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"Three-in-One" Ecological Development and Efficient Utilization Model of Aggregates

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Abstract Green mining and the formation of an effective and efficient development model have become key issues that aggregates enterprises around the world need to solve urgently. On the basis of analyzing the development status of aggregates industry in Xiluodu area, the paper studied the main problems faced in the construction of green aggregates mines at present, and proposed a "three-in-one" ecological, intelligent and efficient green mine construction model for "ecological development", "green logistics" and "solid waste recycling" of aggregates. The study has certain theoretical value and practical significance for the construction of green aggregates mine in Xiluodu area.

Key words Aggregates, Ecological development, Efficient utilization

1 Introduction

In the context of sustainable economic development, mandatory energy consumption standards for building materials such as aggregates need to be formulated urgently. On April 22, 2022, eleven departments including the National Standardization Management Committee, the National Development and Reform Commission, and the Ministry of Industry and Information Technology jointly issued the *Guidelines for the Construction of Carbon Peak Carbon Neutral Standard System* (hereinafter referred to as the *Guidelines*), proposing focusing on basic general standards, as well as development needs such as carbon emission reduction, carbon removal, and carbon market, to basically establish a carbon peak and carbon neutrality standard system. The Guidelines states that by 2025, no less than 1 000 national standards and industry standards (including foreign language versions) will be formulated and revised, and the degree of consistency with international standards will be significantly improved, and energy consumption and energy efficiency standards will be steadily improved. In 2022, China's annual production and sales of aggregates reached 17.4 billion t. Against such a huge market background, the price of aggregates continues to fall due to overcapacity. According to the *2023 China Aggregates Industry Operation Report* released by the China Aggregates Association, the national comprehensive average price of aggregates was 105 yuan/t in December 2023, a decrease of 2.7% from January 2023. In such a severe market environment, how to realize green mining and form an effective and efficient development model has become a key problem that aggregates enterprises around the world need to solve urgently.

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2 Development status of aggregates industry in Xiluodu area

2.1 Aggregates market status

2.1.1 Decreased demand for aggregates. As a building material, aggregates are the largest, indispensable and irreplaceable raw materials in China's social infrastructure construction. In 2023, China's annual consumption of aggregates was about 16.8 billion t[1], equivalent to an average annual consumption of 12.4 t of aggregates per person. The demand and consumption of aggregates resources are second only to water resources, and they are the world's largest mineral products, raw materials and bulk commodities.

According to data released by the National Bureau of Statistics on April 16, 2024, the national real estate development investment was 2 208.2 billion yuan from January to March, a year-on-year decrease of 9.5% (calculated on a comparable basis); residential investment was 1 658.5 billion yuan, a decrease of 10.5%[2]. As a "key chent" in the aggregates industry, the real estate market is undergoing gradual downturn, which will inevitably lead to a gradual decline in the demand for aggregates resources.

2.1.2 Decreased supply of aggregates. At the same time, as various problems such as unenvironmentally friendly mining of aggregates mines, low resource utilization rate, and loss during transportation have become increasingly prominent, the traditional aggregates development model has been severely impacted, and the contradiction between supply and demand between limited resources and unlimited demand is prominent. Eco-efficient development has gradually become the mainstream model in the aggregates development model, and the construction of green mines has become the general trend of the future development of aggregates enterprises. After entering new development stage, the aggregates industry must unswervingly follow the concept of "lucid waters and

lush mountains are golden mountains and silver mountains", lead the high-quality development of the aggregates industry with green innovation and low-carbon development, create a new industrial structure, form a balance between supply and demand, and build a safe supply chain and a green, low-carbon and prosperous ecosystem[3]. At present, there is a shortage of natural aggregates supply in China (Fig. 1). The main reasons include unbalanced development and utilization of aggregates resources, and restricted mining of natural aggregates resources[4].

