A guide to effective composite machining for aerospace components
Introduction

Demands to reduce aircraft fuel consumption and minimise the greenhouse gas emissions associated with air travel is driving the rapid uptake of light yet strong composite materials in the aerospace industry.

Materials such as carbon fibre reinforced plastic (CFRP) and other engineering composites require a different approach to machining than metals, and addressing these challenges efficiently is a key issue for aerospace manufacturers.

This white paper looks at the important industry trends surrounding composite materials in the aircraft industry and the route to best practice machining.

The drive to composites

The worldwide carbon fibre market is set to soar. According to a recent report by Global Business Intelligence, demand is likely to reach 153,700 tonnes by 2020. Compare this to the 52,500 tonnes consumed in 2012, and the trend is clear to see.

With two composites-dominated airliners in the air together with numerous military aircraft, aerospace is the principal market driving industrial demand, chiefly through frame elements such as the fuselages, wing skins, central wing boxes and vertical tails. Some aircraft programmes today consist of approximately 50 per cent composite material.
Fuel efficiency is at the heart of this trend. Composites are around 2½ times lighter than metals and consequently offer designers the opportunity to reduce weight (and hence fuel consumption) without compromising strength. In fact, composites are stronger by weight than aluminium, steel and titanium.

Composites are clearly here to stay for the foreseeable future, which means continuous improvements are imperative for discovering new efficiencies in composite component machining.

One of the most significant process variables is the type of machine deployed. According to industry estimates, around 40 per cent of composite machining applications are undertaken by power feed machines or ADUs (automatic drilling units), while 35 per cent use hand-held machines and 25 per cent of tasks are completed by CNC machine or robot. Although cutting tools can be made to fit various machine designs with the availability of multiple thread couplings, due to the differences between stable and unstable conditions, a cutting tool optimized for a CNC machine is unlikely to be the best choice for an ADU, for example.

Currently, drilling and reaming account for around 70 per cent of composite machining operations – the range of hole diameters is typically 3 to 12 mm, with depths of two-to-five times the diameter. Milling operations comprise the remaining 30 per cent, although this discipline is growing.
Fig 2. Drilling and reaming account for 70 per cent of composite machining operations

Machining characteristics

Among the main differences between machining composites and traditional engineering materials such as metals is that the latter feature natural lines of fracture and stress. This predictability, along with the fact that machinists have accumulated scientific knowledge about metallic materials for hundreds of years, makes machining metals relatively routine.

Conversely, composites offer far less machining predictably due to the presence of a greater number of variables: fibre type, resin type, fibre orientation at point of contact, material thickness, matrix hardness, heat sensitivity and so on. Furthermore, machining composites produces no chips. Instead, the material removal mechanism can be better described as ‘shattering’. As a result, obtaining clean cuts demands a different approach when it comes to tools and techniques.

While many composite materials are around one-fifth the density of steel, the idea that machining should be easy is misplaced. Machining these materials is a dusty, arduous and abrasive process that is hard on tools. The right combination of cutting edge geometry and tool material is paramount.

Common failure modes

The fibrous and layered nature of composites means there are many potential failure modes if the tool or process parameters are incorrect. Delamination, for instance, is where the bond between the fibres and resin begins to fracture causing a region of composite to peel off, usually just past the edge of a hole or milled edge.

Splintering is another prevalent failure mode where uncut fibres remain overhanging the edges of the hole/edge after machining, although, as a defect, the problem is more aesthetic and less mechanically damaging than delamination. Similarly, fibre pull-out occurs when the cutter snags a fibre within the composite, causing it to break away, while another frequently reported defect is uncut fibres, where the drill progresses through the material too quickly. Heat is another common cause of failure as it can locally destroy the resin element of composite parts.
Fig 3. Composite holes are prone to defects and damage

Hole entries, exits and walls are particularly prone to defects and damage that can put them outside quality limits. Making matters worse is the fact that hole quality often deteriorates before any indications of tool inadequacy.

No ISO standards

The vast breadth of composites available in the marketplace means that there is no ISO standard for these materials as there is for metals. Subsequently, every individual machining process and cutting tool solution must be tailored to specific customer requirements to achieve the desired outcome.

