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High Quality Machining for Aerospace Industry

Innovation in rivet-hole drilling and in the distortion-free machining of titanium alloys

The wider use of lightweight materials such as fiber composites, titanium alloys and nickel-based alloys presents the aerospace industry with technical challenges in terms of commercial production.

Classic riveted joints are still irreplaceable in aircraft construction, especially for highly-stressed structures such as wings and control surfaces. Stack materials are used here - with an upper layer of carbon fiber reinforced polymer (CFRP) and an underlying metallic layer, typically of titanium or aluminum alloy. These layers are joined together by rivets. There are about 40,000 rivets on a single aircraft wing. Producing the holes for them in a high-quality, yet cost-effective manner is a real challenge.

Titanium alloy components offer enormous advantages for aviation due to their mechanical and chemical properties, such as low density, high corrosion resistance and high strength. However, they are difficult to machine - and require both special tools and a much longer machining time, compared to steel and aluminum alloys.

Objectives

The Institute of Production Engineering and Photonic Technologies (IFT) at the TU Wien is one of the most important research institutions for machining in the German-speaking world. The IFT has set itself the goal of reducing steep production costs and helping the aerospace industry to become more environmentally friendly through more resource-efficient and low-cost production as well as the wider application of weight-reduced components. The IFT's objectives include:

- producing large numbers of precisely drilled rivet holes more reliably and at lower cost than is currently commercially available
- milling titanium alloys in such a way that distortion is eliminated and costs are reduced

Rivet hole drilling in CFRP-Ti stacks

Currently, two layers of CFRP and the underlying titanium are drilled in a single drilling operation (one-shot drilling). This means a compromise in the cutting-edge geometry of the drill: drilling CFRP requires very sharp tools to avoid delamination or tearing out of individual fibers. Drilling titanium generates very high temperatures at the cutting edge, which requires a stable and thus less sharp cutting edge.

An additional challenge arises with closed structures, typically found on control surfaces such as flaps, slats or spoilers: Debris from the drilling process accumulates on the inside of the component. At present, the component usually has to be disassembled to clean the holes or to deburr them.

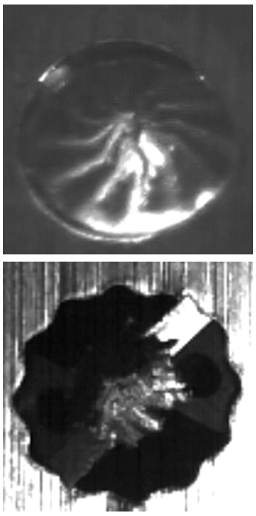
Solution

In order to be able to meet high quality requirements with a single tool, **vibration-assisted drilling (VAD)** is used by the IFT in the metal layer. An axial vibration is superimposed on the feed motion of the drill, whereby the cutting edges are disengaged in certain circular sectors. This enables targeted (kinematic) chip breaking and reduces the thermal load on the drill and workpiece. Over the course of a drilling process, process parameters, vibration assistance as well as the cooling and lubrication strategy are changed according to the requirements in the layers.

Research at the TU Wien is particularly focused on the drilling exit. In conventional drilling, a conical drill cap is formed. The drill cap either breaks off as an impurity and leaves a burr, or remains connected to the end of the hole, which means that time-consuming manual reworking will be needed.

Results

The TU Wien has developed a novel method for Foreign Object Debris/FOD-free one-shot drilling, which allows us to meet high quality requirements in aerospace more cost-efficiently than anyone else. Drill cap formation is successfully prevented; at the same time, borehole quality regarding wall roughness, entry and exit burrs as well as dimensional accuracy of the diameter is significantly improved. This is achieved with tool geometries optimized for VAD and special parameter combinations, in conjunction with a chip extraction system.



Drill caps:
VAD not optimized
VAD optimized

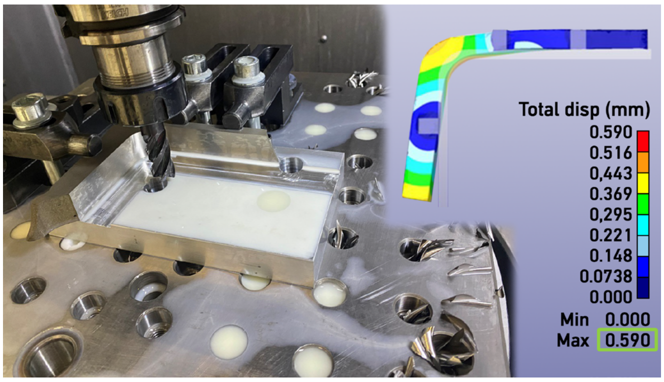
The adaptation of the process to specific applications of industrial partners is supported by simulation models and validated in test runs at the IFT.

Optimized Machining of Titanium Alloy

Titanium alloy workpieces, in addition to being generally difficult to machine, tend to distort during - and even after - machining. This leads to tolerance losses and makes further post-processing necessary. According to a 2019 study by the German Engineering Federation (VDMA), the cumulative additional costs due to residual stress-induced component distortion in the German aerospace industry add up to 850 million EUR annually.

Methods & Results

An optimization algorithm being developed at the IFT allows simulation-based prediction and correction of workpiece distortion during milling of titanium alloys. In the first phase of development, numerical simulation models and setups for experimental analyses were designed and built. Tests were carried out on simplified prototypes. Then, the results from this series of experiments were added to a database. The database is continuously being updated with new experimental results. For the production of a new part with specially defined geometry and tolerance requirements, a simulation of the stress fields in the semi-finished product is needed. The optimization algorithm uses the stress-field simulation as well as the results in the database to specify a machining strategy with an ideal “distortion-sensitive tool path”.



Prototype machining and deviations to be expected

The aim is to achieve a cost-effective method that produces machining operations with minimized distortion and helps to avoid time-consuming and costly trial-and-error. In this way, titanium components can be made in a less expensive and wasteful as well as more widely commercially applicable manner, and thus aircraft can be made lighter.

Your Benefits

The IFT of the TU Wien has more than 40 years of experience with innovation in the field of materials processing and machine tools. The knowledge gained from a multitude of research projects and industrial partnerships enables highly effective cooperation, competent consulting and the efficient implementation of innovation. The TU Wien supports you and makes it possible for you to achieve:

- comprehensive improvement of individual manufacturing processes - with multidimensional objectives
- product- and process-innovation
- optimization of the entire production chain - including machining, logistics, energy consumption and operational efficiency
- access to a diverse network of experienced tool and machine manufacturers
- rapid implementation of innovation ideas for your products
- agile workflows between design, manufacturing and quality assurance via automation of data flows

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