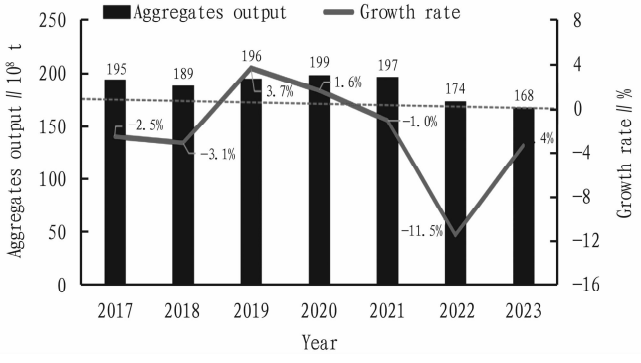

Fig. 1 Changes in China's aggregates production in 2023

2.2 Aggregates resources in Xiluodu Basin

2.2.1 Auction of aggregates resources[5]. On November 25, 2021, the Yongshan County Government auctioned off the mining rights of some aggregates resources in the Xiluodu River Basin. The total length of the Jinsha River channel for sand mining (the reservoir area of Xiluodu Hydropower Station in the Yongshan section) is 125.40 km, and the planned mineable (allowed to be mined) sand reserves of the channel are 8.735 million m^3. There are 8 mineable areas, the mineable length is 53.32 km, the mineable area is 16.85 km^2, and the total volume of mineable sand is 5 million m^3.

2.2.2 Abundant aggregates resources. The structure in the river basin of Xiluodu area is complex, and there are many NE-trending, NW-trending, S-N-trending, E-W-trending folds and faults[6]. The special topography and geomorphology have laid a good foundation for the formation of aggregates resources.

2.2.3 Construction of hydropower stations. The unique topography has also brought unique natural conditions to the construction of hydropower stations. Four famous giant hydropower stations, Xiluodu, Xiangjiaba, Baihetan and Wudongde, have been built in this area. The construction of hydropower stations requires a large quantity of reinforced concrete materials, which has brought a huge test and impetus to the development of the local aggregates industry.

2.2.4 Construction of roads. The waters of Xiluodu are located in the upper reaches of the Yangtze River, southwest of China, with underdeveloped economy and relatively blocked traffic. At the same time, the needs of urban development have also brought certain impetus to the aggregates industry. The main markets in the auction of river sand mining rights in the reservoir area of Shanduan Xiluodu Hydropower Station mentioned above include Dayong Expressway and Tianxingba medium-sized reservoir construction, Xiluodu dam transfer facilities, *etc.* The above projects and local infrastructure construction are expected to require 16 million m^3 of sand. At present, there are only 11 aggregates yards in Yongshan County, and the annual sand supply is only 1.25 million m^3. The above data show that the sales of aggregates in the Xiluodu Basin have good market prospects.

3 Problems in the construction of green mines

3.1 Ecological development The first thing the aggregates industry faces is the problem of resource mining. In the process of aggregates mining, there are basically the following three problems that restrict the development of the aggregates industry: the technical problems caused by production equipment, the environmental pollution problems caused by inadequate management and the low level of resource intensification caused by the small scale of most enterprises.

3.1.1 Technical problems arising from production equipment. The advanced nature of production equipment is the key to restricting the development of an industry, and the aggregates industry is no exception. The aggregates production mainly includes vibrating feeder, jaw crusher, impact crusher, circular vibrating screen and other machines. Machines of different prices and manufacturers will have a certain technical gap, which can easily be reflected in mining efficiency and mining quality.

3.1.2 Environmental pollution problems caused by inadequate management. The management is not in place mainly in two aspects: human resources management is not in place and machinery equipment management is not in place. Inadequate human resource management means that the deployment of personnel is insufficient and the use is unreasonable, resulting in production efficiency not achieving the expected effect; inadequate machinery equipment management refers to problems that cannot be discovered in time during the operation of machinery equipment, slow feedback and untimely processing.

3.1.3 Low level of resource intensification caused by the small scale of most enterprises. Most of the enterprises in the aggregates industry are small in scale, new enterprises continue to emerge, and the market has not undergone large-scale integration. Although the large number and small-scale enterprises have brought impetus to the development of the aggregates industry, there will also be problems such as insufficient investment funds, low level of resource intensification, and chaotic product standards.

