

Major Breakthrough in Multi Material Drilling, Using Low Frequency Axial Vibration Assistance

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ABSTRACT

Aircraft design has mainly changed in the past years, introducing new materials such as CFRP at a large scale. Even if this great change brought many advantages: weight, sustainability, reliability... it upset the way to produce basic parts and to assembly. A special difficulty lies in drilling multiple stacks made of different materials, i.e. metal (aluminum, titanium, stainless steel) + CFRP. Indeed, as the process has to drill through those stacks during a unique operation, cutting conditions and tool technologies are a compromise. As a consequence, tool life cycle, productivity and above all, hole quality are no longer optimum.

Some materials, such as titanium requires low cutting speed and high feed rate whereas CFRP requires opposite trends. Moreover, heat generated by cutting metal (especially titanium) can damage CFRP when overheated metallic chips pass through. Finally, the compromise for cutting conditions and tool technology can generate long metallic chips that may congest drill flutes and entail hole damages or tool breakage.

For ten years, a new technology has been developed consisting in reducing and overcoming chip size. The principle lies in adding a periodic low frequency motion to the constant feed motion of the tool. With optimized parameters (amplitude and frequency) this combination allows to create weak points on the chips that make them break when twisted by the cutting edge. Unlike over processes, micro-peck or micro-shock drilling, the cutter never goes out from the material which avoids shocks and tool breakages.

This technology has been applied to ADE in aerospace field where benefits are significant. Drilling process is perfectly steady during the whole operation: no thrust, torque or heat increases or peaks. Thus, hole quality and tool life cycle are more predictable. This solution has been wide spread in aircraft assembly operations even for mono material drilling where constant small chips prevent ADE congestion and ease part cleaning.

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INTRODUCTION

To ensure ever increasing performances of their products, aircraft builders keep on lightening aircraft structures. As huge progresses have been carried out these past decades in designing and elaborating composite materials, their use has been generalized. In the 80's composite materials represented less than 5% of the global structure mass; they have now reached almost 50%. Associated with metallic materials (Aluminum, Titanium) composite materials allow to minimize weight while maximizing resistance. However this combination complicates assembly operations and especially drilling operations. Indeed, due to their large dimensions and complex shapes, parts to assemble require being drilled and fixed together simultaneously (Ramulu, Branson, and Kim 2001). As a consequence, multi material drilling has become a widespread operation in aerospace industry.

For accessibility and flexibility reasons, ADEs (Advanced Drilling Equipment) are mostly used to achieve drilling operation. These machines are generally powered by pneumatic energy which usually implies constant cutting condition during the drilling operation. Thus, drilling a multi material stack involves making a compromise for: tool technology, cutting conditions, lubrication conditions. In this case, none of the material passed through is drilled in optimal condition. Otherwise, depending on the material sequence in the stack, cutting phenomenon in a material can entail degradation in the neighboring materials. These negative impacts directly affect Quality, Productivity and Costs.

This paper presents a new technology: low frequency axial vibration drilling, which can helpfully solve multi material drilling issues.

PROBLEMATICS

In this section, we will try to set a non exhaustive list of issues in multi material drilling, considering the three main points of view: Quality, Productivity and Costs.

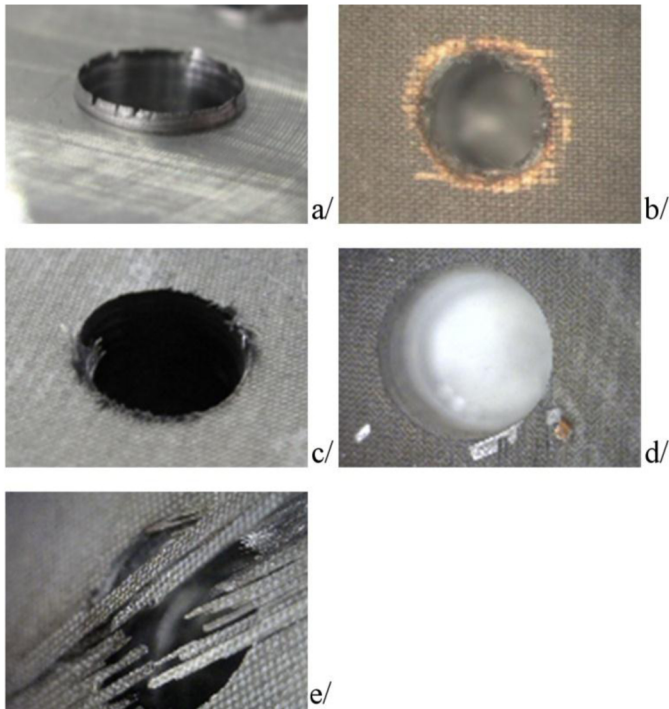


Figure 1. Different kinds of defects in composite material and metallic material.

