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STRATEGIC WASTE MANAGEMENT IN THE MINING AND STONE PROCESSING INDUSTRY: ENVIRONMENTAL SUSTAINABILITY AND INTERNATIONAL EXPERIENCE

The growth of mining activities to meet global demand for minerals necessitates strategic waste management that considers environmental sustainability, energy requirements, and associated environmental risks. Mining poses significant environmental risks through the generation of various waste products, such as tailings and sludge, which require research to assess and mitigate impacts on soil, water, and ecosystems [1].

The increase in natural stone production worldwide (China - 20.82 million tonnes, Italy - 11.93 million tonnes, India - 9.64 million tonnes annually) and in Ukraine (over 10 million tonnes of solid minerals) is accompanied by the generation of a significant amount of waste in solid, powder, and liquid forms. The technological processes of processing natural stone (cutting blocks, chipping, sawing, grinding, and polishing) generate dust waste in an amount exceeding 30% of the original mass of raw materials, and the degree of their utilization is extremely low, only 10%. The accumulation of this biodegradable waste causes significant environmental problems, including the blockage of water flows, air pollution with fine particles, land degradation, aquifer contamination, and reduced soil fertility. Given the scale of the stone mining industry in Ukraine and the environmental threats associated with it, the introduction of integrated technologies for the utilisation of stone mining and stone processing waste, in particular in the production of geopolymer concrete and other construction materials, is not only a pressing task in the context of resource conservation, but also an economically viable solution that meets the modern principles of the circular economy[2].

The slurry generated during mining operations, which accumulates in large volumes in tailings ponds, poses a significant environmental threat. It not only occupies large areas, taking them out of economic circulation, but also creates risks of soil, groundwater, and surface water contamination with heavy metals and other harmful substances. However, thanks to modern technological advances and innovative approaches, pulp can be transformed from an environmentally hazardous waste into a valuable secondary resource.

The use of acceptable stone processing waste from the Zhytomyr region in the production of geopolymers and concrete is a promising area of resource conservation, as the optimal concentration of up to 25% ensures acceptable material strength. Geopolymer concrete made from such waste has environmental benefits, including reduced CO_2 emissions and energy consumption, and demonstrates improved performance compared to traditional concrete. Additionally, slurry and other low-hazardous mining waste can be utilized in the production of building materials and for quarry reclamation.

As a leader in Ukraine in terms of reserves and production of decorative stone, Zhytomyr region faces significant environmental challenges due to the accumulation of industrial waste. Still, it has considerable potential to introduce technologies for recycling

this waste, particularly in the production of geopolymer concrete, which aligns with the principles of the circular economy.

Table 1: Mining and stone processing industry in Zhytomyr region

Features	Data
Decorative stone reserves as a share of total reserves in Ukraine	~35%
The share of high-strength stone types in the total Ukrainian indicator	60%
Annual output of stone products	~400 000 m²
Annual export volume of block raw materials	~1,500 m³
Share of Ukraine's crushed stone reserves	20%
Stone processing waste (2016)	40,95 thsd tonnes
Losses from land pollution (stone pulp)	> 2,1 million UAH
Waste dump volume in Korostyshiv, Zhytomyr region (August 2022)	~24,5 000. m³
Damages from the waste dump in Korostyshiv (August 2022)	14,5 million UAH
Optimal concentration of acceptable stone processing waste for geopolymers	Up to 25%

The use of pulp in the production of building materials, such as ceramic bricks and geopolymer concrete, is a promising area of application. It not only reduces the amount of waste accumulated, but also creates environmentally friendly and durable building materials with improved characteristics. The production of geopolymer concrete using a slurry has significant economic benefits, as it reduces the cost of extracting primary raw materials, lowers the cost of waste disposal, and decreases the energy intensity of production. Additionally, it contributes to the creation of new jobs and the development of a circular economy, where waste from one industry becomes a raw material for another [3].

The successful experiences of EU countries demonstrate the high potential of utilizing industrial waste in road construction. In 2016, 2.3 million tonnes of ash and slag were used for this purpose, accounting for 17.2% of the total volume of waste utilisation. In Finland, this figure reaches 40%. Waste from the stone processing industry, such as granite dust, screenings, and sludge, has similar properties to ash and slag and is also successfully utilized. The use of this waste not only addresses the environmental problem but also enhances the physical and mechanical properties of the road surface, reducing the cost of road construction [4].

A study conducted in Gorno, Italy, demonstrates an effective technology for recovering valuable metals from abandoned mine waste. Using a combination of wet shaking table and froth flotation, the researchers were able to separate the waste into concentrate and nonconcentrate, followed by chemical and mineralogical analysis. The froth flotation with preliminary sub-sample preparation and pH adjustment proved to be particularly effective, achieving a high degree of sulphide mineral recovery. The use of multiple reagent dosing for more significant fractions further improved the results. This

technology not only helps to reduce the environmental burden of waste dumps, but also ensures the recovery of valuable resources, demonstrating a practical example of the circular economy in the mining industry [5].

An analysis of international experience reveals that the utilization of pulp and other waste from the mining and stone processing industries is not only environmentally sound but also economically viable. Technologies such as the wet shaking table and froth flotation enable the efficient separation and recovery of valuable metals, thereby reducing the environmental footprint and promoting resource conservation. Examples from Italy and EU countries highlight the potential of these approaches, demonstrating that industrial waste recycling can be transformed from a costly item into a profitable industry, thereby contributing to the development of a circular economy.

Despite the environmental problems caused by the accumulation of stone processing waste in the Zhytomyr region, research confirms the potential for its practical use, particularly in the creation of geopolymer concrete with enhanced characteristics and reduced environmental impact.

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