3.2 Green logistics In recent years, due to the unbalanced regional production capacity, cross-regional aggregates allocation such as "transporting sand from the south to the north" and "moving sand from the north to the south" has become way to alleviate the contradiction in aggregates supply, which also poses a lot of challenges to aggregates transportation[7].

Green mountains and clear water are equal to mountains of gold and silver. Ore mining and transportation cannot be at the expense of the environment. However, in the actual ore transportation, there are many environmental problems, such as dust pollution and noise pollution. In aggregates transportation, the choice of transportation mode is a complex process, involving many factors such as cost, local natural and human environment. At pres-

ent, aggregates transportation mainly includes three modes: highway, railway and waterway. Highway transportation is very flexible and can cover most places. It is suitable for short-distance transportation between cities and nearer construction sites. The transportation time is relatively short, the cost is relatively high, and it is greatly affected by traffic conditions. Railway transportation is suitable for large-scale aggregates transportation, with relatively low energy consumption and pollution, and is suitable for long-distance transportation. Compared with highway transportation, the cost is lower, but railway transportation needs special railway lines and facilities, not only the construction cost is high, but also the transportation lines are fixed and not flexible enough. Waterway transportation has the lowest cost and the largest transportation capacity, so it is suitable for aggregates transportation between ports, and has relatively low energy consumption and pollution. However, the speed of waterway transportation is low and is greatly affected by the season and weather.

At present, there are still many problems in aggregates transportation. We should actively promote green and efficient transportation methods, reduce safety risks and environmental impacts in the process of aggregates transportation, and provide a strong guarantee for China's infrastructure construction and social and economic development.

3.3 Solid waste recycling In the process of aggregates mining, a large amount of solid waste is produced, which not only requires a lot of space for placement, but also causes great damage to the surrounding natural environment, affects the diversity of biological species and destroys the habitat of wild animals, and causes water pollution. Pollution and soil erosion have had a major impact on human production and life[8]. These large quantities of mine waste rocks are piled up in waste rock storage, tailings pond or dump around the mine for a long time, forming a "secondary mine" (Fig.2), which occupies a large quantity of land resources (Fig.3).

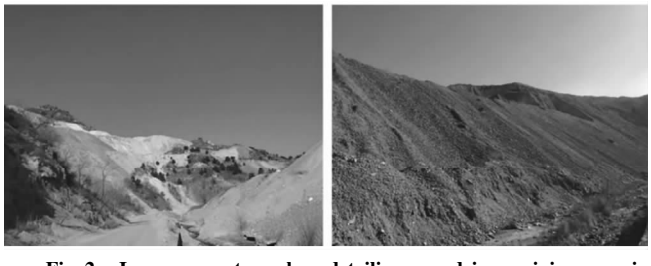

Fig.2 Iron ore waste rock and tailings pond in a mining area in Laiyuan, Baoding City, Hebei Province[9]

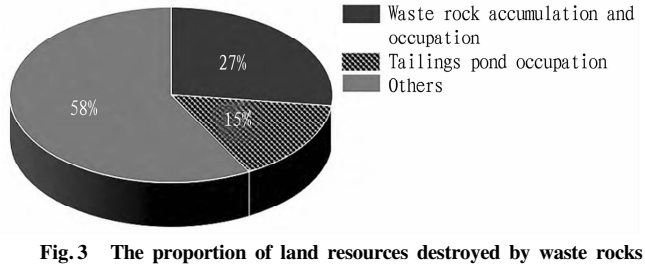

Fig.3 The proportion of land resources destroyed by waste rocks and tailings accumulation and occupation in the development of mine[10]

To solve the solid waste problem, we first need to understand the types of solid waste generated during aggregates mining, as well as the reasons and processes for generating solid waste. There are many types of solid waste generated by the aggregates industry, mainly including tailings, coal gangue, waste rock, industrial waste residue, *etc.*

Tailings refers to the material that has low content of useful target components in the product of the separation operation in the mineral processing and cannot be used in production. Under the current technical and economic conditions, tailings are not suitable for further separation. However, with the development of the times and the improvement of technical level, tailings recovery and utilization may still have further economic value.

