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# A Study on Vegetation Restoration and Ecological Rehabilitation of Mine Slopes Based on Bioengineering Technology

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**Abstract:** This paper studies the application of bioengineering technology for vegetation restoration and ecological rehabilitation of mine slopes. Bioengineering technology is a comprehensive engineering technology that uses living plants and other auxiliary materials to construct slope structures, and realizes the stability, vegetation restoration and ecological rehabilitation of the slopes. Then, the paper reveals the principle and mechanism of bioengineering technology, which is mainly to use the parts of plants, such as roots, stems and leaves, to reinforce, fix and protect the slope soil, and to improve and regulate the slope ecosystem. The paper further explores the methods and techniques of bioengineering technology, and studies and summarizes the specific methods and techniques of plant selection, configuration, planting and management of bioengineering technology. Finally, the paper points out the problems and challenges of bioengineering technology, such as the imperfection of theory and method, the limitation of application and promotion, the deficiency of monitoring and management, and the uncertainty of social and environmental impact, and suggests further research and exploration of bioengineering technology. The paper concludes that bioengineering technology is a promising technology for vegetation restoration and ecological rehabilitation of slopes.

**Keywords:** Slope treatment, Bioengineering technology, Revegetation, Rcological remediation.

## 1. Introduction

Mine slopes refer to the inclined surface formed by the mining process, which is an important part of the mine ecosystem and a sensitive area of the mine environment[1-3]. The impact of mining on the slopes mainly manifests in the following aspects: first, it destroys the original soil and vegetation of the slopes, resulting in the exposure and degradation of the slopes[4]; second, it changes the morphology and structure of the slopes, leading to the instability and failure of the slopes; third, it increases the erosion and pollution of the slopes, resulting in the soil loss and water quality deterioration of the slopes. These problems not only threaten the safety and stability of the slopes, but also affect the ecological function and biodiversity of the slopes, as well as the landscape effect and social benefit of the slopes.

In order to solve the environmental problems of the mine slopes, and achieve the vegetation restoration and ecological rehabilitation of the slopes, various methods and techniques have been adopted in the treatment process, mainly including physical methods, chemical methods, biological methods and comprehensive methods. Physical methods refer to the use of artificial materials or natural materials to reinforce and protect the slopes[5], such as steel mesh, anchor bolts, sprayed concrete, gabion mesh, grass bags, etc. This method can improve the stability and protection of the slopes, but it has high cost, short life, large environmental pollution, and is not conducive to the growth of vegetation and the restoration of ecology. Chemical methods refer to the use of chemical substances to improve and solidify the slope soil[6], such as cement, lime, polymer, etc. This method can improve the physical and mechanical properties of the slope soil, but it will destroy the chemical and biological properties of the slope soil, affecting the ecological balance and biodiversity of the slopes. Biological methods refer to the use of living plants or microorganisms to restore vegetation and ecology of the slopes[7], such as seeding, planting, grafting, inoculation, etc. This method can use the physiological and biochemical effects of plants or microorganisms to strengthen, fix and protect the slope soil, as well as to improve and regulate the slope ecosystem. It has the characteristics of low cost, high efficiency, environmental protection, beauty and sustainability, but it is limited by the slope soil, climate, moisture and other conditions, and requires a long time and more management(Figure 1). Comprehensive methods refer to the comprehensive use of physical methods, chemical methods and biological methods according to the specific situation of the slopes, to achieve the stability, vegetation restoration and ecological rehabilitation of the slopes. This method can fully utilize the advantages of various methods, compensate for the shortcomings of various methods, and achieve the best effect, but it requires a high level of technology and coordination ability.

Bioengineering technology is a kind of comprehensive technology that uses biological methods and physical methods, and uses living plants and other auxiliary materials to construct the slope structure, and realizes the comprehensive engineering technology of the stability, vegetation restoration and ecological rehabilitation of the slopes. The research purpose of this paper is to explore the application principle, method, effect and prospect of bioengineering technology in vegetation restoration and ecological rehabilitation of mine slopes, and to provide theoretical guidance and technical support for the environmental treatment and ecological construction of mine slopes. The research method of this paper is to systematically summarize and analyze the related theory and practice of bioengineering technology, as well as the existing problems and development direction, through literature review, case analysis, effect evaluation and other ways.