The most common composite material for engineering applications is the group known as carbon fibre reinforced plastic (CFRP). The matrix of most CFRPs is generally a polymer resin such as epoxy, although polyester, vinyl ester and nylon are also used. The resin binds the reinforcements together.

Besides carbon, the ‘fibre’ element of the mix can include aramid, Kevlar or glass, for instance. Frequently, these composite reinforcement materials have been pre-impregnated with activated resin. Here, the epoxy resin, which has previously been mixed with hardener, is impregnated into the dry reinforcement fabric to create what is known as a ‘pre-preg’.

Metals such as titanium and aluminium are often stacked in layers with the CFRP to introduce additional design properties. Double stacking (CFRP-Al-CFRP-Ti) is also on the increase, with stainless steel even included for some applications. In turn, these combinations present additional machining challenges: burr formation is a common criterion with titanium and chip control with aluminium, for example. In every case, the material must be identified in relation to surface, structure, fibres, resin and thickness. With stacks, the combination of metal type and thickness are relevant factors.

Commercial considerations

In the aerospace industry, making holes is a dominant driver of efficiency and cost issues, and there are many ingredients to a successful, cost efficient process.

The volume of holes to be produced, for example, impacts tool selection in that a large quantity in one type of composite material must be made efficient using an optimized, typically more expensive tool. A smaller quantity of holes, combined with the ability to accommodate the variation in composites, components and set-ups, indicates a different tool choice.

The amount of operations required to finish a hole in a composite component is a further productivity factor increasing in prominence, as is the eradication of operations such as deburring. Recently, specific tool development has contributed to applications where four hole-making operations have been reduced to one using a more suitable, modern tool. This was achieved by eliminating pre-drilling, reaming and de-burring. One-shot operations can obviously impart huge influence on the economics of manufacturing when high volumes of holes need to be generated.
Tool changing is another influential productivity factor and one that is easily improved using the right technology. Quick-change toolholders, for instance, can reduce this task to just a few minutes at most. Modern toolholding concepts feature high-tech couplings between the spindle interface unit and cutting unit that is easily and quickly changed with high accuracy. Exchangeable head systems are also available, where the head can be changed in a few seconds. Not having to remove the tool shank and or perform any further pre-setting of the cutting edge results in minimal machine stoppages for tool changes.

**Tool materials**

Cemented carbide offers ways to strengthen the tool through the cutting geometry as well as through the shank of the drill, therefore optimizing cutting action and maximizing clearance and material evacuation. The upshot is that many carbide-based drills are particularly suitable for unstable operations involving hand tools. They can also help negate issues such as uneven thrust from operators or variations in guide bush/drill clearance. As such, these drills are also ideal for many operation using power-feed machines.

Carbide and polycrystalline diamond (PCD) have different limitations as tool materials: carbide is strong but wears quickly, while PCD is very wear resistant but more brittle. Combined, however, they represent excellent hole-making solutions. A drill with cemented carbide as the central tool material with cutting edges of PCD is seen as the preferred option for drilling composites when quality levels and consistency are being tightened and higher demands are being made on productivity.

**Vein technology**

Possibly the most significant cutting tool advance for composite materials in recent years has been vein technology. PCD veins are diamond edges integrated in a cemented carbide tool to make use of hard, wear resistant cutting edges within a tough drill shank. A carbide drill has a PCD-edge brazed into a slot positioned sufficiently away from the drill-tip, therefore permitting the use of a high strength brazed joint. The final tool geometry is then ground, leaving the edge shielded to a variable extent by the carbide portion of the drill.

Vein technology allows for variations in cutting geometries that were impractical or even impossible to achieve with conventional PCD-bit processes. As a result, such tools can cope with everything from unstable set-ups through to rigid, high volume applications with precision holes. Sharp cutting geometry is provided that stays keen to the most abrasive of CFRP.

Alternatively, PCD vein drills can be engineered for composites stacked with metals. As such, they can feature micro-grinds positioned strategically to combat areas of high stress concentration. This provides the drill with added ability to remain sharp and accurate throughout an extended tool life.

