

Process Understanding of Dry Drilling CFRP/Aluminium and AL/AL Stacks in IT8 Quality

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ABSTRACT

Drilling holes into metal with MQL (Minimal Quantity Lubrication) is a normal procedure, because the drill is designed for drilling metal and the malleable capability of the metal compensates for the insufficient cutting capability of a worn out drill. Drilling composite materials using the same drill (designed for drilling metal) is a different procedure, because composite fibers are not malleable like metal at all. Due to this fact the tools become very hot trying to forge composite fibers like metal. The elastic behavior of the composite and the delamination inside the hole makes the tool temporary smaller than the diameter of the drill.

The hole in the metal part of the stack remains slightly larger due to the heat and the thermal expansion rate. This paper shows how to drill metal and composite with the same diameter, so that achieving H8 quality is no longer a dream. Besides drilling H8 with cpk higher than 1.7, the dry drilling is one other important goal for aerospace assembly ever since. This paper will show how the dry drilling of aluminum/aluminum and composite/aluminum is feasible and well established in the serial production at the Airbus Bremen plant. The nice side effect of this new technology is the stability of the bores quality and diameter. Even when the tool reaches the end of it's life the cpk and the absolute value remains the same. The slightly linear increase of the burr height acts as an "In Situ Measure Indicator" of the tool life.

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INTRODUCTION

When designing an aircraft, a "Fail Safe Design Philosophy" is used for class 1 parts. When a class 1 part fails the aircraft will not fly properly anymore. Therefore, class 1 parts must be analysed for possible failures. For a "Fail Safe Design Philosophy" all the possible failures will be covered by special functions of the same or other parts. We do have a similar situation by machining aircraft parts. The value of parts is growing along the manufacturing process chain. In most of the cases drilling is one of the final operations. If something goes wrong on this final operation, the risk of ruining the part is very high. Even when the requested quality of the operation result is not reached, an expensive concession has to be written and discussed with the development department. Even the manual reworking, drilling oversize holes, takes time and includes the risk of further defects. When selling the part, the customer will reduce the price of the part based on the number of concessions.

One other main topic is the permanent cost savings in drilling holes. Figure 1 shows that beside the cost for the tools the effort for coolant and related technology is much higher.

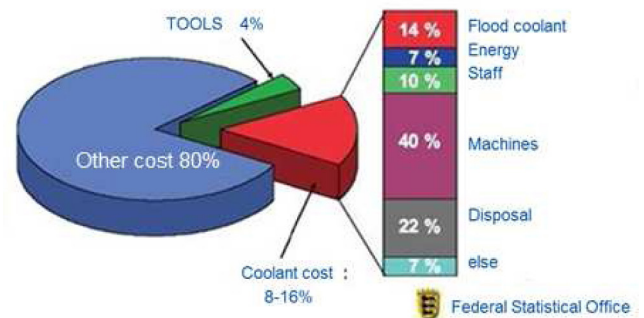


Figure 1. Composite has no plastic deformation capability

High cost of the special MQL oil, the MQL equipment, the qualification, the cleaning operation (of the site, jigs, parts), environmental issues and more critical the remaining oil residue in the aircraft components are often the reason for the request for dry drilling. Even with complex cutting tool coating systems, the dry drilling was not working, due to the metal built-up closing the flute of the tool spontaneously.

Another huge problem is the evacuation of the wet carbon dust. Like the dry powder of cement, the dry carbon dust can be easily extracted. However, a drop of water is enough to harden the cement. The small amount of oil in the MQL hardens the composite dust in

the same way. Even the polished flutes of the cutting tools are jammed with oil and dust, hindering the evacuation efficiency. So dry machining of CFRP materials is easily feasible and has been the state of the art for many years. Besides the already mentioned benefits, the process can be run much more securely and the cpk value is generally higher. The dry carbon fiber dust gets whirled out of the hole due to the spiral of the drill. For deeper holes air though the tool can support the whirling of the dust and the ventilation of the tool inside the hole.

The general problem in the dry drilling of aluminum is the build-up of the adhesive aluminum caused by van der Waals bindings and the cohesion due to the roughness of the surface. During the drilling of composite aluminum, the abrasive composite fibers brush the tool and remove the aluminum build up. The usage of micro peck/vibration drilling additionally helps to prevent build-up. The cleaning mechanism is the dynamic touch and goes between the tool and the part. The build-up prefers rather to stick to the more similar aluminum chip than to the cutting material. The main criteria are to choose the right drilling and vibration parameters to avoid chip accumulation, which might occur even if separated chips are generated.

