Technological and environmental factors of machining the difficult-to-machine materials

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Abstract

An increasing role of the difficult-to-machine materials group can be observed in following industrial sectors: automotive, aerospace and manufacturing (with focus on manufacturing machine elements), which is due to the favorable and unique mechanical, physical and chemical characteristics of these materials. The primary aim of this paper is to present the different options of machining the difficult-to-machine materials, titanium alloys and ceramic in particular. The paper elaborates on the impact of the cutting fluids/lubricants in machining on the environment and, furthermore, the article presents the issues related to the importance of a high level of accuracy in precision machining process of difficult-to-machine elements and the neccessity of required collaboration between specified technologies and appropriate tools.

Keywords

Difficult-to machine materials, lubricants, coolants, precision machining

1. Characteristics of difficult-to-machine materials chapters

Machining is one of the most popular methods for producing machine parts from different materials. The role of the cutting tool during the machining process is to remove unnecessary material from the workpiece.

The difficult-to-machine materials' group is difficult to machine because of their unique mechanical, chemical and physical properties. One of the consequences caused by their properties is an excessive heat generated in the cutting zone while machining the materials and the difficulties associated with draining it. The most common characteristic of the difficult-to-machine materials are: high hardness and high strength. Elevated temperatures that occurred during cutting in the cutting zone, causing intensive wear of cutting tools, which results in shortening the lifespan of the tools and deteriorating quality of the machined surface.

The most difficult-to-machine materials include: titanium-based alloys and nickel-based as well as: ceramics, super alloys, plastics and elastomeric alloys of iron can be classified to the difficult-to-machine materials' group. Exemplary division of difficult-to-machine materials is shown in Fig.1

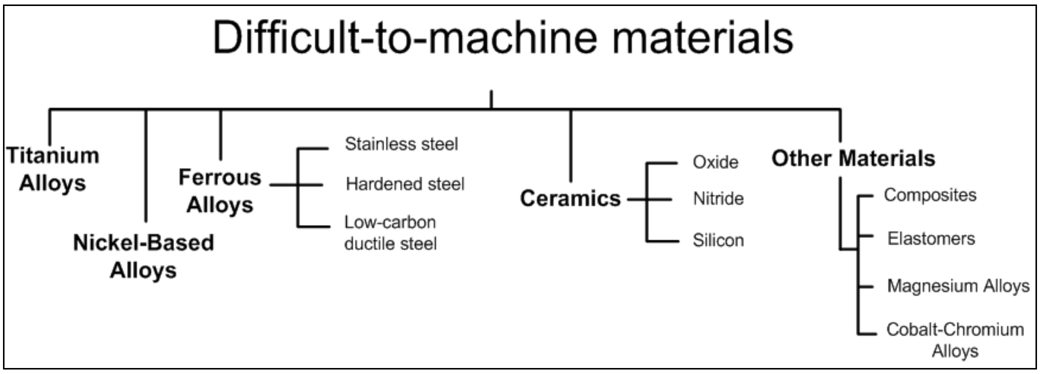

Fig.1. *Difficult-to-machine materials division*

The relatively low density of titanium (4, 54 g/cm^3) makes the structures made of these alloys very lightweight while maintaining its high hardness and high strength. In addition, titanium alloys are characterized by high resistance to corrosion, high creep resistance and high yield strength. All of these properties make titanium alloys a perfect material to be used in extreme conditions and at high loads. However, the aforementioned properties combined with chemical reactivity, low thermal conductivity and self-hardening during processing makes the machining very difficult.

Nickel based alloys elements are characterized by a wide range of temperatures in which they can work. During the processing carried out at elevated temperatures they maintain their good mechanical and chemical properties.

The ceramic material is non-metallic and inorganic and obtains its characteristic specifications when formed in high temperature of at least 800 Celsius degrees, in at least 30% crystalline. Current ceramic materials are considered to be materials with a wide range of physical properties and thus their wide range of usability and different applications.

2. Cutting fluids used during machining

High temperatures, which occur during the cutting process, have a significant impact on the tools life-span reduction and the quality of the surface of the workpiece. The residual stresses and micro-cracks which are created during processing, contribute to a change in the microstructure of the workpiece, which leads to the formation of a white layer.

In order to circumvent the unwanted processes occurring during machining, coolants or cutting fluids are proposed to be used. The main task of the liquid is: to lower the cutting temperature, facilitate chip evacuation from the cutting zone and show good penetrating properties in the contact zone. The different types of coolants and the effectiveness of their usage are shown in Fig.2 [3].

