**Effective Methods for Reducing Wear on Working Surfaces of Mill and Pump Components and the Advantages of Strengthening Technologies**

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**Abstract.** This study investigates effective approaches for reducing wear on the working surfaces of mill and pump components used in abrasive and corrosive industrial environments. The research evaluates various wear-resistant strategies, including material selection, surface strengthening methods, and protective coating technologies. Experimental and comparative analyses were conducted on commonly used alloyed steels and composite materials exposed to slurry-based wear conditions. Results demonstrate that the application of hard carbide-reinforced coatings and technologically enhanced surface strengthening techniques significantly improves durability by reducing abrasive wear, fatigue damage, and corrosion-induced degradation. Field testing of strengthened mill liners and pump impellers showed a decrease in wear rate by up to 30–45% compared to unmodified components. The study highlights the importance of integrating optimized materials, surface reinforcement technologies, and operational parameter control to achieve efficient and long-term wear resistance. These findings contribute to the development of advanced solutions aimed at increasing the reliability and service life of mills and pumps in the mineral processing and energy industries.

**INTRODUCTION**

In modern mineral-processing and energy-industry applications, components such as mills and pumps frequently operate under extremely harsh conditions: high velocities, abrasive and often corrosive slurries, high mechanical loading, and cyclic fatigue. Working surfaces of components (for example liners in grinding mills, impeller vanes and casings in slurry pumps) suffer from a combination of wear mechanisms—abrasive wear, impact/erosion, adhesive wear, fatigue wear and corrosion-assisted degradation.

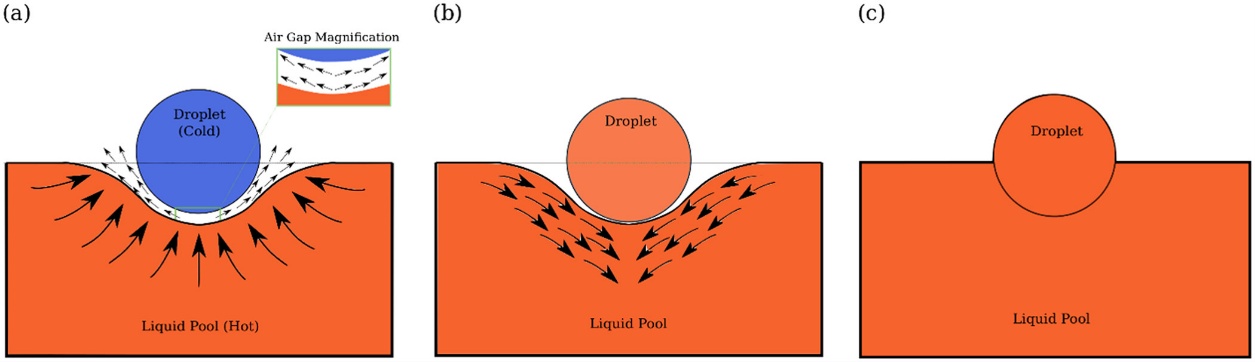
**Development of wear-resistant technologies for industrial equipment (2020–2030).**

In the period from 2020 to 2030, special attention in industrial and energy sectors is being paid to increasing the reliability and service life of mechanical equipment such as mills and pumps that operate under abrasive and corrosive conditions. The implementation of advanced wear-resistance and surface-strengthening technologies is considered a strategic direction to enhance the efficiency and sustainability of production processes. These projects are carried out primarily through industrial partnerships and private investment by manufacturers and independent engineering companies.

To achieve the targeted performance indicators for improved equipment durability during 2020–2030, it is planned to introduce and expand the use of modern surface engineering methods, including high-hardness coatings, laser surface modification, and composite reinforcement. The target parameters involve a significant reduction of wear rates (by 30–45%) and an increase in component service life by up to twofold. Annual benchmarks for the adoption of strengthening technologies in key industrial sectors have been established to ensure continuous progress in improving reliability and operational efficiency [1–5].