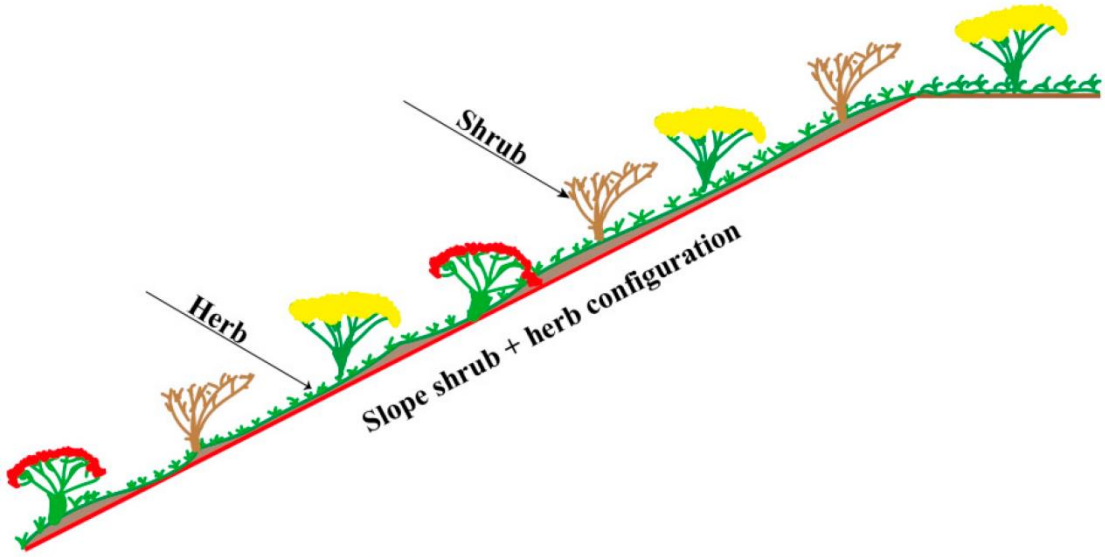


**Figure 1.** The configuration of grass and shrub vegetation on the slope[8]

# 2. Concept and Principle of Bioengineering Technology

## 2.1. Definition of Bioengineering Technology

Bioengineering technology is a comprehensive engineering technology that uses living plants and other auxiliary materials to construct the slope structure, and realizes the stability, vegetation restoration and ecological rehabilitation of the slopes[9-11]. Bioengineering technology is a typical ecological engineering technology, which is based on ecology as the theoretical foundation, engineering technology as the means, ecological benefit as the goal, and achieves the harmonious coexistence of human and nature through artificial intervention and regulation.

Bioengineering technology is based on living plants as the main body, using the physiological, biochemical and ecological effects of plants to strengthen, fix and protect the slope soil, and improve and regulate the slope ecosystem. It is assisted by other auxiliary materials, using artificial materials or natural materials, such as steel mesh, anchor bolts, sprayed concrete, gabion mesh, grass bags, etc., to reinforce and protect the slope structure, and improve the stability and protection of the slopes. It is a means of comprehensive engineering technology, which comprehensively uses biological methods and physical methods according to the specific situation of the slopes, and realizes the stability, vegetation restoration and ecological rehabilitation of the slopes, and achieves the best effect. The fourth is to take ecological benefit as the goal, and through the application of bioengineering technology, not only improve the safety and stability of the slopes, reduce soil erosion and environmental pollution, but also restore the ecological function and biodiversity of the slopes, improve the landscape effect and social benefit of the slopes.

