Processing and recycling titanium waste

Titanium components account for up to 15 per cent of the total weight of modern aircraft. The material is light and very stable. However, up to 95 per cent of the original titanium is left over as waste chips during the entire manufacturing process. These are contaminated and until now it has not been possible to recycle them so that they are suitable for reuse in aircraft construction. Scientists have therefore developed a method that can process and recycle titanium chips with high purity.

High cost and competitive pressures prevail in aviation. Aircraft need to become lighter while still maintaining maximum structural stability. This can be achieved with lightweight construction materials, for example carbon fibre composite or titanium. This metal can be processed into components up to four metres long with a thickness of two millimetres. For production, about 20 times the volume of the actual component is required. Following several machining processes that include cutting, turning, milling and boring, up to 95 per cent of the original titanium is left over as waste chips. These chips are contaminated with coolants and lubricants, or are mixed with foreign substances. So far, theses have not been able to be recycled at a reasonable cost. Therefore aircraft builders always use new, primary material made from titanium sponge for the titanium components. The production of titanium sponge alone accounts for up to 80 per cent of the energy required for a titanium component.

In collaboration with industrial partners in the RETURN research project, scientists at Leibniz Universität Hannover have developed new solutions for the high-quality recycling of chips, whereby the goal is to reduce energy consumption. To this end, the researchers have investigated the entire process chain for producing the components and have analysed the energy and material flows. Furthermore, they have analysed the sources of contamination for the chips. These are either foreign substances or chemical impurities. Another focus was on developing improved machine tools that manage without conventional coolants. Project leader Professor Berend Denkena from the Institute of Manufacturing Engineering at Leibniz Universität Hannover sums up: "In order to meet the requirements of the aircraft industry, we always have to mix the recycled titanium with titanium sponge. Depending on the machining process used, we can use up to 93 per cent of the recycled titanium for producing
new, high-quality aircraft components, which means that the proportion of the primary material made of titanium sponge can be as low as 7 per cent.”

Detecting and preventing contamination
The scientists investigated the points throughout the entire process chain where foreign substances were mixed among the chips. These substances can include, for example, aluminium, copper or cleaning textiles. In order to prevent impurities caused by foreign substances, machine tools that process different materials need to be cleaned before the processing of the titanium can start. The same applies to the collecting containers for the chips. Since, however, chips from foreign materials cannot be completely removed, the Hanover-based researchers have developed and tested a process-integrated control system. The chips pass through a spectroscopy on a conveyor belt. The identified extraneous parts are then automatically sorted out.

The second source of unwanted substances are chemical impurities. These include oxygen, carbon and nitrogen. The cooling lubricants are mainly responsible for the carbon deposits, while the oxygen mainly comes from the ambient air. Since the oxygen and carbon content in the metal significantly determines the mechanical properties of the titanium component, the aircraft industry places high demands on the chemical composition of titanium alloys. The Ti-6Al-4V titanium alloy predominantly used for aviation applications only allows small quantities of additional elements in addition to the main components titanium, aluminium and vanadium. The maximum permitted levels for oxygen, nitrogen and carbon are therefore 0.2 per cent, 0.05 per cent and 0.08 per cent respectively. Further constituents may only be contained in the alloy to a maximum of 0.1 per cent. For most alloy manufacturers, the limits for oxygen and carbon are even stricter. In order to prevent impurities as much as possible, the scientists have therefore investigated other processing methods.

Processing titanium without coolants
Machining with cryogenic cooling, i.e. with cold liquid nitrogen at a temperature of minus 196 degrees Celsius, has proved successful. This makes it possible to dispense with carbonaceous coolants and lubricants. Until now these have been necessary in order to cool the tools when processing the titanium. This reduces wear on the tools. With cryogenic cooling the low temperature largely prevents the chips from oxidising and the oxygen input therefore remains below 6 per cent, which is comparatively low. The improved cooling with nitrogen enables the service life of the deployed tools to be almost doubled. As an alternative, the scientists also investigated dry machining. This was not successful because the higher temperatures increased the oxygen input relative to working with coolants and lubricants, and the service life of the tools also decreased.

Energy balance
This type of titanium processing requires considerable energy. Around 62,300 kilowatt hours are required in order to produce a component weighing 40 kilograms. The largest portion is used for producing titanium sponge. Machining with the cryogenic cooling process enables the energy balance to be significantly reduced in comparison with the previous production process without recycling. In the new process, the energy consumption is 67 per cent lower, which is equivalent to almost 42,000 kilowatt hours.