Application Status and Prospect of Biomass Straw in Metallurgical Industry

Jiaqi Li[a], Jingbo Ren[b], and Xiaole Du[c]

College of Metallurgy and Energy, North China University of Science and Technology, Tangshan 063210, China

[a]3366239813@qq.com, [b]3232951283@qq.com, [c]2460891954@qq.com

Abstract

The application of biomass straw as a renewable resource in the metallurgical industry is a key pathway to promote the green and low-carbon transformation of the steel industry. This paper systematically reviews the physicochemical properties of biomass straw and its current applications in the metallurgical field, with a focus on analyzing the core mechanisms, practical effects, and bottleneck issues of four major technological directions: injection of reducing agents, combustion heat supply substitution, gasification for synthetic gas, and pyrolysis biochar. Industrial practices have shown that injecting biomass straw can reduce fossil fuel consumption by 23 kg per ton of steel and decrease the iron oxide content in slag by 1.8 percentage points; pyrolysis biochar can replace fossil reducing agents in electric arc furnace steelmaking; and combustion heating technology has been successfully implemented in small and medium-sized metallurgical enterprises. However, challenges remain for large-scale promotion, including alkali metal corrosion, equipment adaptability, raw material supply costs, and process stability. In the future, efficient and intensive utilization of biomass straw resources for achieving carbon neutrality in the metallurgical industry should be facilitated by optimizing pyrolysis processes, developing intelligent control systems, constructing regional supply chains, and aligning policy support with carbon market mechanisms.

Keywords

Biomass Straw; Metallurgical Applications; Injected Reducing Agent; Pyrolytic Biochar; Combustion Heating; Green Low Carbon; Alternative Reducing Agents.

1. Introduction

Against the backdrop of the continuous advancement of global industrialization, the metallurgy industry, as a fundamental sector, plays a crucial supporting role in economic development[1]. However, the traditional metallurgical industry heavily relies on fossil energy, which not only leads to the increasing depletion of resources but also triggers a series of severe environmental issues[2]. According to statistics, the carbon dioxide emissions produced by the metallurgical industry account for a significant share of global industrial emissions each year, which has a substantial impact on global climate change. Meanwhile, with the continuous enhancement of environmental awareness and the deep-rooted concept of sustainable development, seeking green and sustainable alternative energy and raw materials has become crucial for the transformation and upgrading of the metallurgical industry. In this context, biomass straw, as a rich renewable resource, is gradually coming into the spotlight. As an agricultural powerhouse, our country has an extremely abundant

ISSN: 2414-1895 DOI: 10.6919/ICJE.202508_11(8).0022

supply of crop straw, with a massive annual production. If properly utilized, it will provide strong support for the sustainable development of the metallurgical industry.

Currently, research on the application of biomass straw in the metallurgical industry has started relatively early abroad, yielding a series of influential results. As early as the end of the 20th century, some developed countries began to pay attention to the potential of straw in the energy sector, gradually expanding research to related applications in the metallurgical industry. In terms of biomass energy utilization technology, countries such as those in Europe and North America are in a leading position. Denmark has achieved significant results in the energy utilization of straw[3]. The advanced straw direct-fired power generation technology developed by it has been commercialized on a large scale, and the Avedo power plant burned a large amount of straw every year [4], It not only meets the heating and electricity needs of local residents but also provides certain support for the power supply of the metallurgical industry. The United States has made significant investments in the research of biomass energy conversion technology, developing various efficient technologies for straw pyrolysis gasification and solidification molding. The exploration of these technologies in the metallurgical industry has also made positive progress. A research team in the United States purified and enhanced the syngas produced from straw pyrolysis and gasification, enabling it to replace some traditional fossil fuels for heating metallurgical furnaces, thereby reducing carbon emissions while achieving diversified energy utilization. In contrast, Japan has focused on the research and development of technology for extracting alcohol fuel from straw cellulose, actively exploring its potential applications in the metallurgical industry, with related technologies gradually progressing toward practical use.