Quality Point of View

Prior studies (Zitoun, Krishnaraj and Collombet 2010) showed it is more appropriate (if possible) to firstly drill CFRP and secondly metallic material (metal → CFRP) in order to avoid delamination at the tool output (Fig 1/c, 1/e). However, in this case, when drilling the metallic layer, hot metallic chips may burn CFRP surface (Fig 1/b). This is particularly proven with metal like titanium that generates high temperature during cutting (Shyla and al. 2010).

In the opposite case (i.e. firstly metal layer and secondly CFRP layer), when passing through the stack interface (CFRP→metal), a change in thrust occurs that may generate a gap between materials. This gap can possibly allow occurrence of a metallic burr and/or metallic chip intrusion at the interface (Fig 1/a, 1/d). For quality reasons, these are non-acceptable defects that require cleaning and may also burn CFRP surface.

Another quality issue is due to the compromise on cutting conditions. Long metallic chips may appear that can congest the tool flutes and generate a high friction on the finished surface of the hole. This friction usually deteriorates roughness. In the worst case, this may entail a tool breakage because of the constant rising torque due to flute congestion.

Productivity Point of View

The compromise on cutting conditions directly affects productivity, as ADEs generally work with constant rotation speed and feed rate. Therefore, operation cycle times are far from the optimum.

To avoid quality defects due to flute congestion, one (or more) prepierced hole(s) is(are) made to limit chip flow. This(these) additional operation(s) strongly affects productivity by multiplying cycle times by the number of prepierced holes.

Another technical solution to limit flute congestion is peck drilling. Peck drilling consists in stopping the feed during the operation, removing it from the material and restarting the process. Basically, pecks should occur every time the stroke is equal to tool diameter. For deep boring, this may substantially increase cycle time.

Moreover, as ADEs are powered by pneumatic energy, their performances are not as steady as for a NC machine. Indeed, a torque increase should slow down rotation speed and therefore decrease feed rate. Usually, torque constantly rises during the drilling operation as long metallic chips rub along the hole surface that is widening with depth.

Cost Point of View

The global compromise on the process also affects tools that must maintain quality for any layer of the stack. On the one hand solutions have been found to improve or develop tool technologies: new geometry, new material, new coating... unfortunately, this leads to quite expensive tools. On the other hand, these very technical tools often have a lesser life cycle. Both tool cost rise and life cycle decrease leads to greatly increase cost per hole.

Besides, tool life cycle decrease is not as detrimental as tool life cycle uncertainty. Indeed, flute congestion may lead to a tool break during the process. This phenomenon is not predictable and entails a random tool life cycle. Costs due to a broken tool (potentially stuck into the material) are often consistent: exemption, repair, quality inspection...

Synthesis

For the three aspects, quality, productivity and cost, former techniques which enabled to control chip generation in a mono material (composite or metal) are no longer effective because of the compromise on the process. Most issues listed above are due to a lack of control of the metallic chips. In order to sustain and improve quality and performance of process in multi material drilling, metallic chip characteristics must be considered as full part of the hole quality as well as geometry, roughness... and not just as a waste. The next section presents a brief state of art on the techniques to control the metallic chip generation.

STATE OF ART ON TECHNIQUES TO CONTROL METALLIC CHIPS

Throughout this section, we will list both well-known and emerging techniques that can help controlling metallic chip generation in multi material drilling processes. This overview will be weighted by critical analysis of each solution.

