Study of Porosity in Cutting Tools During Titanium Machining

Popular Science Summary

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Voids are observed in a worn cutting tool used in titanium machining. These unwanted cavities worsen the resistance to plastic deformation at elevated temperatures, making it more fragile and prone to premature breakage. To improve the tools one critical question needs to be answered: Why do such pores form in the tool when machining ?

When producing titanium components for the aviation and medical industry subtractive machining is the established manufacturing method. One of these machining processes includes the removal of material by pressing and moving a tool along the workpiece. Although the tools developed for this type of application have excellent hardness and durability, tool wear is inevitable. Several different wear mechanisms occur during titanium machining. Diffusion wear, in which atoms from the tool move to the workpiece material and visa versa, is the most critical to mechanism contributing to reduced tool life. This study investigates if diffusion wear causes porosity in the cutting tool. The porosity is undesirable because it weakens the tool leading to accelerated wear. The study aims to gain knowledge regarding the possible porosity formation in cutting tools, this is of importance in order to further improve the tools resistance to plastic deformation.

Several worn cutting tools were studied using a scanning electron microscope (SEM), an imaging technique used both for topography and element characterization. In one cutting tool, pores <1µm are observed at the cutting edge, see Figure 1. In an effort to understand why such pores form during machining diffusion couple experiments were carried out. The diffusion couple experiment involved coupling titanium and tool material together. Thereafter, the couple was heated to various temperatures (800-1000 C) and pressure (0-2.5 GPa) for a determined time to imitate the conditions during machining. The diffusion couples experiment is favoured when studying diffusion since the experiment is static, allowing large interfaces to form and reaction products to be studies. The downside of this is that during machining material is constantly replenished and therefore new phases and mechanisms can act during machining.

Various diffusion couple experiments showed interesting results, in some samples distinct voids are present in the tool material as shown in Figure 2. In other samples, no evident pores are present which is in agreement with prior diffusion couple studies. Voids are found irregularly among the samples which is believed to be a consequence of the different diffusion couple methods used in the study.

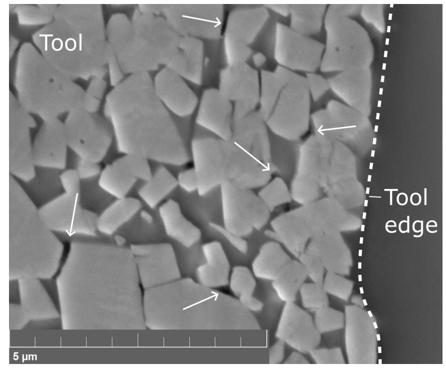

Figure 1: Cutting edge of a worn insert, voids are indicated by arrows.

The pores found in the diffusion couple were hypothesized to be caused by the phenomenon Kirkendall porosity. This is where material A moves into substrate B at a faster rate than the motion of B into A. The movement of atoms undergoes a process at which a neighboring vacancy site swaps place with the atom, known as substitutional diffusion. Since the movement of material A into B is considerably fast, vacancies will move in the opposite direction towards substrate A. Kirkendall pores will form in material A due to merging vacancies. In this study material A is the cobalt constituent in the cutting tool and B is the titanium. The cobalt diffusion into titanium is higher than the titanium diffusion into cobalt which is a requirement for Kirkendall porosity.

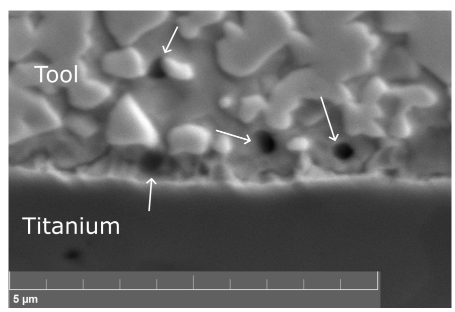

Figure 2: Diffusion couple between titanium and tool material, voids are indicated by arrows.

The results of this study indicate the formation of pores is caused by Kirkendall porosity during diffusion wear. This systematic study, which examined diffusion couples created at a range of temperature - pressure combinations and demonstrates the formation of porosity in milling and turning inserts. Nevertheless, this investigation moves the research regarding porosity in inserts during titanium machining forward.

[1] Botermans, C. (2023) *Study of Porosity in Uncoated Cemented Carbide Tools During Titanium Alloy Machining.* Master's thesis. Lund University.