Research on the application of biomass straw in the metallurgical industry in China, although started somewhat later, has been developing rapidly. In recent years, with the continuous enhancement of national policies regarding the utilization of renewable energy and environmental protection requirements, domestic research institutions and enterprises have intensified their research efforts on the application of straw in the metallurgical field. In terms of straw power generation, there are numerous projects under construction across the country, with widespread distribution, including large-scale projects in Henan, Heilongjiang, and Liaoning provinces. These straw power generation projects provide clean electrical energy for the metallurgical industry, effectively reducing dependence on traditional thermal power and lowering carbon emissions. In the preparation of metallurgical auxiliary materials from biomass straw, domestic researchers have developed specific performance adsorbents and slagging agents through special treatment and modification of straw, which are used for impurity removal and slag adjustment in the metallurgical process, yielding good results. This article systematically reviews the development of the application of biomass straw in the metallurgical industry, providing reference significance for further research.

2. Characteristics of Biomass Straw and its Theoretical Basis for Metallurgical Application

The physicochemical properties of biomass straw play a crucial role in its effectiveness within the metallurgical industry. See Table 1 , regarding physical properties, biomass straw exhibits a relatively low density, typically ranging from 100 to 300 kg/m³, which requires larger spaces for transportation and storage, thereby increasing costs. Its moisture content varies according to species and harvest season, generally falling between 10% and 30%; higher moisture content can adversely affect its combustion efficiency and pyrolysis processes, necessitating pretreatment. The particle size distribution of straw is also quite complex, often requiring milling to meet metallurgical process demands. With respect to chemical properties, the elemental composition of biomass straw mainly comprises carbon, hydrogen, and oxygen, along with minor quantities of nitrogen and sulfur, as detailed in Table 1. Its volatile matter content is significantly high, generally ranging from 70% to 85%, which facilitates the release of combustible gases during heating and yields a high calorific value, typically between 15 and 20 MJ/kg. The ash content is relatively low, generally between 1%

Volume 11 Issue 8, 2025
DOI: 10.6919/ICJE.202508_11(8).0022

and 10%; however, the composition of the ash is complex, containing alkali metals such as potassium and sodium, which may lead to corrosion of the furnace lining in metallurgical processes and thus requires careful management.

Table 1. Elemental composition of biomass straw

Type of straw	C/%	H/%	O/%	N/%	S/%	Ash content/%	Remarks
Type of straw	42-49	5.0-6.5	37-45	0.6-1.0	0.1-0.3	4-8	High cellulose, commonly used as fuel or feed.
Wheat straw	43-47	5.2-6.0	40-44	0.5-0.8	0.1-0.2	6-10	Widely available, with a higher ash content.
Rice straw	38-42	4.8-5.5	33-37	0.5-1.2	0.1-0.3	**12-20**	The ash content is extremely high, with a high silica content.
Cotton stalks	44-48	5.5-6.2	35-40	0.7-1.5	0.1-0.4	3-7	The lignin content is relatively high.
Sugarcane bagasse	45-49	5.8-6.5	42-46	0.2-0.6	<0.1	2-5	By-products of sugar factories, low ash content.
Soybean straw	44-47	5.5-6.0	40-43	**1.2-2.0**	0.1-0.3	5-8	The nitrogen content is relatively high.
Straw	39-43	4.9-5.6	35-39	0.6-1.1	0.1-0.3	**10-17**	Similar to rice straw, with high ash content.

