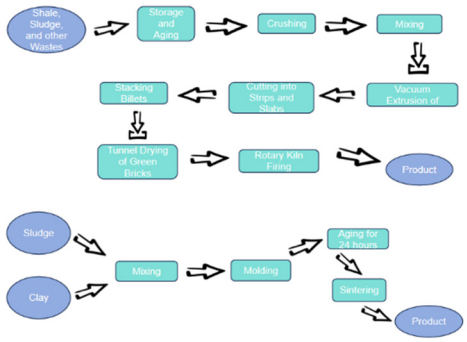

Fig.6 The process of using sewage sludge to produce bricks

Shi [17] conducted the first analysis of the chemic-al composition of dried sludge and clay in 2011 and mix-ed them in different proportions. By using an orthogonal design scheme and conducting level experiments, the effects of sintering temperature, sintering time, and the sludge-to-clay ratio on the compressive strength of the bricks were analyzed, and the experimental structures were vis-ually and statistically analyzed. The research results sho-wed that sintering temperature and sludge-to-clay ratio had a significant impact on the compressive strength of the bricks, while the effect of sintering time was not sig-nificant, confirming the feasibility of using sludge for brick making.

The addition of trace elements in sludge has also received attention. Wei et al. [18] systematically studied low-calcium sintered red mud bricks and controlled the residual content of calcium silicate to regulate compressive strength, bulk density, softening coefficient, and water absorption. By controlling the content of cement and fl-y ash, they controlled the molding pressure, compressive strength, bulk density, softening coefficient, and water absorption. Mastersizer 3000 particle size analyzer (Hydro EV mode) and X-ray fluorescence analyzer (XRF, ZSX100e) were used to measure the particle size and chem-ical composition of calcium silicate residues. X-ray diffr-action analyzer (XRD, Philips X'Pert PW3040-60) was used to characterize the phase composition of Cu-K calc-ium silicate slag and unburned brick samples by α radia-tion (40 kV, 40 mA, 15°/min). Scanning electron micros-cope (SEM, ULTRA PLUS-43-13) equipped with an en-ergy-dispersive spectrometer (EDS, X-Max50) was used to analyze the microstructure of the samples. The exper-imental results showed that the prepared unburned brickscould completely eliminate alkali activation, which is be-neficial for the long-term durability of building materials and the full quantification and scale utilization of red mud.

In 2021,Zhang et al. [19] conducted a feasibility analysis of sludge resource utilization in brick making,considering its low raw material cost and strong market competitiveness, providing favorable support for the utilization of sludge materials. Meanwhile, Qi[20] described the benefits of harmless treatment of sludge and emphasized the importance of using clayey materials for sludge brick making. The need for sterilization, deodorization, and stabilization treatment of sludge was also emphasized. In 2022, Zhao et al. [21] and Li [22] conducted tests on brick samples using the same approach. Zhao et al. [21] prepared test blocks of shale, slag, silt, and municipal sludge through a series of methods including drying. Li [22] performed tests by using the compaction molding method, and the strength indicators of the bricks mixed with sludge and clay complied with national standards. Subsequently, Li [23] conducted experimental research on the process route, key technologies, and performance parameters of a sludge plant,aiming to obtain the optimal sludge mixing ratio and achieve the full utilization of sludge, thereby meeting the requirements of China's economic and high-tech development.

3.2 Urban and Industrial Solid Waste Brick Making

Urban and industrial solid waste is a global problem. Currently, most cities both domestically and internationally face the urgent issue of solid waste disposal and are exploring and summarizing advanced technologies and practical experiences in waste treatment.Urban and indu-strial solid waste are defined as solid or semi-solid mate-rials discarded or abandoned during production, life, or other activities,including materials in containers and sub-stances and materials specified by laws, regulations, and administrative provisions to be included in waste manag-ement. It also includes industrial waste such as tailings, coal gangue, fly ash, slag, smelting waste oil, chemical waste, and industrial waste materials produced during industrial production and processing.

In recent years, the utilization of industrial and urb-an solid waste has been widely employed in the field of waste resource utilization, particularly for brick making [3,6,8,24-28] (Figure 7). Li et al.[29] mixed eligible municipal waste with clay, which not only protected the urban environment but also increased social and economic benefits. Zhao [30] analyzed the resource utilization of

industrial solid waste (coal gangue) in brick making and proposed effective control measures to improve the comprehensive economic benefits of coal gangue bricks. Wang et al. [7] introduced three methods for making waste brick, including using waste materials to replace soil for firing, utilizing adhesive materials for bonding, and for-ming inorganic polymers or geopolymer through chemi-cal reactions. However, commercial production and app-lication of waste brick are limited due to the lack of rele-vant standards and slow acceptance in the industry.