The second issue is the storage of solid waste. Space for storage of solid waste is essential because of the large volume of solid waste generated and because of technical constraints that prevent immediate recovery and disposal. However, in the current situation where land resources are extremely scarce, the storage space for solid waste is very limited. In addition, during storage, solid waste can cause serious damage to the environment. For example, the surrounding rocks, slag, tailings and waste rocks and mining pits of abandoned mines produced in the mining process are usually not treated in time, which seriously damages the ecological environment[11], and a large quantity of waste rocks can even destroy farmland and forests; waste residue accumulates through various chemical reactions, may dissolve in water and penetrate downward, causing large-scale land pollution, resulting in land acidification, alkalization and hardening; the accumulation of coal gangue may lead to spontaneous combustion, cause fires and release large amounts of sulfur dioxide, causing serious air pollution.

Finally, there are problems with the recycling of solid waste. Due to technical and economic constraints, solid waste generated by the aggregates industry is often unable to be recycled and reused in a timely manner. At present, the treatment of solid waste often only involves stacking, landfilling, incineration, biodegradation, *etc.*, without making full use of solid waste, resulting in a large amount of waste of resources. Solid waste has a wide variety of types and requires a variety of recycling technologies. During the recycling process, residual waste may still exist, and new waste may even be generated, which requires substantial technical research costs.

4 Research on ecological development and efficient utilization model

4.1 Ecological development

4.1.1 Green mines. In the development stage, carbon emissions are the highest under the extensive development model (Fig.4). And it is obvious that carbon emissions are mainly generated in the production stage, so the production stage is an important stage for building green mines.

The optimization of the process can effectively reduce energy consumption and negative impact on the environment. The traditional wet production process of machine-made aggregates is prone

to problems such as large water consumption, occupation of a large amount of arable land, and great geological hazards. Therefore, the "pre-dry and post-wet" machine-made green aggregates production process, which combines the characteristics of wet process and dry process, is produced. This process can effectively ensure product quality, realize the goals of water saving, material saving, land saving, and eliminating geological hidden dangers, as well as dust-free and tailings-free production[12]. At the same time, it also adopts the semi-dry process of "breaking instead of grinding" and "wet first and then semi-dry"[13]. In addition to the effect of semi-dry process on dust prevention, noise prevention and sewage treatment are also part of process optimization. New noise-isolating materials, multi-row delayed blasting, multi-stage blasting, fully enclosed technology in workshops[14] and sewage classification treatment method also make the overall process more environmentally friendly and green.

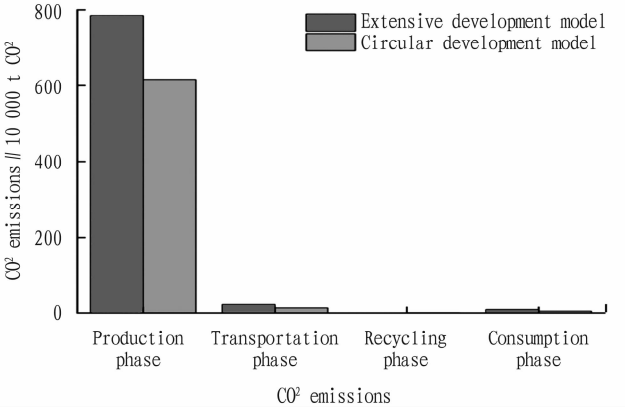

Fig. 4 Comparison of carbon emissions between extensive development model and circular development model

4.1.2 Smart mines. The innovation and upgrading of machines is also an important way to realize ecological development. Today, with the continuous development of the globalization process, the aggregates industry will inevitably need technological empowerment in the future to realize intelligence and informatization, that is, the integration of intelligence and informatization, and use informatization to drive industrialization, promote informatization with industrialization, and take a new road to industrialization. The essence of the integration of intelligence and industrialization is the demand traction of industrialization and the technology drive of informatization[15]. For the overall intelligent management and control, Zhou Yu and Li Yong proposed that the construction of the digital aggregates mine construction system can be realized from bottom to top, mainly including the perception layer, execution control layer, system operation and maintenance layer, and centralized management and control layer[16].