3. Application of Biomass Straw in Metallurgical Industry

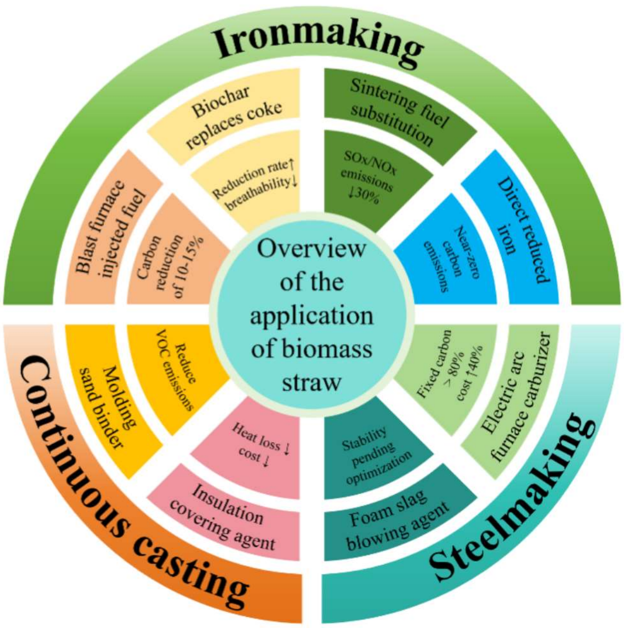

Figure 1. Application of biomass straw in metallurgical industry

Biomass straw has a variety of application pathways in the metallurgical industry, showing broad application prospects, as shown in Figure 2. Biomass straw is widely used in ironmaking, steelmaking and casting in the metallurgical industry. In the field of ironmaking, biochar replaces coke as the core, although the reduction rate of iron ore is improved, the lack of mechanical strength leads to a significant decrease in the permeability of the blast furnace column. Sinter fuel substitution can reduce SOx/NOx emissions by 30%, and the negative impact of alkali metals on sinter strength needs to be controlled. Blast furnace injection achieves carbon emission reduction of 10-15%, which is limited by alkali metal corrosion and is difficult to scale. In the steelmaking process, biochar-based foam slag blowing agent was explored, which has not yet been industrialized due to insufficient gas release stability. In the casting field, carbonized straw is used as a thermal insulation covering agent to reduce heat loss, and its ash content can be prepared to protect slag, but the composition fluctuates greatly; Straw molding sand binder can reduce VOC emissions by about 10% instead of pulverized coal. In the future, it is necessary to improve the strength through catalytic pyrolysis, build a regional pretreatment system, and drive large-scale application with supporting carbon pricing policies.

4. Analysis of Application Status and Technical Path

4.1 Injection of Reducing Agent

The crushed biomass straw is directly injected into the converter as a reducing agent to replace traditional fossil fuels, which represents an important technical direction for the iron and steel industry to explore green and low-carbon smelting. The core principle is to use the abundant fixed carbon and volatile matter in biomass to participate in the iron oxide reduction reaction in the high-temperature molten pool. Industrial test data show that when the proportion of biomass injection reaches 15%, the energy saving and emission reduction effect is significant: the consumption of fossil fuels per ton of steel can be reduced by 23kg, and the iron oxide content in the end slag is reduced by an average of 1.8 percentage points. This not only directly reduces the use of non-renewable resources such as coal and the carbon emission intensity of the steelmaking process, but also indirectly reduces the loss of iron and improves the metal yield by reducing the FeO content in the slag, which preliminarily verifies the dual potential of biomass resources to realize fossil energy substitution and process intensification in the steel process.

However, the technology also faces key challenges in practical application, mainly due to the inherent physicochemical properties of biomass straw. Its low ignition point makes it easy to burn prematurely during injection and conveying and when entering the converter's high-temperature flue gas area. This phenomenon not only causes the loss of effective reducing components of biomass and the decline of utilization rate, but also causes violent melt pool sputtering, which poses a significant threat to the stability of the smelting process, equipment safety and operator protection. In order to systematically solve this bottleneck problem, Anshan Iron and Steel Group innovatively constructed a dynamic control model of "moisture content-injection rate-melt pool reaction". Based on the profound influence of biomass moisture content on its ignition temperature, combustion rate and endothermic effect, the model effectively inhibits the uncontrolled combustion in the injection pipeline and furnace mouth area by optimizing and controlling the moisture content and injection gas flow rate of the injection material in real time, significantly alleviates the frequency and intensity of spraying, and greatly improves the reliability of the injection process and the anterograde level of the overall smelting.