## 2.2. Principle of Bioengineering Technology

The principle of bioengineering technology is mainly to use the parts of plants, such as roots, stems and leaves, to strengthen, fix and protect the slope soil, and improve and regulate the slope ecosystem. Specifically, the roots of plants can strengthen and fix the slope soil in the following ways. The anchoring effect of roots, that is, the roots form a complex network structure in the soil, connect the soil particles tightly, increase the cohesion and friction angle of the soil, improve the shear strength and erosion resistance of the soil (Figure 2); the water absorption effect of roots, that is, the roots absorb the water in the soil, reduce the water content and pore water pressure of the soil, reduce the softening and liquefaction of the soil, increase the stability and bearing capacity of the soil; the secretion effect of roots, that is, the roots secrete organic acids, polysaccharides, enzymes and other substances, change the chemical and biological properties of the soil, promote the aggregation and structuration of the soil, increase the density and hardness of the soil; the respiration effect of roots, that is, the roots consume the oxygen in the soil through respiration, produce carbon dioxide, reduce the redox potential of the soil, inhibit the acidification and corrosion of the soil, increase the buffering capacity and corrosion resistance of the soil.

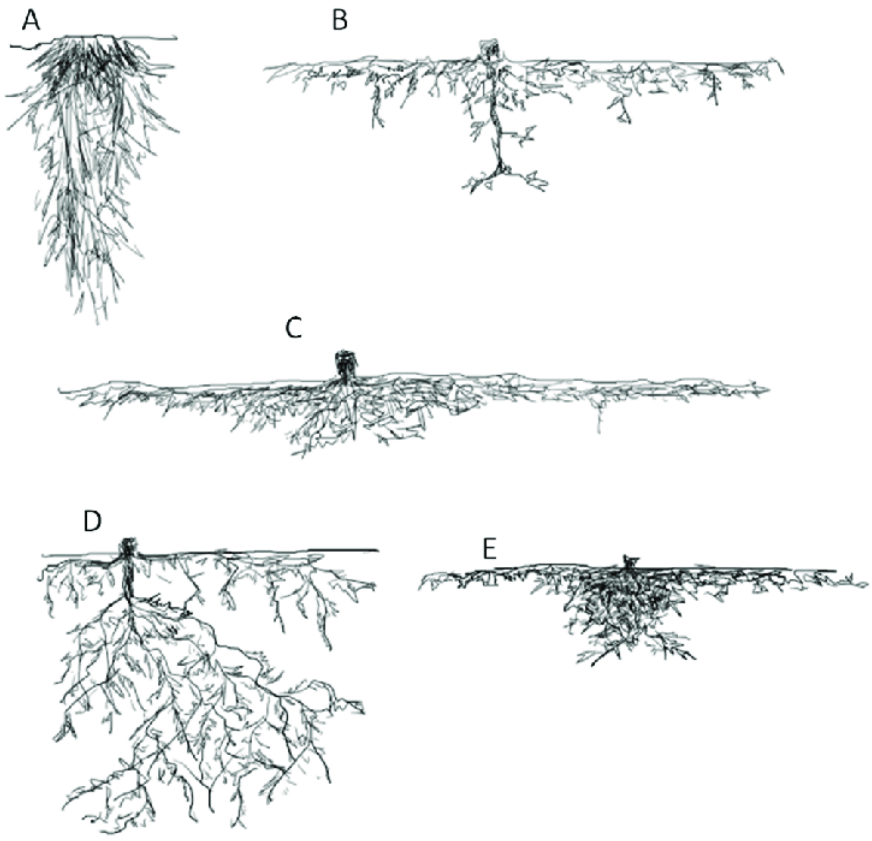


**Figure 2.** Different root systems development. (A) Tuft and deep root systems, (B) taproot root system, (C) superficial root system, (D) taproot and horizontal lateral roots, (E) heart-shaped root architecture[7].

The stems and leaves of plants can protect and improve the slope soil in the following ways: first, the shading effect of stems and leaves, that is, the stems and leaves block the sunlight, reduce the surface temperature and evaporation of the slopes, reduce the water loss and drought of the slopes, increase the water retention and utilization of the slopes; second, the interception effect of stems and leaves, that is, the stems and leaves intercept the rainwater, reduce the runoff and erosion of the slopes, increase the infiltration and percolation of the slopes, improve the hydrological and hydraulic conditions of the slopes; third, the buffering effect of stems and leaves, that is, the stems and leaves buffer the impact force of raindrops, reduce the scouring and erosion of the slopes, protect the surface soil and vegetation of the slopes; fourth, the nutrition effect of stems and leaves, that is, the stems and leaves produce organic matter through photosynthesis, and transform it into organic fertilizer through humification, increase the soil fertility and productivity of the slopes[12, 13].