We decided to sort techniques by principle. A first way to eliminate or soften metallic chip issues consists in producing a smaller volume of chips per operation. As the chip flow decrease, flute congestion and related problems tends to diminish. A second method is to ease the chip evacuation by limiting any element that would slow down chip flow into the flutes. A third way suggests play on the chip size in order minimize chip volume for a similar mass of extracted material.

Diminution of Material Removal Per Operation

A classical and widespread technique is cascade drilling. The aim is to make one or more initial holes before a reaming operation. In this way, metallic chip flow is limited when finishing the hole surface. Quality is maintained in the multi material stack and studies proved this technique was efficient for an industrial use ([Brinksmeier, and Janssen 2002](#)). Unfortunately, productivity and costs are deeply affected by cascade drilling thus it requires several tool references and several cycle times compared to a single shot operation.

A second way to reduce chip flow during the operation is core drilling. This operation uses a trepanning tool that removes only peripheral material, the core being extracted with the tool ([Mathew, Ramakrishnan and Naik 1999](#)). The main problem lies in the cost of such a tool concept and the core extraction which requires specific systems.

Chip Extraction Facilitation

To ensure a good metallic chip evacuation, a first solution is to improve chip slip in the flutes. Many possibilities exist yet the more suitable are: special coating with low friction factor and polished flutes ([Guibert 2008](#)). These solutions can bring real benefits but the duration of the performance is not always warranted and benefits vanish if the tool needs re-sharpening.

A second solution is to enlarge flute section ([Guibert 2008](#)). Therefore, the chip flow is easier and phenomena due to flute congestion tend to be eliminated. In return, tools are weakened and are prone to rupture.

Peck drilling is a well known method (above described) that can ease metallic chip extraction. It is widely used in boring operation where the ratio depth/diameter is high. However, operation cycle time strongly affects productivity and this process entails complex cycles which are not easily compatible with the use of ADEs.

Shortened Chips

A classical way to reduce metallic chip size and therefore, to force them to split consists in playing on cutting conditions (rotation speed and feed) and tool geometry (cutting edge and cutting face) ([Ko and Lee 2001](#)). Concerning cutting conditions, studies in mono material drilling (metal) solutions have long been known and are effective. Yet, compromise in cutting condition for multi material stacks often bans this classical method. The second point consisting in local specific cutting geometry is a common solution, especially the use of chip breaker. This technique offers many benefits by facilitating chip breakage and therefore minimizing chip size. However, chip breakers do not allow an easy tool re-sharpening, which deeply affects costs.

By nature, drilling is a continuous cut operation (cutting edge never goes out from the material during the whole cycle). An idea to shorten metallic chips is to introduce interrupted cut process, like in milling operation ([Denkena, Boehnke and Dege 2008](#)). The principle is to use a mill instead of a drill and proceed to a contouring-like operation. Interrupted cut basically generates short chips easily extractible. This technology ever used in aerospace industry ([Novator](#)) gives good results. Nevertheless, process has to be completely changed and in some cases can't be treated for difficult access holes.

Another way to produce short chips in drilling is vibratory drilling. The principle has been set in the 50's in the Moscow State Technical University n.a. N.E. Bauman (MSTU) and consists in adding an alternative axial motion to the constant axial motion (feed). The idea is to locally modify the instant feed and thus to break the chip. There are several technologies of vibratory drilling. One is high frequency vibratory drilling (10 to 50 kHz) using ultrasonic vibration. The main disadvantage of this technology is that it requires an external source of energy and cumbersome equipment. At the opposite, low frequency vibration technologies have been developed. Some requires external source of energy (hydraulic, electric) which involves the same problem than the ultrasonic solution. Self-sufficient technologies exist. One is self-sustained excitement vibratory drilling system ([Guibert 2008](#)). The principle is to find cutting conditions that generate and maintain an unstable state of the system, creating self-sustained vibrations. The main advantage of this solution is to minimize encumbrance. In return, the process is highly dependent of parameter variations (rotation speed, feed rate, material properties...). This solution is not convenient for multi material drilling even less relevant for ADEs. One last solution is forced low frequency axial vibration drilling. As for self-sustained vibration system, this technology does not require any external source of energy and mechanically forces the tool to oscillate. Its simple principle allows an easy integration to any mean of production: CN machine, drilling dedicated spindle or ADE. In the next section, this technology will be described and analysed.