In the future, in order to further improve the economic and environmental benefits of biomass injection technology, it is still necessary to deepen research and application development in multiple dimensions. Fine optimization of process parameters is the foundation, and it is necessary to deeply explore the optimal crushing particle size distribution, injection carrier gas pressure and flow, spray gun insertion depth and angle, etc., so as to strengthen its mixing and reaction kinetics conditions in the molten pool and improve the utilization efficiency of reducing agent. The adaptability and intellectualization of injection equipment is the key, and the research and development of high-temperature resistant and anti-tempering special spray gun structure, efficient and accurate material metering and conveying system, and the integration of online monitoring and feedback control to

ISSN: 2414-1895 DOI: 10.6919/ICJE.202508_11(8).0022

build an intelligent injection platform are the hardware guarantee for stable and efficient injection. It is necessary to systematically carry out the basic research on the reaction path, reduction kinetics and its influence on the thermodynamic state of the molten pool of biomass pyrolysis gasification products in the complex high-temperature environment of the converter, so as to provide a solid theoretical basis for process design and process control. Through multidisciplinary collaborative innovation, biomass injection technology is expected to become an important technical fulcrum for the green transformation of the iron and steel industry.

4.2 Combustion Heating Substitution

It is also an important direct utilization technology to use the heat generated by biomass straw combustion to replace some traditional fossil fuels and provide heat for the converter smelting process. Although the calorific value of biomass straw is lower than that of traditional fossil fuels, it has the advantages of being renewable and carbon neutral. In the combustion process, the combustion equipment needs to be properly modified to adapt to the combustion characteristics of biomass straw. For example, it is necessary to increase the adaptability of the feeding device to ensure that the straw can enter the combustion furnace evenly and stably; At the same time, it is necessary to optimize the structure and combustion parameters of the combustion furnace to improve the combustion efficiency and reduce the emission of pollutants. At present, this technology has been applied in some small metallurgical enterprises, but its application in large-scale converter smelting is still in the experimental stage and needs further research and improvement.

4.3 Gasification of Synthetic Gas

Using the heat generated by biomass straw combustion to replace part of the fossil fuels for heating the converter smelting process is an important technical path to realize the green transformation of the energy structure of the steel production process. As a renewable resource, the combustion process of biomass straw is essentially to re-release the carbon dioxide fixed in the plant growth stage, which can theoretically achieve near-zero carbon emissions and has significant carbon neutrality advantages. Although its low-level calorific value is generally lower than that of high-quality coal, its original content of pollutants such as sulfur and nitrogen is low, and its environmental friendliness is outstanding. At the heart of the technology is the efficient combustion of biomass, converting its chemical energy into heat energy from high-temperature flue gas or steam, which is then fed into the converter process to compensate for smelting heat loss, preheat scrap or maintain molten steel temperature, thereby directly reducing the consumption of fossil fuels such as coal, natural gas or heavy oil. Preliminary industrial practice shows that the rational application of this technology can effectively reduce the carbon footprint of steel production, which is in line with the requirements of the national "dual carbon" strategy for deep decarbonization in the industrial field.

However, the unique physical and chemical properties of biomass straw require targeted modification and optimization of existing combustion equipment to ensure stable, efficient and clean combustion. The adaptability upgrade of the feeding system is the first link, and it is necessary to solve the problems of fluffy, easy winding and poor fluidity of straw. This often involves the use of forced, wear-resistant pretreatment and conveying equipment, such as twin screw feeders with anti-tangle structures, high-inclination belts or pneumatic conveying systems, and the integration of precise metering control units to ensure that the straw is fed into the combustion furnace continuously, evenly and controllably. The in-depth optimization of the structure and parameters of the combustion equipment is more crucial: in terms of structure, it is necessary to design the furnace volume and shape that adapt to the high volatile matter and rapid precipitation characteristics of straw, and configure a reasonable air distribution system to promote the full combustion of volatile matter and coke; In terms of parameters, the air excess coefficient, combustion temperature and residence time need to be precisely controlled. At the same time, it is necessary to strengthen the coordinated control of pollutants, such as inhibiting the formation of nitrogen oxides by optimizing the combustion temperature field, or adopting efficient dust removal and adding alkali metal removal devices if necessary to meet increasingly stringent environmental standards.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202508_11(8).0022