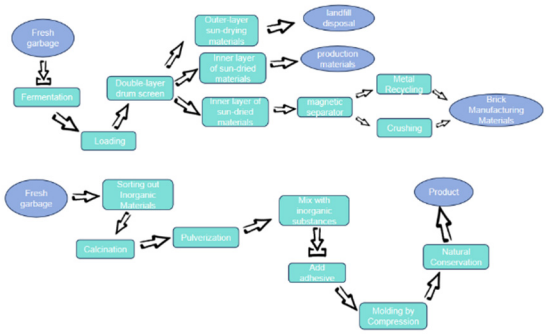

Fig.7 Process flow of brick-making from municipal solid waste.

Additionally, researchers have used new raw materials to produce sintered brick. Gao et al. [31] used slag as a partial replacement for cement to produce burned-free bricks and conducted exploratory experiments using orthogonal test methods to test the compressive strength of non-fired bricks under the influences of slag content, lime content, and forming pressure. Literature [32] characterized the structure, performance, microscopic structure, and morphology of waste-free sintered pavement bricks using solid waste residues (waste magnesia-alumina spinel) from industries like metallurgical ceramics after ball milling and provided references for the comprehensive utilization of waste in brick making. Shen et al. [33] dried and crushed construction waste from a new constructionsite in 2023, formed brick blanks using a certain combin-ation method, analyzed the chemical composition through XRF and XRD, tested the mechanical properties and SEM microstructures of recycled bricks, and studied the in-fluence mechanism of clay mineral composition on recy-cled bricks and waste soil.

3.3 Brick Making with Other Waste Materials

Of course, waste management techniques extend be-yond brick making using sludge, red mud, urban, and industrial solid waste. There are other technologies for brick making using waste materials [1,5,34-37], all of which contribute to achieving sustainable development of resources.

Li et al. [38] designed an energy-saving brick syste-m under the IoT background. They adopted a three-tier hierarchical cascade control mode, including management level, coordination level, and execution level, as well as automation design for key processes such as molding, stacking, kiln operation, shuttle car operation, finished product loading, and workshop network, aiming to achieve efficient, stable, and automated production lines.

Zheng et al. [39] used polymeric solidification materials with simple and environmentally friendly processes and low treatment costs to study the relevant characteristics of making bricks with fly ash. Lin et al. [40] investigated the types, compositions, characteritics, and status quo of recycled plastic bricks at home and abroad in 2022 and proposed future research directions. Document[41] discussed the influence of using crushed bricks as aggregate in the structural performance, mechanical per-formance, and shrinkage performance of recycled brick aggregates, as well as elaborated on preparation process-es, strength, and durability. In addition, incremental crush-ing technology has been applied to improve resource uti-lization and promote the sustainable development of Ear-th's resources.

4 Conclusion

Based on the review of literature, this paper condu-cts a visual analysis using VOSviewer and Citespace to review and summarize the research on solid waste resou-rce utilization for brick making in recent years. The following findings are obtained: Firstly, the awareness of utilizing solid waste for brick making is not high, and there are still certain limitations in the technology, with many studies focusing on only one aspect. Secondly, in recent years, research on solid waste brick making technology has gradually expanded from brick raw materials and techniques to process and detection indicators. Thirdly, in the research on solid waste resource utilization for brick making, the waste utilization and different raw material ratios have been widely applied. Finally, solid waste resource utilization increasingly adopts internet technology to control the production chain, achieving efficient, stable, and automated production lines.

Based on the discussion of the actual situation in China, the author believes that at least the following three issues need to be addressed in future research on solid waste resource utilization for brick making:

(1) Firstly, there are various types of waste, and different types of waste have different impacts on the performance and quality of bricks, thus requiring research and optimization of their characteristics. In addition, the production cost of solid waste brick making is relatively high,so further research is needed on process improvement and equipment optimization to reduce costs and increase production capacity. At the same time, solid waste brickmaking also faces challenges such as quality certification, market promotion, and policy support in practical appli-cations.

(2) Future research on solid waste brick making needs improvement in technology and processes. On the one hand, the mechanical performance, durability, and environmental adaptability of solid waste brick making can be improved through optimization of ratios and manufacturing processes. On the other hand, exploring new raw materials for solid waste brick making, such as agricultural waste and industrial slag, can increase the source of raw materials and product diversity. In addition, research

findings from other fields such as building materials, materials science, and environmental engineering can be applied interdisciplinary to the study of solid waste brick making.

(3) When conducting research on solid waste brick making, environmental and sustainable development factors need to be fully considered. On the one hand, solid waste brick making technology itself can reduce resource consumption and environmental pollution, so the preparation process needs to be further optimized to minimize negative environmental impacts. On the other hand, the life cycle assessment and environmental impact of solid waste brick making should be evaluated t assess its sustainability in practical applications.

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