**EXPERIMENTAL RESEARCH**

It is known from the general theory of tribology and surface engineering that the wear intensity of mill and pump components directly affects the main operational characteristics of mechanical systems. Thus, under different load and speed conditions, the frictional interaction between the working surfaces generates stress fields with variable amplitude, frequency, and direction. In turn, technical regulations and standards set strict limits on the durability and reliability parameters of industrial equipment. When the composition and concentration of abrasive particles in the slurry change, it becomes necessary to maintain stable mechanical performance by applying advanced wear-resistant and strengthening technologies [2].



**FIGURE 1.** Schematic of a droplet interacting with a liquid pool: (a) cold droplet with air gap, (b) partially wetted droplet, (c) fully resting droplet.

The problem of overcoming the instability of wear and fatigue damage is solved through the application of surface orientation systems—methods that optimize the micro-geometry and hardness distribution of working surfaces in contact zones. This ensures uniform load transfer for components with complex geometries, such as pump impellers and mill liners, which operate under multi-directional wear flows. To simplify the process of analyzing surface stress and wear distribution, a new approach was introduced - the Discrete Surface Strengthening Function (DSSF) method. This technique describes the local strengthening and wear intensity as a discretely specified spatial function, allowing for more accurate prediction of wear behavior and optimization of coating placement [3]. There are two principal technical approaches to stabilizing wear resistance during operation. The first approach involves direct mechanical improvement of material properties-such as changing surface hardness or modifying the structural phase composition through heat or laser treatment. The second approach focuses on applying protective coatings that convert the unstable wear behavior of the surface into a stable, controlled state by forming a hard, fatigue-resistant layer.Analysis of possible material and technological options for strengthening working surfaces shows three main groups of methods suitable for use in mills and pumps: [4].

**– Material substitution** (using alloyed steels and composites),

**– Surface modification** (heat treatment, laser strengthening, peening),

**– Protective coating application** (carbide, nitride, or composite overlays).

Each of these methods has its own advantages and disadvantages. The first concept, material substitution, is simple and reliable, often referred to as the “classical metallurgical approach.” This method involves using alloyed or high-chromium steels with improved wear properties. However, it can only partially address corrosion and fatigue wear under highly variable operating conditions, which can lead to uneven surface degradation and increased vibration of mechanical assemblies. The second concept, surface modification, includes thermal and thermochemical treatments as well as modern methods such as laser hardening. This approach allows flexible control of hardness and microstructure depth, providing a broad operational range for wear resistance. However, such technologies often require complex equipment and involve high processing costs [5].

The third concept, protective coating technologies, involves applying hard composite or carbide-reinforced coatings to the working surfaces. The typical thickness of these layers ranges from several hundred micrometers to a few millimeters, depending on the wear mechanism. Within this layer, it is possible to maintain stable mechanical and corrosion-resistant performance, similar to the effects obtained in full reinforcement technologies. Unlike the previous concept, this method can be applied selectively to critical zones, thus reducing overall cost[6]. For industrial systems operating under variable loading conditions, it is crucial to ensure consistent wear resistance and dimensional stability of components. Achieving a stable wear rate at variable mechanical and corrosive loads is one of the major challenges in the operation of autonomous and continuous-duty processing systems. An effective way to solve this problem is through the combined application of surface strengthening and protective coating technologies. Therefore, in recent years, engineers and researchers have shown growing interest in hybrid methods that integrate both mechanical strengthening and coating deposition, capable of fully solving the challenges of durability, corrosion protection, and fatigue resistance in mill and pump components. This applies primarily to working elements operating under variable mechanical stresses, abrasive flows, and temperature gradients, where the relationships between stress (σ), wear rate (W), and surface hardness (H) determine the overall service life of the equipment [7].

**RESEARCH RESULTS**

Modeling of mills and pump components with advanced surface strengthening technologies. Currently, various methods are applied to reduce wear, including thermal spraying, hardfacing, laser cladding, and surface alloying. However, the issues of modeling and predicting the effectiveness of combined strengthening methods on working surfaces have not been studied in sufficient detail. The advantage of using combined surface strengthening is that the mechanical and operational characteristics of components show higher indicators compared to single-method treatments. In addition, the surface quality after treatment is considered very close to the ideal profile, which reduces friction, vibration, and energy losses during operation [8].

