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The “Engineer” publishes the most significant results of scientific and applied research carried out in universities of transport profile, as well as other higher educational institutions, research institutes, and centers of the Republic of Uzbekistan and foreign countries.

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Increasing the role of titanium alloys in the aviation industry: problems and solutions

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Abstract: This article analyzes the importance of using titanium alloys in the aviation industry, their unique physical-mechanical properties, and the complexities of the manufacturing process. It discusses the processing technologies of titanium alloys, the issues of improving cost efficiency, and optimizing technological regimes. The relevance of this topic is based on scientific and practical approaches to the use of advanced materials in the aviation industry.

Keywords: titanium alloys, aviation industry, machining technologies, material properties, corrosion resistance, lightness and strength, technological optimization, scientific and practical research, production costs, aviation innovations

1. Introduction

Titanium alloys have become one of the most important materials in the aviation industry due to their unique properties such as high strength, lightness, and corrosion resistance. These characteristics play a significant role in ensuring the reliability, efficiency, and long service life of aircraft and other aviation equipment. Titanium alloys are especially important for ensuring the lightweight nature of aircraft structures, as well as optimizing fuel consumption by reducing their weight [1].

However, the challenging mechanical processing and high production costs of titanium alloys limit their widespread use. The processing of titanium alloys typically requires high temperatures, special tools, and technological procedures, leading to higher production costs. Additionally, due to the high density and hardness of titanium, operations such as shaping, cutting, and welding become more difficult, which reduces production efficiency. The table below compares the properties of titanium materials with those of other materials [5;10].

Material	Strength (MPa)	Corrosion Resistance	Specific Gravity (g/cm³)	Machining Complexity
Titanium Alloys	1000-1200	High	4.5	High
Aluminum	400-500	Medium	2.7	Medium
Steel	800-2000	Low	7.8	Low
Composite Materials	150-300	Very High	1.8-2.2	Low

- **Strength (MPa):** The material's resistance to tensile stress.
- **Corrosion resistance:** The material's ability to withstand oxidation or other harmful effects in environmental conditions.
- **Machining complexity:** The difficulty of working with the material during production (requires high-level cutting tools and technologies).

Therefore, optimizing the processing of titanium alloys and improving technological regimes are important scientific and practical issues. Such optimizations can be achieved by implementing new processing technologies, creating specialized equipment for more efficient material processing, or developing new alloys. These processes will enable broader use of titanium alloys in the aviation industry and help reduce production costs [8; 9].

2. Research Methods and Results

Studies on the use of titanium alloys in the aviation industry highlight their unique physical-mechanical properties. The material's high strength, corrosion resistance, and lightweight make it an ideal choice for reducing aircraft structure weight, increasing efficiency, and extending service life. Specifically, titanium alloys are widely used in **aircraft engines** (for turbine blades, compressor parts, and other engine components due to their high strength and heat resistance, **Ti-6Al-4V), braking systems (Ti-6Al-2Sn-4Zr-2Mo** (Beta Titanium)), and fuselage parts (where strength and impact resistance are required, for primary elements of the aircraft chassis with the **Ti-10V-2Fe-3Al** alloy), as they provide high performance and optimize fuel consumption by reducing weight [2].

However, the mechanical processing of titanium alloys is very complex, as the high strength and hardness of these materials make cutting and shaping challenging. Specifically, issues such as cutting speed and tool wear reduce production efficiency [3]. Therefore, it is necessary to implement innovative technologies to improve the manufacturing process. Based on research, a number of solutions have been proposed to develop optimal technological regimes for processing titanium alloys and to improve the design of cutting tools to increase their efficiency, addressing the challenges encountered during the processing of titanium alloys [4].

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Several challenges arise in the processing of titanium alloys:

- Due to their low thermal conductivity, heat accumulates in the tool zone during the cutting process, causing rapid tool wear.
- The high chemical reactivity of the material may lead to reactions with the cutting tool, negatively affecting the surface quality.
- The strength and elasticity properties cause vibrations during the processing, making it difficult to maintain accuracy.

To prevent and resolve these challenges in the processing of titanium alloys, the following methods should be applied [5].

