A whole stack of challenges

There are fundamental technical and industrial changes affecting our everyday life, but that occur out of sight. Unlike, for instance, the development of new computer technologies, they remain unnoticed by many of us - even when they are, in their own fields, just as significant. One example is the use of materials in aircraft construction.

For decades, aircraft were built mainly of aluminum, but that is now a thing of the past. A simple comparison shows how great the significance of composite materials has now become: when the Boeing 777 first took to the air in 1994, it was built with just seven percent composite materials. In the latest model, the Boeing 787 Dreamliner, these materials have already reached a proportion of 43 percent. And this also means that efficient machining of composite materials in a reliable process has become a crucial criterion for the profitability of aircraft manufacture. And this is exactly the field being researched by the composites experts at LMT Belin and LMT Onsrud. Drilling what are known as "composite stacks" is of particular interest here. A glance at the status of tool development at LMT Belin in this field illustrates the technical challenges this involves.

"In aircraft manufacture we often have to deal with carbon-fiber reinforced (CFR) materials The difficulties we face in machining these materials are, however, different from those found with metals: CFR materials are highly abrasive, have unfavorable vibration and resonance behaviors, and are sensitive to being overheated. The carbon fibers, moreover, cannot be cut in the normal way, but must be "sheared". This means that we have to leave behind familiar paths when we develop the corresponding tools." Martin Danielczick knows what he is talking about. He is the manager of the "Plastic & Composites" segment at LMT Tool Systems, LMT's marketing company. In this function, he also looks after the close corporation between Tool System and the producing factories. Both LMT Belin in France and LMT Onsrud in the USA are the competence centers within the group responsible for machining composites, plastics and aircraft components, although the other main members of the LMT group and LMT's alliance partners also contribute to the what the segment has to offer.

A materials combination with consequences

"Stacks" are often at the heart of the drilling involved in aircraft manufacture. The skin segments, fuselage and wing segments of an aircraft are manufactured from "stacked" layers, and these can consist not only of CFR materials but also of titanium or aluminum. Depending on the component in the material, these layers may be between four and 10 millimeters thick. This combination of materials faces the tool developer with an even greater challenge: "Even the machining of plain CFR has particular difficulties. Fibers from the material matrix can, for example, be pulled out at the exit of the hole. Exit edges, as a result, are not clean. In addition, local overheating or excessive peeling forces can often separate individual material layers from one another. This kind of "delamination" is the typical kind of damage we see in fiber composite materials," explains Danielczick. If it is now necessary to machine a combination of CFK and metal, further problems arise: aluminum residues can be "smeared" into the layer boundary or the interior CFR surface. Titanium chips, on the other hand, have the effect of additional, and naturally unwanted, cutting as they are transported away through the CFR layer, which is most often on the surface. "In any case, machining titanium and aluminum presents different challenges. Tools, for instance, require a twist in order to carry chips away efficiently. When machining titanium, moreover, the tool has to be cooled by minimal quantity lubrication," explains Danielczick.

Machining in just one "go"

How have these challenges in aircraft construction been met until now – the application of stacked components is, after all, advancing at a great pace? Danielczick explains: "So far it has been usual to carry out a variety of machining steps, known as 3-shot or 2-shot operations. In the 3-shot procedures, drilling into the solid, drilling out and reaming each represent an individual working step, while in 2-shot procedures, drilling into the solid and reaming/counter sinking are separated from one another. From today's point of view, 3-shot processes are no longer technically necessary. 2-shot working, on the other hand, is a reliable process frequently used for heterogeneous stacks of CFR with aluminum or titanium." All the same, the description Danielczick gives us already suggests the development target that has priority with LMT's tool engineers: "The target has to be one-shot machining for any combination of materials."
The reasons are not hard to see: a tool that drills, reams and countersinks in a single working step brings a massive reduction in production cycle times and in the cost of each hole. It is, of course, necessary that the quality requirements for dimensional accuracy and for the avoidance of delamination are satisfied at the same time. For the designers at Belin, however, this challenge means that a range of questions about the design have to be clarified for every new tool development – the cutter geometry, the number of cutters and cutting material, for example. And the answers are going to be different for every material and combination of materials that needs to be machined.

Process reliability with the LMT countersink drill

"The question about a reliable machining process for CFR-aluminum stacks with a one-shot process has been answered," explains Danielczick. "And the answer is: countersink drills coated with PCD or diamond." Whereas carbide tools remain often the most economical total solution for pure aluminum applications, the heavy abrasion means that it is essential to use diamond cutting materials when combinations with CFR materials are to be machined. All the same, tools fitted with PCD are competing increasingly with diamond-coated carbide tools in this field. "And, of course, here again, the central criterion is the avoidance of delamination and overheating," adds Danielczick with reference to the importance of the quality of the hole machining.
The multi-step geometry is an important feature of the one-shot tool. The countersink drill has, in a sense, three parts: the drilling segment with a large relief angle is followed by a drilling out or reaming segment, and finally by a segment for countersinking the hole. "Nevertheless it is not possible to make generally valid statements about the length and diameter of the solid drilling stage or of the additional dimensions for the finishing stage. It is exactly these parameters that we have to change depending on the layer thickness and the proportions of fibers in the CFR layers." Depending on the field of application (e.g. CFR/CFR or CFR/aluminum machining), there are yet other parameters, such as the cutting angle or the helix, that distinguish the various countersink step drills. The target, however, always remains the same: a reliable drilling process for composite stacks in just one "shot".

Next target: CFR-titanium machining

But the developers have not yet solved every task needed for stack machining: "Drilling and reaming CFR-titanium stacks in a single shot has so far only been possible in a few particular cases. There is still no general solution for these cases," adds Danielczick. Three factors are responsible for this: first of all, particularly when drilling into solid titanium, the wear on the tool is enormous. Tool lifetimes suffer as a result. Secondly, the titanium chips being removed act like additional cutting edges, changing the diameter of a hole in the CFR layer. Thirdly, the extremely high level of heat developed when drilling titanium can cause delamination in the CFR. "Constant, reliable process results for every common combination of materials is at present only provided by the two-shot method with a drill and a reamer" is Danielczick's summary of the present state of development. The question is therefore easy to see: when will LMT's engineers achieve the goal of "one-shot machining through CFR and titanium"? Danielczick's comment is: "We have already achieved very good results in some particular applications – the target is no longer far off..."

Foto: The question of reliably machining CFRP/aluminium stacks in a one-shot process has now been answered. The answer is: PCD or diamond-coated countersink drills.

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