**TABLE 1**. Assignment of wear mechanisms and strengthening methods to mill and pump components

|  |  |  |  |
| --- | --- | --- | --- |
| **Component / Surface Zone** | **Dominant Wear Mechanism** | **Strengthening Method Applied** | **Expected Benefit** |
| Mill roller surface | Abrasive wear (hard particles) | Thermal spraying with carbide overlay | Reduced surface wear by 10-15% |
| Pump impeller blades | Corrosion and erosion | Laser cladding with corrosion-resistant alloy | Extended service life, less material loss |
| Mill grinding chamber | Surface fatigue and impact wear | Shot peening surface nitriding | Improved fatigue resistance and toughness |
| Pump shaft seals | Adhesive wear and friction | Hardfacing with composite coatings | Reduced friction, less downtime |
| Mill liner plates | Cavitation and erosive wear | Ceramic coating and surface texturing | Minimized cavitation damage and wear |

Wear of working surfaces in mills and pumps is a critical factor that limits the operational lifespan, efficiency, and reliability of these components. Effective methods to reduce wear not only enhance durability but also improve overall system performance. The main strategies for mitigating wear involve the selection of high-performance materials, the application of surface strengthening techniques, the use of protective coatings, and the optimization of operating conditions [9].

1. ***Selection of High-Performance Materials.*** The use of alloys and composite materials with high hardness and superior wear resistance significantly reduces material degradation under operational loads. Materials with enhanced microstructural stability are particularly effective in minimizing abrasive, erosive, and adhesive wear mechanisms commonly observed in mills and pumps [10].
2. ***Surface Strengthening Technologies*.** Advanced surface strengthening methods, including thermal treatments (e.g., induction hardening, nitriding), mechanical treatments (e.g., shot peening, surface work hardening), and hybrid techniques, increase the hardness and fatigue resistance of working surfaces. These processes enhance load-bearing capacity, reduce deformation under cyclic stresses, and extend the functional lifespan of components [11].
3. ***Protective Coatings and Layers***. Application of protective coatings, such as ceramic, metallic, or composite layers, provides an additional barrier against direct mechanical and chemical impacts. Coatings reduce friction, inhibit corrosion, and improve resistance to erosive wear, thereby contributing to more uniform surface degradation and prolonged operational intervals [12].
4. ***Optimization of Operating Conditions***. Monitoring and optimizing operational parameters—including load, rotational speed, temperature, and lubrication—play a crucial role in minimizing wear. Proper lubrication reduces direct surface-to-surface contact and friction, while maintaining operational parameters within design limits prevents premature material fatigue and deformation [13]. By integrating these approaches, the wear rate of mill and pump components can be significantly reduced. The benefits include lower maintenance costs, extended service intervals, reduced vibration and noise, and improved energy efficiency. Strengthening and protective technologies also contribute to more uniform stress distribution and smoother surface profiles, which enhance the overall reliability and performance of the equipment [14].

In conclusion, a systematic combination of advanced materials, surface strengthening methods, protective coatings, and optimized operational strategies is essential for minimizing wear, maximizing component lifespan, and improving the operational efficiency of mills and pumps [15].

**CONCLUSIONS**

As can be seen from previous studies, the application of advanced surface strengthening technologies and wear reduction methods in mills and pumps significantly enhances operational efficiency and prolongs the lifespan of machine components [13-20, 7, 1]. Studies indicate that replacing conventional treatments with modern strengthening techniques on working surfaces provides the following advantages:

1. The possibility of operating mill and pump components under higher load and pressure conditions without premature wear, thus increasing the reliability of the equipment.
2. Improved mechanical characteristics, including higher resistance to abrasive, erosive, and fatigue wear, which enhances the overall torque transmission and operational stability.
3. Reduction of friction and contact losses by 7–15%, depending on the type of strengthening technology used, leading to lower energy consumption.
4. Minimization of surface defects and microcracks, which reduces vibration, noise, and additional mechanical stress during operation.
5. High efficiency and longer service life over a wide range of operating conditions, ensuring reduced maintenance costs and increased productivity.

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