Smart mines realize digital management of resources, automatic management and control of production, full-process less-manned and unmanned operations, and intelligent decision-making based on industrial big data. It is intrinsically safe, resource-intensive, green and efficient, and is an important means to promote the transformation and upgrading of mining enterprises, and improve its core competitiveness[17-19].

In view of the characteristics of scattered and chaotic aggregates enterprises and relatively difficult supervision, competitive enterprises can stand out through policy regulation, use their own advantages to integrate regional resources, and achieve intensive mining of aggregates.

To realize the ecological development of aggregates, one is green and the other is intelligence. Green is realized by production technology, while intelligence is realized by technological innovation. Through green and intelligent construction, the purpose of improving the quality and efficiency of aggregates production is achieved. In intelligent construction, unmanned and systematized modes are relatively advanced technical means. Through cloud computing and background monitoring, the efficiency of the overall production line is improved and production energy consumption is reduced; for emergencies and problems, they should get immediate feedback and be dealt with in a timely manner.

4.2 Green logistics The finished products after aggregates mining are usually transported to relevant sites for use through logistics. The traditional way is to transport them multiple times by truck to the destination. Green logistics refers to the logistics activities that use advanced logistics technology, production concepts, and loading and unloading machinery in packaging, transmission, shipment, circulation and other links, thereby reducing resource consumption, reducing environmental pollution, and realizing corporate profits[20].

There are many ways to realize green logistics, including increasing the proportion of railway transportation, increasing the design and transformation of special containers for aggregates, and green reprocessing. For the traditional truck transportation, there is also a corresponding all-purpose loading and weighing management system[21], which realizes the queuing scheduling, automation of access control management and intelligent transportation through the IC card.

As far as the mode of transportation is concerned, there are generally several types such as "highway-to-railway", "highway-to-waterway" and "multimodal transport", and pure highway transport can also be used for short distances. The highway transportation has high mobility, high efficiency and strong adaptability, but the transportation distance is limited. It is generally more than 80 km, has poor economic benefits, damages roads and pollutes the environment; the railway transportation speed is fast and the cost is low, but most aggregates enterprises do not have special railway lines, the operation is difficult, and it is easy to cause secondary pollution to the environment during transportation; the waterway transportation has the largest transportation volume, long distance, and low cost, but it is not suitable for mountainous areas with complex terrain, and at the same time, the transportation time is relatively long, and usually it can't achieve the goal at one time. It requires "waterway-to-highway" and "waterway-to-railway"[7]. The unique topography and geomorphology conditions in Xiluodu area determine that railway transportation is difficult to carry out on a large scale, and it is not very suitable for waterway transportation of bulk goods under rugged terrain conditions.

Therefore, for areas with inconvenient transportation, the logistics transfer of aggregates can be carried out by transportation to

neighboring cities. In order to avoid pollution to the urban environment, the transfer place can be chosen in the suburbs close to railways or waterways, preferably the downwind direction of the dominant wind. Transportation efficiency can be improved through logistics transfer, and measures such as new energy vehicles can be taken to reduce carbon emissions during transportation.

4.3 Solid waste recycling

4.3.1 Concept of solid waste recycling. After the mining and transportation stage, the recovery of waste and construction waste in aggregates mining is also a relatively important part. On May 18, 2016, the General Office of the State Council issued the *Guiding Opinions on Promoting the Steady Growth of the Building Materials Industry, Adjusting Structure and Increasing Benefits*, pointing out that the development of special cement, aggregates, and component products should be accelerated. It is necessary to actively use solid waste such as tailings waste and construction waste to replace natural resources, and develop products such as machine-made aggregates, concrete admixtures, and block wall materials. In July 2021, the 14th *Five-Year Plan for Circular Economy Development* issued by the National Development and Reform Commission pointed out that it is necessary to strengthen the comprehensive utilization of resources. It is necessary to strengthen the comprehensive utilization of low-grade ore, associated ore, tailings, *etc.* It is necessary to strengthen the comprehensive utilization of resources, promote the coordinated disposal of urban waste, build a resource recycling industrial system, and improve the efficiency of resource utilization. It is proposed that by 2025, the comprehensive utilization rate of bulk solid waste should reach 60%.