The improvement and regulation effect of plants on the slope ecosystem mainly manifests in the following aspects: first, the restoration of the ecological function of the slopes, that is, the plants provide food, habitat, refuge and other services, attract and nourish other organisms of the slopes, such as insects, birds, small mammals, etc., increase the biodiversity and ecological complexity of the slopes, and form a complete ecosystem; second, the regulation of the ecological process of the slopes, that is, the plants participate in and affect the material cycle and energy flow of the slopes, such as carbon cycle, nitrogen cycle, water cycle, etc., maintain and balance the ecological balance and stability of the slopes, resist and adapt to the environmental changes and disturbances of the slopes[14]; third, the provision of ecological services of the slopes, that is, the plants provide a series of ecological services, such as water conservation, soil conservation, air purification, climate regulation, landscape beautification, leisure and entertainment, etc., increase the ecological value and social value of the slopes[15].

## 2.3. Advantages of Bioengineering Technology

Bioengineering technology has the advantages of low cost, high efficiency, environmental protection, beauty and sustainability compared with other methods and techniques. Low cost advantage, hat is the main materials of bioengineering technology are living plants and other auxiliary materials, which have relatively low prices, and can use local resources, reduce transportation and construction costs, and at the same time, the construction and management of bioengineering technology are relatively simple, do not need complex equipment and professional personnel, save human and material resources. High efficiency advantage, that is, the effect of bioengineering technology can be shown in a short time, and with the passage of time, the effect will be better and better, because the growth and development of plants will continuously enhance the stability and ecology of the slopes, forming a self-repairing and self-maintaining system, which does not need too much later maintenance and management. Environmental protection advantage, that is, the materials and processes of bioengineering technology are environmentally friendly, do not produce harmful waste and pollutants, but purify and improve the environment of the slopes, increase the ecological services of the slopes, such as

water conservation, air purification, climate regulation, etc., and provide more benefits for human and nature. Beauty advantage, that is, the effect of bioengineering technology is a natural and harmonious beauty, which will not destroy the original appearance and characteristics of the slopes, but will increase the color and level of the slopes, improve the landscape value and aesthetic value of the slopes, and provide more space and opportunities for people's leisure and entertainment. Sustainability advantage, that is, the effect of bioengineering technology is a long-term and stable effect, which will not decay or disappear with the change of time, but will update or optimize with the renewal and succession of plants, forming a dynamic balance and development state, adapting and coping with the environmental changes and disturbances of the slopes, maintaining the ecological function and biodiversity of the slopes.

# 3. Classification and Methods of Bioengineering Technology

## 3.1. Plant Selection

Plant selection is a key link of bioengineering technology, which directly affects the effect and efficiency of bioengineering technology[16]. Plant selection should be based on the specific conditions of the slopes, such as soil, climate, moisture, light, slope, aspect, etc., and the target function of the slopes, such as stabilization, restoration, rehabilitation, beautification, etc., and comprehensively consider the growth characteristics of the plants, such as roots, stems, leaves, flowers, fruits, seeds, etc., and the ecological adaptability of the plants, such as drought tolerance, cold tolerance, salt tolerance, pollution tolerance, disease and pest resistance, etc., and select the suitable plant species and varieties for the slopes.

Generally speaking, the plants of bioengineering technology should have developed roots, which can effectively fix and strengthen the slope soil, such as the fibrous roots of herbaceous plants, the adventitious roots of shrubs, the buttress roots of trees, etc. The stems and leaves are dense, which can effectively protect and improve the slope soil, such as the creeping stems of herbaceous plants, the branches of shrubs, the crowns of trees, etc. The flowers, fruits and seeds are rich, which can effectively increase the color and level of the slopes, such as the inflorescences of herbaceous plants, the fruits of shrubs, the seeds of trees, etc. The growth rate is fast, which can effectively shorten the restoration and rehabilitation time of the slopes, such as the annual or perennial herbaceous plants, the sprouting or grafting of shrubs, the cutting or transplanting of trees, etc. The ecological adaptability is strong, which can effectively adapt to and cope with the environmental changes and disturbances of the slopes, such as the drought or cold tolerance of herbaceous plants, the salt or pollution tolerance of shrubs, the disease and pest resistance or wind resistance of trees, etc.

