ADVANCED ENGINEERING APPROACHES FOR MINIMIZING FRICTION AND WEAR IN WORKING COMPONENTS OF LIGHT-INDUSTRY MACHINES

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Abstract: *This article presents a theoretical and literature-based analysis of friction and wear mechanisms occurring in the working components of light-industry machinery. To improve the reliability and service life of machine elements, the tribological properties of different engineering materials — including hardness, friction coefficient, and wear rate — were comparatively evaluated. The results indicate that polymer-based and composite materials (such as PA6, textolite, basalt-fiber and carbon-fiber hybrids) demonstrate superior tribological performance compared to conventional steel counterparts, particularly under lubrication-free or medium-load operating conditions. Additionally, it was found that the effectiveness of the lubrication system plays a critical role in extending the service life of components by minimizing surface degradation. The findings of this study contribute to enhancing energy efficiency, reducing maintenance costs, and improving overall operational performance in light-industry machinery.*

Keywords: *light-industry machinery; friction; wear; tribology; steel; polyamide (PA6); textolite; basalt-fiber composite; lubrication system; wear resistance.*

INTRODUCTION

The operational efficiency of light-industry machinery largely depends on the durability, wear resistance, and service life of its moving machine elements. These machines — including textile, spinning, knitting, and cotton-processing equipment — typically operate at high rotational speeds and under prolonged loading conditions. As a result, frictional interaction intensifies, leading to accelerated wear of working components, a decline in machine reliability, and an increase in maintenance costs.

A review of the literature shows that methods for mitigating wear can be classified into three main categories: (i) constructive or design-based solutions (selection of geometry and friction pairs), (ii) choice of optimal materials and protective coatings, and (iii) technological approaches such as lubrication, heat treatment, and surface modification. Research in these domains is aimed at improving energy efficiency, extending the operational lifespan of components, and ensuring environmentally sustainable machine performance.

The issues of friction and wear have long been among the most fundamental topics in mechanics and machine design. The development of tribology as a scientific discipline — particularly since the mid-20th century — has made it possible to theoretically model frictional interactions and to develop methods for reducing surface degradation. The friction laws established by Archard, Amontons, and Coulomb were significantly advanced by Greenwood, Bowden, and Tabor, whose works demonstrated that frictional behavior is governed not only by surface pressure and roughness, but also by microstructural properties, hardness, and surface chemistry.

Traditional approaches used to enhance tribological performance include:

- Lubrication, which lowers the friction coefficient by forming a protective film between contact surfaces (mineral, synthetic, or hybrid lubrication systems);
- Heat treatment, which increases surface hardness and improves wear resistance;
- Protective coatings, such as chromizing, nitriding, or phosphating, which improve corrosion and abrasion resistance.

In recent years, extensive research has focused on the use of composite materials in wear-prone elements of light-industry machinery. Polymer-based materials such as PA6, PA66, and textolite, as well as fiber-reinforced composites (basalt-fiber and carbon-fiber hybrids), have been shown to provide several advantages over metals, including low density, enhanced corrosion resistance, and improved tribological characteristics. Moreover, nanoscale additives (e.g., graphene and carbon nanotubes) have been reported to significantly reduce the friction coefficient and improve lubrication behavior, especially when combined with functional surface coatings.

Experimental investigations carried out in textile and cotton-processing machinery confirm that insufficient lubrication can accelerate wear by a factor of 2–3. Consequently, modern equipment increasingly incorporates hydrodynamic and mixed-lubrication systems to maintain stable contact conditions. Studies also indicate that basalt-fiber composites can exhibit a 25–30% reduction in friction coefficient and a 1.5–2-fold increase in service life compared with conventional steel components.

Materials and Methods

In light-industry machinery, frictional interaction is predominantly observed in the following wear-prone working components:

- Shaft–bearing assemblies, which operate under high rotational speed and continuous mechanical loading;
- Friction disks and transmission gears, which function as direct power-transmitting friction pairs;
- Scraper and cutting tools, which are subjected to intensive abrasion during the processing of cotton and fiber materials.