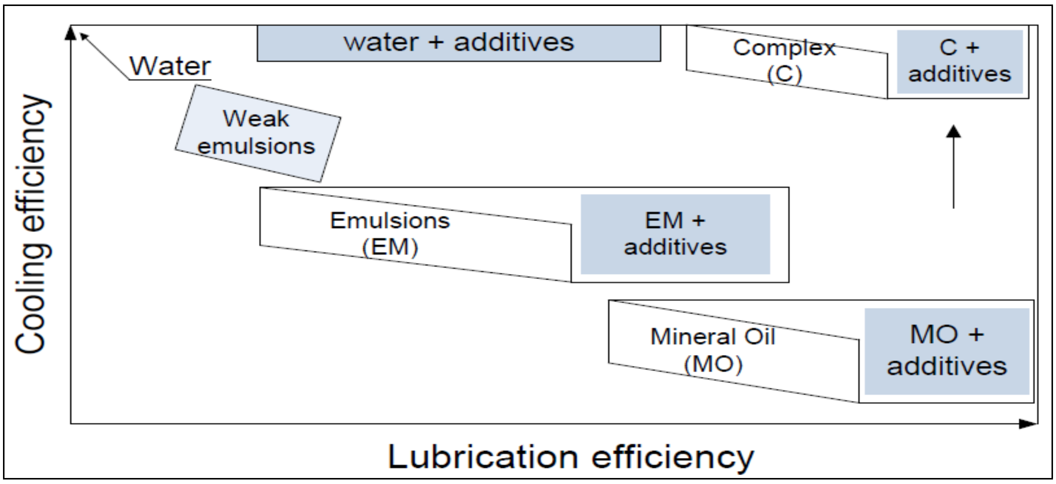

Fig.2. *Effectivenes of different types of cooling-lubricating fluids [3]*

Figure 2 shows that pure water or water plus additives have very good cooling properties, but its lubricating properties are unsatisfactory. The most satisfactory lubricants are based on mineral oil and/or mineral oil plus additives but it is characterized by poor cooling properties. The use of coolants (except water) is associated with number of disadvantages that include:

- the need to use substantial amounts of emulsifiers, a substances that help in formation of emulsions,
- emulsifiers oxidize during processing, resulting in lowering the resistance for the corrosion of the workpiece,
- the growth of bacteria and microbes,
- difficulties with disposal.

The presence of fungi and bacteria causes the dissolution of the emulsions, which as a result, creates a harmful for human health odor that can cause lung diseases and increase the possibilities of the following cancers: esophagus, pancreas, colon, and skin cancer. Another problem associated with cutting fluids is their disposal, as most of the liquids are not biodegradable, and the disposal cost can be even four times greater than the purchasing cost. According to [7] the research works and tests it is possible to assume that the modern machining fluids can be made based on the aqueous surfactants (Surface Active Agent), which meet the fundamental criteria for the cooling- lubricating fluids such as: lubricity, bio-stability and cleaning ability. The major advantage from using the surfactants is lack of adverse effects on human health and biodegradability, which consequently reduces the disposal cost of machining fluids and decreases the risk of worker's diseases.

3. Precision machining of difficult-to-machine materials

3.1 Machining of ceramics

This paper presents the results of research on precision machining of ceramic materials - zirconium (ZrO_2) and single crystal sapphire (αAl_2O_3), both can be applied in medical engineering. According to the literature, inclusions may affect the density of the material. The density of single crystal sapphire, measured with an accuracy of 0.05% by hydrostatic weighing method, varies from 3.992 g/cm^3 to 4.013 g/cm^3 for colored dark red Cr_2O_3 containing 2.97% (chromium dependence is linear). The density, determined experimentally is usually lower than in the calculated values of density, which is associated with the occurrence of micro-cracks or micro-pores in the crystals.

Monocrystalline treated biomaterial α-Al_2O_3 was modified by inclusions of Cr_2O_3 and TiO_2 (0.03% ÷ 0.05%). Experimentally determined parameters were: hardness = 1874 ÷ 2253 HV; indicator of the fragility I_b = 458µm$^{-0.5}$, flexural strength σ_z = 700 ÷ 1300 MPa; compressive strength σ_s = 2950 MPa, Young's modulus E = 510 GPa, fracture toughness K_{1C} = 3.4 ÷ 5.6 Mpa · m$^{1/2}$[4].
The precision machining of super hard ceramic components, requires the conjunction of three movements: rotational movement of the workpiece and the rotation of the tool and feeder of the tool which is positioned at a certain angle for the workpiece.
To complete the formation process, special abrasive tools were created (Fig. 3), which part was covered with diamond grains.

Fig.3. *Grinding tools for machining spherical elements*

The advanced machining system allows to obtain the technological quality of the endoprosthesis heads (Fig.4) as per following diameters d = 20 ÷ 40 mm, as per ISO norm where surface roughness R_a=0, 04 µ ÷ 0, 08 µ; shape accuracy Δd=0, 5÷1, 0µ and diameter tolerance Td= ±10µ ÷ 16µ.