At present, the biomass straw combustion heating technology has achieved a certain degree of engineering application in small and medium-sized metallurgical enterprises, mainly used to provide auxiliary heat sources for electric furnaces, refining furnaces or rolling heating furnaces, and has accumulated valuable operating experience. However, its large-scale integration into the energy supply system of modern large-scale converters still faces serious challenges and is still in the experimental exploration stage. The main bottlenecks include: large-scale stable fuel supply and logistics cost control problems - the huge heat demand of converters requires the establishment of a large, efficient and low-cost straw collection, storage, transportation and pretreatment supply chain; Complexity of heat load matching and system integration: It is technically difficult to couple the heat flow of biomass combustion into a complex thermal system with strong intermittent and dynamic changes of the converter. Uncertainty about the potential impact on the main process – if the biomass ash composition enters the converter system with hot air or steam, what impact it may have on the lining life, molten steel purity or subsequent processes needs to be further studied and verified; Economic competitiveness – In the absence of strong carbon constraints or subsidies, there is pressure to compete with low-cost fossil fuels. Future research needs to focus on the construction of an efficient and intensive utilization model of regional straw resources, the development of a highly intelligent biomass combustion-heat system integration technology that adapts to the characteristics of converter smelting, an in-depth evaluation of the impact of the whole process of material and energy flow, and an exploration of policy support and carbon market mechanism to promote the commercial application of this technology in large iron and steel conglomerates.

4.4 Pyrolysis of Biochar

Pyrolysis biochar technology produces three main products: biochar rich in fixed carbon, liquid tar and flammable gas, by placing biomass straw in an oxygen-free or oxygen-deficient environment for medium and high temperature thermochemical transformation. The core value of this technology lies in its product, biochar, which has great potential as a green reducing agent due to its high fixed carbon content and low volatile characteristics. It is particularly suitable for electric arc furnace steelmaking processes and can partially or completely replace traditional fossil-based reducing agents. Its advantages are: the high fixed carbon content ensures strong reducing ability, which is conducive to the efficient reduction of iron oxides; The low sulfur characteristics significantly reduce the risk of sulfur increase of molten steel and improve the quality of steel. At the same time, biochar is derived from renewable resources, and its carbon dioxide emissions in its life cycle are much lower than those of fossil fuels, which is in line with the deep decarbonization needs of the steel industry. The integrated baking-rapid pyrolysis process developed by Andersson's team at Chalmers University of Technology in Sweden is a major breakthrough in this field: through gentle roasting pretreatment of wheat straw to remove part of the volatile matter and water, and then combined with rapid pyrolysis, high-quality biochar with a fixed carbon content of up to 85% and a sulfur content of less than 0.1% has been successfully prepared, and its physical and chemical indicators fully meet or even exceed the strict requirements of electric arc furnace steelmaking for reducing agents, providing a model for the high-value utilization of biomass resources.

The key to achieving stable and controllable production of high-quality biochar lies in the precise regulation of the core process parameters of the pyrolysis process. Temperature is the core factor, which directly affects the product distribution and biochar properties: lower temperature is conducive to tar yield, but biochar has relatively low fixed carbon content and high reactivity. Higher temperatures increased the carbon content, graphitization and stability of biochar, but increased the gas yield. The heating rate and residence time work together: rapid pyrolysis is beneficial to maximize the biochar yield and optimize its pore structure. Slow pyrolysis helps to improve the mechanical strength of biochar. The reaction atmosphere also significantly affects the pyrolysis path and product characteristics. In addition, maximizing the value of by-products is key to improving process economy and environmental friendliness: the tar produced can be converted into high value-added fuel oil or chemical feedstock through catalytic reforming or hydrorefining; Due to its high calorific value, pyrolysis gas can be directly used for combustion heating, power generation by internal combustion engines, or as a syngas raw material after purification. The construction of a cascade efficient utilization system of all biomass components is an important support for the commercialization of this technology.