Based on the literature, the commonly used material groups for such machine elements can be classified as follows:

- Metallic materials: structural steels, cast iron, and bronze — traditional but susceptible to rapid wear in dry or high-load conditions;

- Polymer-based materials: polyamide (PA6, PA66), caprolon, and textolite — lightweight and more stable under frictional contact;
- Composite materials: basalt-fiber, carbon-fiber, graphite-reinforced, and hybrid polymer matrix composites.

To evaluate wear resistance and frictional behavior, the following tribological methods are widely applied in tribological research:

1.Tribometric tests: Friction pairs such as "shaft–bearing" or "disk–block" are tested on a dedicated tribometer. Standard literature test parameters include 0.3–0.5 MPa surface pressure, 0.5–1.0 m/s sliding velocity, and a 60-minute test duration. The primary output is the friction coefficient (μ).

2. Hardness measurement: The hardness of material surfaces is determined using Brinell or Vickers methods. For example, in the Brinell HB 10/3000 method, a 10 mm diameter indenter is applied under a 3000 N load to assess resistance to plastic deformation.

3. Wear rate assessment: The volumetric or mass loss of the sample is recorded after a defined friction period. A widely used reference indicator is the mass loss (mg/hour) after one hour of continuous sliding.

4. Thermal stability analysis: The microstructural resistance of materials to elevated temperatures is evaluated in the range of 150–250 °C. Changes in hardness and friction coefficient are monitored as a function of heating rate and exposure duration.

5. Lubrication system efficiency: The influence of mineral, synthetic, and blended lubricants on tribological performance is compared. Literature data show that mineral oils can reduce the friction coefficient by approximately 15–20%, whereas synthetic lubricants may provide a reduction of up to 25–30%.

Table 1. Comparative analysis of material hardness, friction coefficient, and wear rate

Material type	Hardness (HB)	Friction coefficient (μ)	Wear rate (mg/hour)	Advantages
Steel (grade 45)	180–200	0.35–0.40	High	High mechanical strength; cost-effective
Textolite	80–100	0.25–0.28	Medium	Lightweight; inexpensive; dielectric properties
Polyamide (PA6)	70–90	0.22–0.26	Low	Good frictional stability; wear-resistant
Basalt-fiber composite	110–130	0.18–0.22	Very low	High durability; eco-friendly; excellent stability

Note: The data presented in the table are consolidated from various literature sources.

Results and Discussion

The results presented in the table, along with the supporting literature review, demonstrate that the materials commonly used in the working components of light-industry machinery exhibit significant differences in terms of their tribological performance. These differences are primarily influenced by surface hardness, microstructural composition, and lubrication conditions.

Conventional metallic materials such as steel and cast iron are widely used due to their high strength and low manufacturing cost. However, their friction coefficient remains relatively high (μ ≈ 0.35–0.40), which leads to an increased wear rate under prolonged operation. Literature sources indicate that in the absence of an efficient lubrication system, the service life of steel-based components may decrease by a factor of 2–3. Therefore, the application of metallic materials is justified mainly in systems where a stable lubrication regime can be ensured.

In contrast, polymeric materials such as polyamide (PA6/PA66) and textolite demonstrate a 25–30% reduction in friction coefficient compared with steel, as well as considerably lower wear rates. These materials also offer additional advantages such as corrosion resistance and ease of manufacturing. However, their tendency to undergo thermo-mechanical deformation at elevated temperatures limits their use to moderate-load and low-speed operating environments.

The literature further confirms that lubrication techniques play a decisive role in tribological performance enhancement: mineral oils typically reduce the friction coefficient by 15–20%, while synthetic lubricants may reduce it by up to 25–30%. Hybrid or combined lubrication systems provide the highest effectiveness by simultaneously lowering friction and protecting the surface against corrosion.