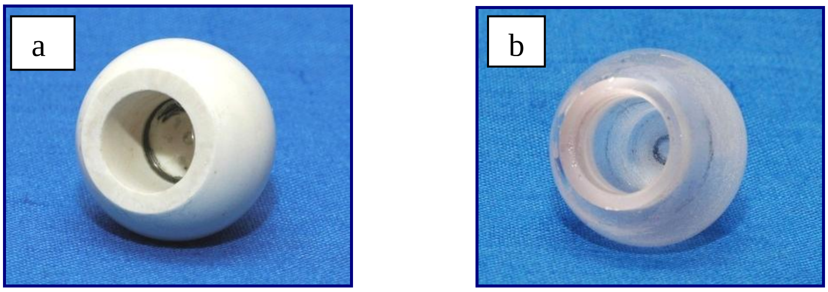

Fig.4. *Ceramic head hip replacement: a) Zirconia ZrO_2, b) Single crystal sapphireAl_2O_3*

3.2 Machining of titanium alloys and nickel-based alloys
Milling operations have been subjected to elements made of titanium alloy Ti6Al4V and Inconel 718 .The tests were performed as per the direction of the object's feed motion speed, when in relation to the circumferential direction of the velocity vector of the milling cutter Up-cut milling was performed (Fig. 5) with a feed rate equal f = 0.09 mm / tooth and down-cut milling (Fig.6) with a feed rate equal f=0.09mm/tooth.

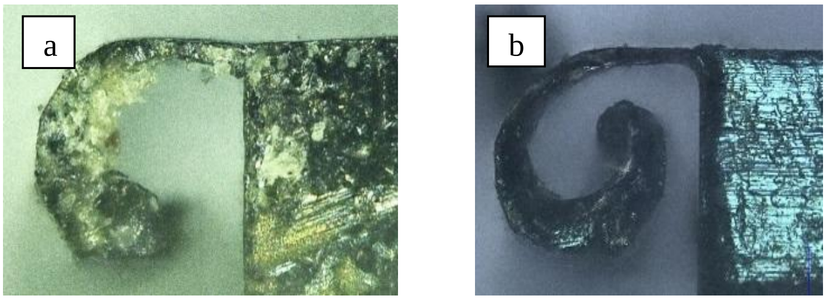

Fig.5. *Burrs formed after up-cut milling a) Inconel 718 b) Ti6Al4V*

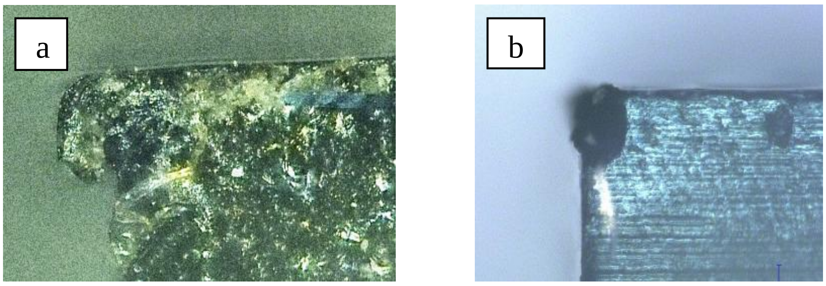

Fig.6. *Burrs formed after down-cut milling a) Inconel 718 b) Ti6Al4V*

Machining of titanium alloys and nickel-based alloys is very problematic. It is mainly due to the occurrence of very high temperatures during machining process. In order to obtain the required shape, the machining process is performed at low speed and feed rates as compared to the treatment of materials with good machinability. Additional difficulty is a low coefficient of elasticity, which can be the cause of deformation of titanium elements when exposed to the forces, exerted by the cutting edge that then, return to their initial state. This results in excessive chipping of the tools, and in increase of the temperature when cutting. Another factor influencing the presence of the elevated temperatures during processing is poor thermal conductivity of titanium and nickel-based alloys. The chips created during processing of difficult-to-machine elements enables transfer of heat only in 25 percent, while during the machining of steel parts in 75 percent. Poor thermal conductivity directs the main stream of the temperature on the cutting edge of the tool, which is a main reason behind a high weariness of the tool and reduction in machining capacity because of the lower cutting speeds. Fig. 7 shows the temperature in the primary deformation zone and Fig. 8 pictures a heat's balance during cutting process.