Although laboratory research has fully verified the feasibility and superior performance of pyrolysis biochar technology, it still faces a series of challenges to be solved urgently when it is applied to large-scale industrial application, especially in the field of electric arc furnace steelmaking with huge energy consumption. Large-scale production bottlenecks bear the brunt: In the scale-up process from batch laboratory reactors to continuous and high-capacity industrial plants, complex engineering problems such as uniform heating of materials, heat and mass transfer efficiency, tar blockage, equipment wear and long-term stable operation are faced. This requires the development of efficient, reliable, and large-scale pyrolysis reactors and supporting systems that adapt to the characteristics of biomass. Cost competitiveness is another core constraint: the high cost of collection, transportation, storage and pre-treatment of biomass feedstocks; The investment in the construction of large-scale and automated pyrolysis plants is huge; At present, the production cost of high-quality biochar is generally higher than that of traditional fossil-based reducing agents. Reducing the cost of the whole life cycle requires a multi-pronged approach: optimizing the regional straw collection, storage and transportation mode to reduce the cost of raw materials; develop high-efficiency and low-energy pyrolysis technology and equipment; Dig deep into the economic value of tar and pyrolysis gas; and explore external incentives for carbon tax policies or green subsidy mechanisms. At the same time, it is necessary to systematically evaluate the potential impact of large-scale application of biochar on the electric arc furnace smelting process, and establish perfect quality standards and application specifications. Future research needs to focus on the large-scale and engineering verification of key equipment, intelligent control of the process, economic optimization of the whole chain and environmental benefit assessment of the whole life cycle, so as to promote the technology from the laboratory to industrial application and provide substantial support for the green and low-carbon transformation of the steel industry.

5. Conclusion and Prospects

The application of biomass straw as a renewable resource in the metallurgical industry has shown significant potential for energy conservation and emission reduction, but it still faces the core bottleneck of large-scale promotion. The results show that its high volatile content and low-carbon sulfur characteristics can effectively replace fossil energy: the injection technology can reduce carbon by 23kg per ton of steel and slag iron oxide by 1.8 percentage points through the dynamic control model of "moisture content-injection rate-melt pool reaction", pyrolysis biochar can meet the demand for high-quality reducing agent in electric arc furnaces, and combustion heating technology has successfully verified the carbon neutrality advantage in small and medium-sized metallurgical equipment. However, the common challenges are alkali metal corrosion, insufficient mechanical strength of biochar, high cost of raw material collection and lack of large-scale equipment, which restrict the industrialization process.

In the future, it is necessary to make breakthroughs through multi-dimensional synergy: develop alkali metal removal and catalytic pyrolysis technologies at the process level to improve the strength and ash stability of biochar; At the equipment level, research and development of 100-ton continuous pyrolysis reactor, high-temperature resistant intelligent injection system and biomass-converter thermodynamic coupling device; At the industrial chain level, a regional straw intensive supply chain with steel mills as the core will be built, and the "biochar-tar-gas" multi-generation model will be implemented to reduce costs and increase efficiency; At the policy level, the quality standards of biomass reducing agents should be established, and the competitiveness should be enhanced by relying on the carbon tax and green subsidy mechanism. Only by integrating technological innovation, industrial chain integration and policy drive can we realize the leap of biomass straw from "laboratory

ISSN: 2414-1895 DOI: 10.6919/ICJE.202508_11(8).0022

verification" to "industrial-grade application", and finally provide a quantifiable technical path for the carbon neutrality goal of the steel industry.

Acknowledgments

Natural Science Foundation.

References

[1] G.W. Wang, L.Q. Zhang, J. Fu, et al. High-Quality Recycling and Utilization of China's Steel Scrap Resources in the Context of Carbon Peaking and Carbon Neutrality. Strategic Study of CAE. 2024,26(03):63-73.

[2] X.Y. Wang, B. Li, C. Lv, et al. China′s Iron and Steel Industry Carbon Emissions Peak Pathways. Research of Environmental Sciences. 2022,35(02):339-346.

[3] L. Hou, W. Wang, B. Liu, et al.Research Progress on Domestic and Overseas Straw Burning Control and Its Inspiration for Air Pollution Prevention and Control in China. 2025:1-33.

[4] Q.Y. Zhang, Y. Gao. Overview of the Recycling and Utilization of Agricultural Residue Abroad. World Environment. 2019,(02):74-76.