**CoroMill® Plura compression end mill**

Among the latest tools to emerge from Sandvik Coromant is the new CoroMill® Plura compression end mill for composites. Different to conventional end mills, this cutter combines positive and negative helix design to ‘compress’ the top and bottom of the component edge and so minimize any opportunity for splintering.
Suitable for edge milling applications on material with a minimum thickness of 6 mm, the new compression end mill offers micro-geometry with six cutting edges for surface finishes (Ra) of well under 4 µm and high material removal rates. Among the cutting data users can expect to see is cutting speeds of 200-400 m/min, along with feed rates of 0.03-0.06 mm/tooth for roughing and 0.02–0.04 mm/tooth for finishing. Conventional up-milling strategies are recommended as these give less vibration.

**CoroDrill® 854 and 856**

Among other standard solutions are CoroDrill® 854 and CoroDrill® 856. The former is best for fibre-rich materials with extra capability to minimize tendencies for fraying in holes. It has spurs at the drill periphery to cut fibres and avoid splintering, and is also good for CFRP stacked with aluminium layers.

CoroDrill® 856 is for drilling resin-rich CFRPs. It has double-angled cutting geometry which delivers soft entry and exit capability to minimize delamination.

**CoroDrill® 452**

Tools for hand-held machines need special qualities to resist deflection and the presence of non-axial forces. Here the CoroDrill® 452 range offers great potential.

The drills offer low thrust force due to innovative split point geometry and smooth drill exit resulting from a left-hand helix on a right-hand drill. Sharp cutting edges produce high quality holes offering tolerances of ±0.025mm using a drill bushing. This can be improved further, to ±0.01mm, using the CoroDrill® 452.R-C range of reamers.

CoroDrill® 452 can also meet the challenge of drilling composite/metallic stack materials using hand-held machines. Here, CoroDrill® 452.1-CM features a double margin flute design and self-centring drill point to impart accuracy. Both pilot and non-pilot versions are available depending on application and again, a low thrust force design reduces burr upon exit. Reamers are also available for these operations.

**CD10 series PCD vein drill**

For CFRPs stacked with titanium, CD10 series PCD vein drill technology is a preferred choice when using power feed or CNC machines.

Here, Sandvik Coromant has many specific aerospace machining examples that highlight the potential benefits on offer. For instance, take the drilling of wing boxes made from carbon fibre/titanium stacks. These components are processed typically using power feed machines and require reduced burr on exit and good surface finish. Shown to achieve excellent hole quality and consistent manufacturing with 90-hole tool life (9.525 mm diameter, 12 m/min cutting speed, 0.05 mm/rev feed) is the use of CD10 diamond veined tipped drills with 86PT point geometry.
CoroMill® 590

From a milling perspective, any aerospace manufacturers performing surface machining on primary structure carbon fibre wings or wing boxes should look no further than CoroMill® 590 with CD10 PCD inserts. This tooling combination will allow cutting speeds in the region of 300 m/min.

CoroMill® 390

Sturtz milling using CoroMill® 390 offers a fast machining strategy that involves tilting the tool relative to the component surface. The resulting shallow ellipse allows greater step-over to be used without exceeding the maximum permissible cusp height.

CoroMill Plura S215 for milling and edging

CoroMill Plura S215 offers many different geometry options, such as a compression helix design for thicker CFRP or when equal geometry is needed for both sides of the composite sheet. There is also a low helix design of +5° when the bottom surface is the most important and -5° when the top side is most important and down-forces are critical.

The tools come in different grades to maintain sharp edges, or are diamond coated for longer tool life but where ultra-sharp edges are not top priority. There is also a PCD brazed version for long tool life and enhanced surface finish.

Conclusion

Ultimately, the future looks extremely rosy for tooling technologies in the composites machining sector. Ongoing research at Sandvik Coromant includes projects examining orbital drilling, edging solutions (low helix), CFRP stack machining simulation and the ongoing study of wear mechanisms in CFRP composites. Equipped with the enabling technologies for machining composites, there will be no limit to what aerospace manufacturers can achieve in the years to come.
About Sandvik Coromant

Sandvik Coromant is a global leading supplier of cutting tools, tooling solutions and know-how to the metalworking industry. With extensive investments in research and development we create unique innovations and set new productivity standards together with our customers. These include the world’s major automotive, aerospace and energy industries.

Sandvik Coromant has 8000 employees and is represented in 130 countries. We are part of the business area Sandvik Machining Solutions within the global industrial group Sandvik.

For more information visit the website at www.sandvik.coromant.com.