Heat management:

- **Cooling systems:** Using high-pressure and efficient cooling systems reduces heat in the tool zone during cutting. For example, water-oil mixtures:
- Special additives in cooling fluids ensure faster heat dissipation.
- Water-oil emulsions prevent corrosion and enhance operational efficiency.

These systems not only effectively dissipate heat during processing but also improve cutting precision, extend tool life, and enhance surface quality.

- **Special cutting tools:** Heat-resistant coated tools, such as tungsten carbide or ceramic-coated tools, can be used.
- Due to the low thermal conductivity of titanium alloys, high temperatures are generated in cutting zones.
- **Tungsten carbide tools:** Withstand high heat (800–1000 °C), preventing rapid tool wear.
- **Ceramic tools:** Operate at very high temperatures (above 1000 °C) and do not react with the metal, making them ideal for titanium materials [7].

Managing chemical activity:

- **Protective coatings:** Applying special chemical coatings to tool surfaces can reduce the likelihood of reactions. Examples include **TiN, TiAlN, AlCrN, DLC,** and **ZrN.**
  - Additionally, protective coatings offer the following benefits:
- Prevent wear on the tool surface.
- Enhance heat resistance.
- Prevent reactions with titanium.
- Improve smoothness, making the processing easier and enhancing precision.
- **Improving the working environment:** This involves optimizing conditions to control and enhance the interaction between tools and materials during the processing of titanium alloys. Several methods can be applied for this purpose:
- **Use of inert gases:**
  - Titanium alloys exhibit high chemical activity, reacting with oxygen, nitrogen, or hydrogen in the air.
  - This degrades surface quality and complicates the cutting process.
  - *Application:* Inert gases, such as argon or helium, are introduced into the working area to form a protective layer that prevents reactions and preserves surface quality [9].
- **Use of cooling and lubricating agents:**
  - To reduce heat generation and friction during the process, water-oil emulsions are used.
  - These help slow tool wear and improve accuracy.
- **Temperature control:**
  - Excessive heat in the cutting zone accelerates tool wear and reduces processing quality.
  - High-pressure cooling systems, cryogenic cooling (liquid nitrogen or carbon dioxide), or mist cooling methods are used to regulate temperature.
- **Dust and debris management:**
  - Dust and debris generated during processing can affect quality and damage equipment.
  - Ventilation systems or dust extraction devices are employed to maintain a clean working environment.
- **Firm tool mounting and adjustment:**
  - Stability during cutting ensures accuracy.
  - High-quality clamping devices and sturdy mounting systems are used to prevent tool movement.

3. Reducing vibrations

Stable equipment: These are modern machines and systems designed to ensure high precision, durability, and resistance to vibrations when processing titanium alloys. Examples of such equipment include the

DMU monoBLOCK series and the NHX 6300 (horizontal machining center) [6].

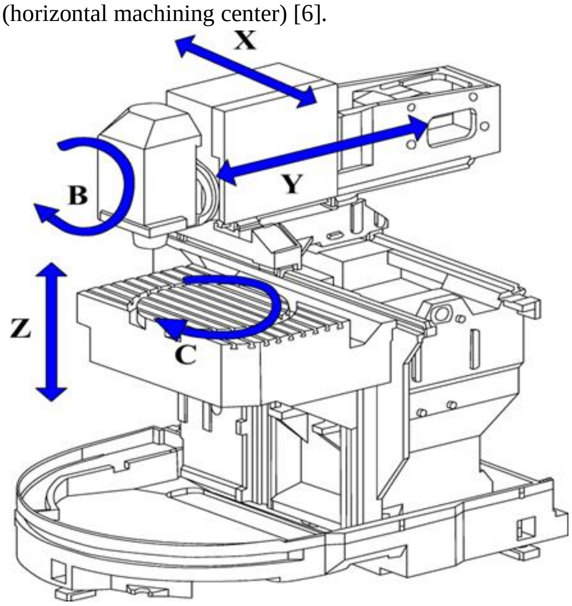

Figure 1. DMU-80

Figure 2. NHX 6300

4. Conclusion

Titanium alloys play a crucial role in the aviation industry as lightweight and durable materials. Their high corrosion resistance and mechanical properties enhance the efficiency of aircraft structures and engines. However, challenges in processing and high production costs limit their application, necessitating process optimization and the adoption of innovative technologies.

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