DRY DRILLING IN GENERAL

When drilling into metal, not the forces at the tip, but the temperatures at the edges of the drill causes the formation of burr. The maximum temperature occurs at the drill tip. The heat wave in front of the drill accumulates at the exit hole and softens the material. The axial pressure then is able to generate the burr, because the force cutting the material is higher than the force for forging the material.

A tool which only heats up the relevant area at the tip independently and under minimal heat generation was not easy for us to develop. However, with such a tool, coolant is no longer necessary and the dry drilling of carbon fiber / metal composites becomes possible. The polished surface of the tool flutes and the part remain free from buildup. This new tool concept has already qualified for flying applications.

Another way to prevent the build-up and to enhance the tools life / efficiency is the use of PVD or CVD diamond coatings. The PVD diamond coating is in the range of conventional coating price wise. The cold DLC (Diamond Like Coating) is a 2-4µm thick layer of SP2 Diamond. Tools with DLC coating can be striped, reground and recoated without problem.

In order to prevent the cohesion, polished flutes are very common. For the build-up on the tool, adhesion is the remaining mechanism for polished flute design. The DLC is an organic coating chemical. That means that there will be no strong van der Waals bindings (adhesion) between the metal (aluminum) and the carbon (DLC Coating) possible. In fact diamond coatings (SP2 and SP3) and polished flutes shows the best resistance against build-up when machining aluminum, preventing both adhesion and cohesion.

In case of dry drilling stacks with composite/Alu the hardness of DLC Coating (Sp2) with around 2.500 Vickers is not wear resistant enough.

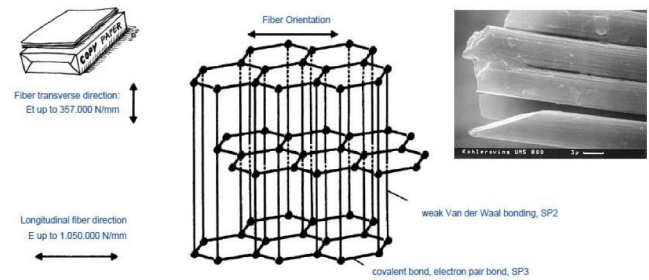


Figure 2. Modelling the chemical structure of a diamond fibre

Before going into machining and cutting tool details, we should clarify the physical character of the carbon fibers. A carbon fiber has two different types of chemical bonds. Along the fiber there are covalent bonds (SP3). This leads to an elastic modulus up to 1.050.000 N/mm, similar to natural diamond. Vertical to the fiber orientation we have van der Waals' interaction (SP2). This SP2 interaction is the reason why the fibers are so flexible.

Modelling of carbon fiber material is similar to a pack of copy paper, with much higher stability along the papers and less stability between the single papers (Figure 2). Bending the copy paper package is not a problem. But in case of pressure or tensile stress along the paper each piece of paper takes a part of the load.

In the case of cutting carbon fiber in fact, we are facing the longitudinal stability and hardness of a material similar to diamond (SP3) and the hardness of around 10.000 Vickers. That's the reason why we have extremely high abrasive wear on the tool when using steel or even solid carbide. Cutting tools with diamond like carbon (DLC), characterized with around 2.500 Vickers, will wear down rapidly the same as steel or solid carbide. The only solutions that work on the same level are CVD diamond coatings, PCD tipped tools and other diamond related cutting materials.

For the task to prevent the build-up, CVD diamond (SP3) works the same as DLC (SP2) chemical wise. The surface of home epitaxial grown diamond coatings are quite smooth (Figure 3) [1]. This lowers the risk of build-up by cohesion between metal and the roughness of the diamond coated surface. Unfortunately this type of diamond coating deposition is very expensive and its mechanical properties are not so tough. A microcrystalline film, with randomly orientated triangular {111} facets (hetero epitaxial) is more suitable for higher mechanical stability.



Figure 3. Characterization of Diamond Coating variations

The randomly oriented diamond crystals are well linked between each other. Due to that the surface of a diamond coated cutting tool is quite stable but rough (Figure 3). For the drilling of composite/Alu the