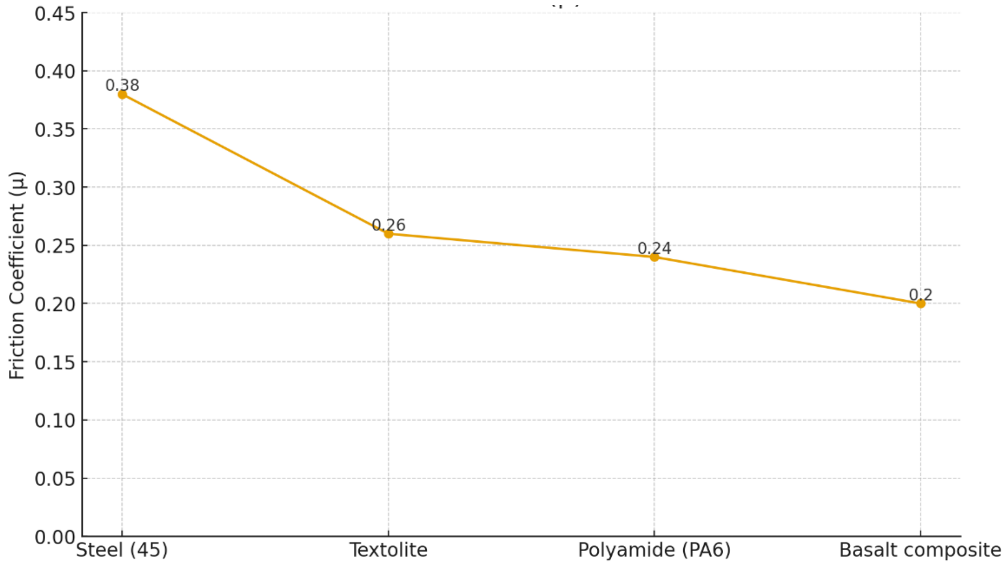

Figure 1. Comparison of the Friction Coefficient (μ) for Different Engineering Materials Used in Wear-Prone Machine Components

The obtained research results indicate that replacing traditional metallic materials with modern composite materials in the working parts of light industry machines significantly increases their wear resistance. At the same time, the implementation of efficient lubrication systems, as well as the use of polymer and composite-based materials, contributes to reducing the machines' energy consumption and extending their operational service life.

A review of the literature shows that although metallic materials possess high strength, their relatively high friction coefficient and wear rate limit their long-term performance without effective lubrication systems. Polymer materials, on the other hand, are characterized by low density, low friction coefficient, and corrosion resistance, but their mechanical stability decreases under high loads and elevated temperatures.

According to recent studies, composite materials based on basalt and carbon fibers are considered among the most promising solutions. These materials can significantly reduce friction parameters and extend the service life of components by 1.5–2 times. Furthermore, the use of synthetic and combined lubrication systems plays a decisive role in enhancing tribological performance.

General scientific recommendations:

- Design and manufacture the most wear-prone parts using composite materials.
- Improve lubrication systems based on synthetic and mixed oils.
- Conduct an in-depth study of the tribological properties of polymer and composite materials enriched with nanoparticle additives.
- Introduce tribometric testing methods into industrial practice to optimize the production process.

Conclusion: The obtained results demonstrate that replacing conventional metallic materials with composite alternatives in the wear-prone components of light-industry machinery significantly enhances wear resistance. Moreover, the implementation of efficient lubrication systems, together with the use of polymeric and composite materials, contributes to reducing energy losses and extending the operational service life of machine elements.

The literature review confirms that, although metallic materials possess high mechanical strength, their relatively high friction coefficient and wear rate limit their effectiveness in the absence of a stable lubrication regime. Polymeric materials offer advantages in terms of low friction, lightweight structure, and corrosion resistance, but their applicability is restricted under high-temperature and high-load operating conditions. Basalt- and carbon-fiber composites represent the most promising solution, as they provide a substantial reduction in friction and can increase service life by a factor of 1.5–2 compared with conventional metals.

Furthermore, modern synthetic and hybrid lubrication systems play a decisive role in enhancing tribological efficiency and ensuring stable long-term performance of machine components under real industrial conditions.

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