According to the growth habits and ecological functions of plants, the plants of bioengineering technology can be divided into the following categories: first, pioneer plants, that is, the plants that can quickly cover and stabilize the slopes in the early stage of restoration and rehabilitation, such as clover, alfalfa, Bermuda grass, etc., shrubs such as black locust, lemon, plum, etc., trees such as willow, poplar, alder, etc.; second, main plants, that is, the plants that can form and maintain the main structure and function of the slopes in the middle stage of restoration and rehabilitation, such as herbaceous plants such as sheep grass, ice grass, dogtooth root, etc., shrubs such as seabuckthorn, tamarisk, forsythia, etc., trees such as pine, locust, camphor, etc.; third, auxiliary plants, that is, the plants that can increase and optimize the diversity and beauty of the slopes in the late stage of restoration and rehabilitation, such as herbaceous plants such as iris, dandelion, violet, etc., shrubs such as rose, lilac, camellia, etc., trees such as plum, peach, cherry, etc.

## 3.2. Plant Configuration

Plant configuration refers to the reasonable arrangement and combination of plant species and quantities according to the morphology and structure of the slopes, and the growth characteristics and ecological functions of the plants, forming a coordinated and unified vegetation system[17]. Plant configuration should follow the adaptation principle, that is, plant configuration should adapt to the natural conditions of the slopes, such as soil, climate, moisture, light, slope, aspect, etc., and select the suitable plant species and varieties for the slopes, and avoid using unsuitable or harmful plants. Function principle, that is, plant configuration should conform to the target function of the slopes, such as stabilization, restoration, rehabilitation, beautification, etc., and select the plant species and varieties with corresponding functions, and achieve the function maximization of the slopes. Structure principle, that is, plant configuration should form a reasonable structure, such as level, density, distribution, proportion, etc., and select the plant species and varieties with different levels, densities, distributions, proportions, etc., and achieve the structure optimization of the slopes. Aesthetic principle, that is, plant configuration should create a beautiful landscape, such as color, shape, style, rhythm, etc., and select the plant species and varieties with different colors, shapes, styles, rhythms, etc., and achieve the landscape beautification of the slopes.

According to the configuration mode of plants, the plants of bioengineering technology can be divided into single configuration, mixed configuration, layered configuration, and zonal configuration. Single configuration is to use only one plant species or variety, forming a single vegetation layer, such as clover, black locust, willow, etc., which is simple and easy, but lacks diversity and beauty, and is easily affected by diseases, pests and environmental changes. Mixed configuration is to use multiple plant species or varieties, forming a diverse vegetation layer, such as clover, alfalfa, sheep grass, etc., shrubs such as black locust, seabuckthorn, rose, etc., trees such as willow, pine, plum, etc., which is rich and colorful, with diversity and beauty, and can improve the ecological function and biodiversity of the slopes, and resist and adapt to the environmental changes and disturbances of the slopes. Layered configuration is to divide the plants into different levels according to their growth height, forming a three-dimensional vegetation system, such as herbaceous plants as the first layer, shrubs as the second layer, trees as the third layer, which makes full use of the space of the slopes, increases the three-dimensional sense and level sense of the slopes, and can realize the complementarity and coordination between plants, and improve the ecological efficiency and stability of the slopes. Zonal configuration is to divide the plants into different zones according to the different parts of the slopes, forming a zonal vegetation system, such as herbaceous plants as the upper part of the slopes, shrubs as the middle part of the slopes, trees as the lower part of the slopes, which fully considers the difference of the slopes,

increases the diversity and richness of the slopes, and can realize the adaptation and matching between plants and slopes, and improve the ecological adaptability and coordination of the slopes.

# 4. Research Progress and Prospects of Bioengineering Technology

Bioengineering technology, as a new technology for vegetation restoration and ecological rehabilitation of slopes, has received wide attention and application at home and abroad in recent years, and has achieved some important research results and practical experience, but there are also some problems and challenges that need further research and exploration.