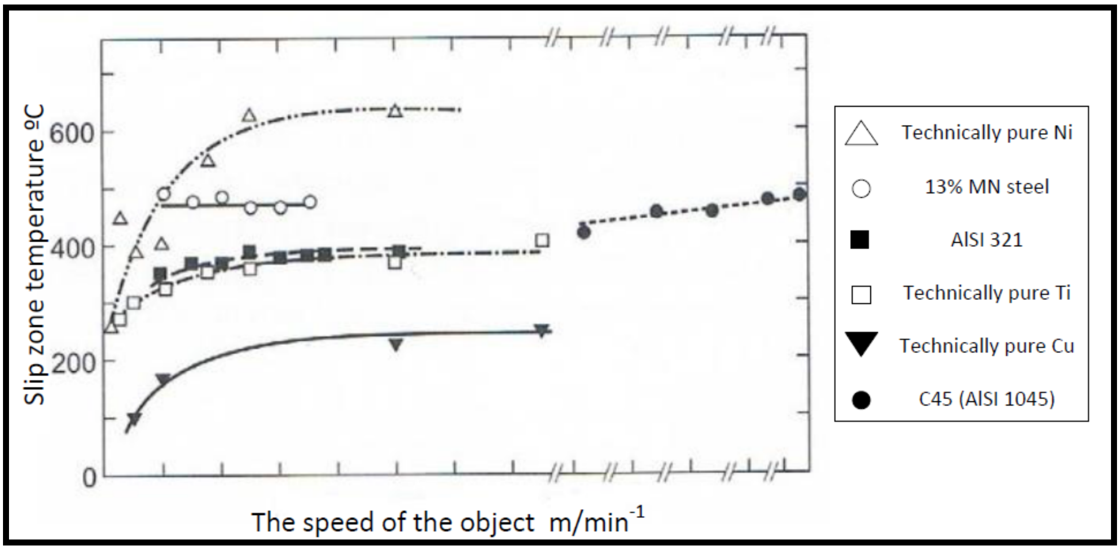

Fig.7. *The temperature in the primary deformation zone*

In order to facilitate and improve the cutting process, an oil mist is used during the processing, which works as cooling and lubricating medium. Its task is to reduce the temperature of the cutting process and reduce the friction between the cutting tool and the workpiece. In addition, oil mist positively impacts the quality of the workpiece's surface by continuous removal of the chips, which are created during machining.

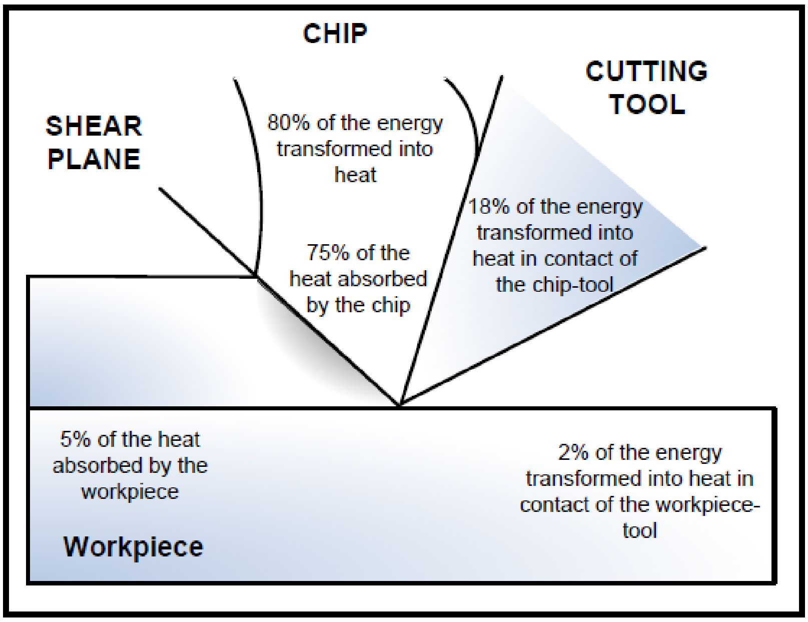

Fig.8. *Heat's balance during the cutting process*

4. Summary

Difficult-to-machine materials such as: nickel alloys, titanium alloys and ceramic materials are characterized by very good mechanical properties and some of them by bio-acceptability. Therefore, it is possible to apply those materials in various industries. In order to obtain the required properties of the surface and the desired shape during processing, it is required to use modern technology and coolants in order to reduce the temperature of the cutting process and to extend the durability of the cutting tools. The use of cutting fluids is associated with many risks such as: growth of bacteria, irreversible damage to the worker's health and formation of dangerous situations in the workplace, consequently the search for new solutions, during which the use of coolants would not be necessary (for example, dry machining, MQL - Minimum Quality of Lubricants, treatment at cryogenic temperatures) is important. Despite many attempts, none of the above methods is as effective as cutting with a cooling lubricant. Benefits from the application of difficult-to-machine materials, and also the difficulties associated with their processing, confirm the need for further research and the pursuit of further tests in order to improve the processing methods of these materials.

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