For the recycling of different types of aggregates waste, there should be different treatment schemes. For the waste generated in the mining process, it can be piled up nearby, and can be piled up, stored or even processed in the recycling station; for the recycling of construction waste generated in urban construction, there should be a unified recycling and treatment site far away from the urban area. It is worth noting that good classification should be paid attention to during the recycling process to avoid excessive accumulation that may affect the efficiency when it is processed.

4.3.2 Solid waste recycling. It is not limited to aggregates mining enterprises, and recycling ways at all levels have been developed for the construction waste of real estate and infrastructure in various areas of China, and used in strengthening roadbed fillers, recycled brick production and recycled aggregate production[22]. The aggregates waste produced by aggregates mines can be used to prepare artificial sand with fly ash based geopolymer, which can not only realize the recycling of industrial solid fly ash waste, but also prepare machine-made aggregates with better quality[23]. Based on the application of aggregates made from waste rock in concrete, it is found that the mechanical properties of aggregates made from waste rock are relatively stable, and can completely replace natural aggregates to prepare high-strength and high-durability concrete. However, the grading of aggregates prepared from waste rock is poor, resulting in poor workability of the prepared concrete, and problems such as segregation and bleeding are prone to occur. The working performance of the concrete mixture can be adjusted by partially replacing natural river sand or admixture compounding technology[24].

The construction waste generated in urban construction can also be turned into subgrade waste material or temporary construction materials for some roads through secondary utilization, or used as mortar for building a wall and plastering. It can also be used for architectural decoration and materials such as solid bricks, paving bricks and lattice bricks. It can even replace coarse aggregate for recycling. According to the experimental data of the National Engineering Laboratory for Solid Waste Resource Recycling of Guilin University of Technology, Guangxi, when the proportion of coarse aggregate in concrete materials replaced by sieved concrete fragments in construction waste is between 0% and 40%, the strength of concrete does not decrease, and it gradually increases when the mixing rate of concrete fragments is about 20%. And because the concrete block has higher void ratio, higher water absorption rate, rougher surface and larger surface area than crushed stone or pebble, it can reduce the collapsibility of concrete. The apparent density of concrete blocks is lower than that of crushed stones and pebbles, it is conducive to reducing the weight of the concrete itself, thereby improving the seismic performance of the concrete[25].

5 Conclusion

In accordance with the analysis of the current situation of the aggregates industry, restricting and prohibiting mining is an important method to ensure the orderly operation of the aggregates industry, but it is not the fundamental method to solve the sustainable development of the aggregates industry. The sustainable development of the aggregates industry needs to accelerate the construction of modern green mines and explore new models of ecological development and efficient utilization of aggregates. By analyzing the problems existing in the links of aggregates development, transportation and recycling, the study explores the formation of a closed-loop "three-in-one" ecological development and efficient utilization model of aggregates integrating ecological development, green logistics, and solid waste recycling, in order to empower the aggregates industry, promote the ecological, intelligent, efficient, and intensive construction of the industry, boost the sustainable and high-quality development of the aggregates industry, and promote the smooth operation of the real estate industry and even the national economy.

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with the needs of the processing process, optimize resource allocation, form a complete industrial chain, and improve the overall efficiency of agricultural production. Secondly, in the agricultural production process, accelerate the promotion of new technologies such as water-saving irrigation and precision fertilization, reduce the waste of water and fertilizer resources, and improve agricultural production efficiency. It is recommended to accelerate the application of agricultural mechanization and intelligent technology, achieve automation and intelligence in agricultural production processes, reduce labor costs, and improve the quality and efficiency of agricultural production.

5 Conclusions

The Belt and Road Initiative provides a valuable opportunity for China's rural agricultural economic management. This paper points out the current problems affecting the healthy development of rural agricultural economy, and puts forward a series of targeted innovative strategies through the research on the innovation of rural agricultural economic management model in the context of the Belt and Road Initiative. By making innovation in the management model of rural agricultural economy, we aim to promote the sustainable and healthy development of rural agricultural economy, and contribute to the realization of rural revitalization and national economic development.

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