The research of bioengineering technology mainly includes two aspects: theoretical research and applied research[18]. Theoretical research mainly discusses the principles, mechanisms, models, evaluation and other issues of bioengineering technology from the perspectives of ecology, soil science, engineering mechanics, etc., and provides theoretical guidance and technical support for the application of bioengineering technology. Applied research mainly discusses the methods, techniques, effects, economy and other issues of bioengineering technology from the perspective of engineering practice, and provides practical experience and suggestions for the promotion and optimization of bioengineering technology[18].

The concept and definition of bioengineering technology have been clarified, and the similarities and differences between bioengineering technology and other related technologies, such as ecological engineering technology, vegetation engineering technology, ecological restoration technology, etc., have been distinguished, providing a unified understanding and basis for the research and application of bioengineering technology. The principles and mechanisms of bioengineering technology have been revealed, and the physical, chemical and biological processes and laws of the effects of plant roots, stems and leaves on the reinforcement, fixation and protection of slope soil, and the improvement and regulation of slope ecosystem have been analyzed through experiments and numerical simulations, providing scientific basis and methods for the design and construction of bioengineering technology. The models and evaluation of bioengineering technology have been established, and the influence and effect of bioengineering technology on the stability and ecology of slopes have been simulated and predicted by establishing the coupling models of multiple factors such as plant-soil-water-air, and the evaluation indicators and systems of bioengineering technology have been established, and the advantages and disadvantages and applicability of bioengineering technology and other technologies have been evaluated and compared, providing quantitative standards and references for the selection and optimization of bioengineering technology. The methods and techniques of bioengineering technology have been explored, and the specific methods and techniques of plant selection, configuration, planting and management of bioengineering technology have been studied and summarized through experiments and demonstrations, such as the propagation methods of plants, such as seeds, seedlings, tissue culture, grafting, etc., the configuration methods of plants, such as single, mixed, layered, zonal, etc., the planting methods of plants, such as sowing, planting, grafting, inoculation, etc., the management methods of plants, such as irrigation, fertilization, pruning, disease and pest prevention, etc., providing operational guidance and skills for the implementation and maintenance of bioengineering technology. The effects and economy of bioengineering technology have been verified, and the application effects and economic benefits of bioengineering technology on different types and conditions of slopes have been verified and evaluated through monitoring and analysis, such as the application effects of bioengineering technology on slopes of different engineering types, such as highways, railways, water conservancy, mines, etc., the application effects of bioengineering technology on slopes of different environmental conditions, such as drought, cold, salinity, pollution, etc., the advantages and disadvantages and applicability of bioengineering technology compared with other technologies in terms of cost, efficiency, environment, beauty, etc., providing typical cases and data for the promotion and application of bioengineering technology[19].

# 5. Conclusion

Bioengineering technology is a comprehensive technology that uses biological methods and physical methods, and uses living plants and other auxiliary materials to construct slope structures, and realizes the comprehensive engineering technology of slope stabilization, vegetation restoration and ecological rehabilitation. The principle of bioengineering technology is mainly to use the parts of plants, such as roots, stems and leaves, to reinforce, fix and protect the slope soil, and to improve and regulate the slope ecosystem.

For future development, we should strengthen the theoretical research of bioengineering technology, deeply explore the principles and mechanisms of bioengineering technology, establish and improve the models and evaluation of bioengineering technology, and provide theoretical guidance and technical support for the application of bioengineering technology. We should strengthen the applied research of bioengineering technology, widely carry out the experiments and demonstrations of bioengineering technology, summarize and popularize the methods and techniques of bioengineering technology, and provide practical experience and suggestions for the promotion and optimization of bioengineering technology. We should strengthen the monitoring and management of bioengineering technology, improve and update the monitoring means and equipment of bioengineering technology, rationalize and standardize the monitoring frequency and range of bioengineering technology, fully and timely obtain the monitoring data and information of bioengineering technology, and scientifically and effectively manage the measures and methods of bioengineering technology, and provide operational guidance and skills for the implementation and maintenance of bioengineering technology. We should strengthen the social and environmental impact research of bioengineering technology, assess and predict the social benefit and risk of bioengineering technology, assess and predict the environmental effect and impact of bioengineering technology, consider and coordinate the social and environmental adaptability and coordination of bioengineering technology, and provide quantitative standards and references for the selection and optimization of bioengineering technology.

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