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New Tools Needed

New cutting tool materials are required for new generation airframes.

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The growing use of composites, titanium and stacks containing both materials in structural applications is driving major change in the airframe industry. These represent challenging applications that require cutting tool materials that are both very hard and tough.

Airframe Industry

To increase aircraft efficiency and reduce lifecycle costs, aircraft manufacturers are using more composites and titanium (See Figures 1 and 2 on pages 76 and 77). The Boeing 787 (shown above) and the Airbus A350 airframes, for example, will consist mostly of composites by weight. In the business jet market, Hawker Beechcraft's Premier IA and Hawker 4000 will have all-composite fuselages and Eviation's EV-20 Vantage will have all-composite wings and fuselage.

The use of composites facilitates part consolidation and bonding, reducing the number of fasteners required. However, the majority of fasteners eliminated are "acreage fasteners"—large numbers of smaller diameter fasteners that can be made with automated processes. Most of the holes that are left are more challenging, larger diameter holes in thicker, multiple-material stacks. Because contact between graphite composites and aluminum can cause galvanic corrosion, structural components attached to graphite composites are generally made from titanium. These two materials are difficult to drill and are even more difficult to drill when combined in a stack. In addition to having different drilling parameters than traditional materials, they also require different cutting tool materials.

Carbon Fiber Challenges

Carbon fiber composites pose several machining challenges, including:

- The material is very abrasive, producing high tool wear rates,
- Anisotropic properties (due to combining a soft matrix and hard fibers in varying orientations) means that the cutting tool experiences varying cutting resistance,
- The plastic matrix limits cutting temperature,
- Fiber reinforcement requires a sharp cutting edge, high shear geometry and high velocity for clean cutting,
- The laminate structure is prone to delamination under excessive cutting forces (e.g., high drilling thrust), and
- Dust is created instead of chips, requiring control by vacuum collection or flood coolant.

Titanium Machining Challenges

Titanium also poses unique machining challenges, including:

- Low elastic modulus because the material pushes away during cutting, and "springs back," requiring high clearance angles,

- Low thermal conductivity leads to high cutting temperatures (80 percent of heat generated goes into the tool compared with 50 percent when cutting steel),
- High chemical reactivity at higher temperatures means titanium has a tendency to weld to the tool, leading to tool chipping and failure,
- Workhardening, especially at low feed rates,
- High strength is maintained at elevated temperature,
- Segmented chips, which create cyclic forces and tool fatigue, and
- Greater susceptibility to surface damage during machining operations, resulting in appreciably lower fatigue life.

In addition to the challenge of drilling these dissimilar materials together, the following challenges arise in current aircraft assembly. They are drivers for increased performance and quality requirements from the drilling process:

- The need to drill larger diameters and thicker stacks,
- Increased trend toward one-shot drilling, dry or near-dry machining and one-up assembly to reduce assembly time,
- Although there is increased use of both large- and small-scale automation, pneumatic drill motors are still primarily used in final assembly operations, and
- Increased use of lean principles.

These items all reduce tool life to the degree that a new cutting tool material is needed to reduce the cost per hole and improve productivity. Another driver for longer tool life is decreased flow time in final assembly. For the 787, the goal is a 3-day flow in final assembly and the goal for the Lockheed Martin F-35 Lightning II is to produce one plane per day out of final assembly. For comparison, the 737 is at a 10-day flow (down from 22 days in 2000, with a goal of 8 days) and the 777 is at a 25-day flow. Part of the ability to achieve a 3-day flow on the 787 is due to moving some of the work upstream, so the pieces arrive prestuffed with aircraft systems but, as noted before, drilling in final assembly is the most challenging operation.

Ideal Cutting Tool Material

In general, the desirable properties for a cutting tool material are:

- Small grain size to be able to produce a sharp cutting edge,
- High hardness, including high hot hardness, to provide excellent abrasive wear resistance,
- Good toughness (high tensile rupture strength and fracture toughness) to maintain a sharp cutting edge without chipping or deformation under a cutting force's dynamic action,
- Good thermal conductivity to remove heat from cutting zone,
- Thermal stability to maintain integrity at cutting temperatures, and
- Low chemical affinity or reactivity to the workpiece material.

The degree to which each of these properties is needed depends on the workpiece material. The difficulty is finding all of these properties in the same material. Generally there is a tradeoff between hardness and toughness (Figure 3), but both are needed for the combination of carbon fiber-reinforced polymer and titanium.

Drilling fiber-reinforced composites, such as CFRP, is similar to drilling

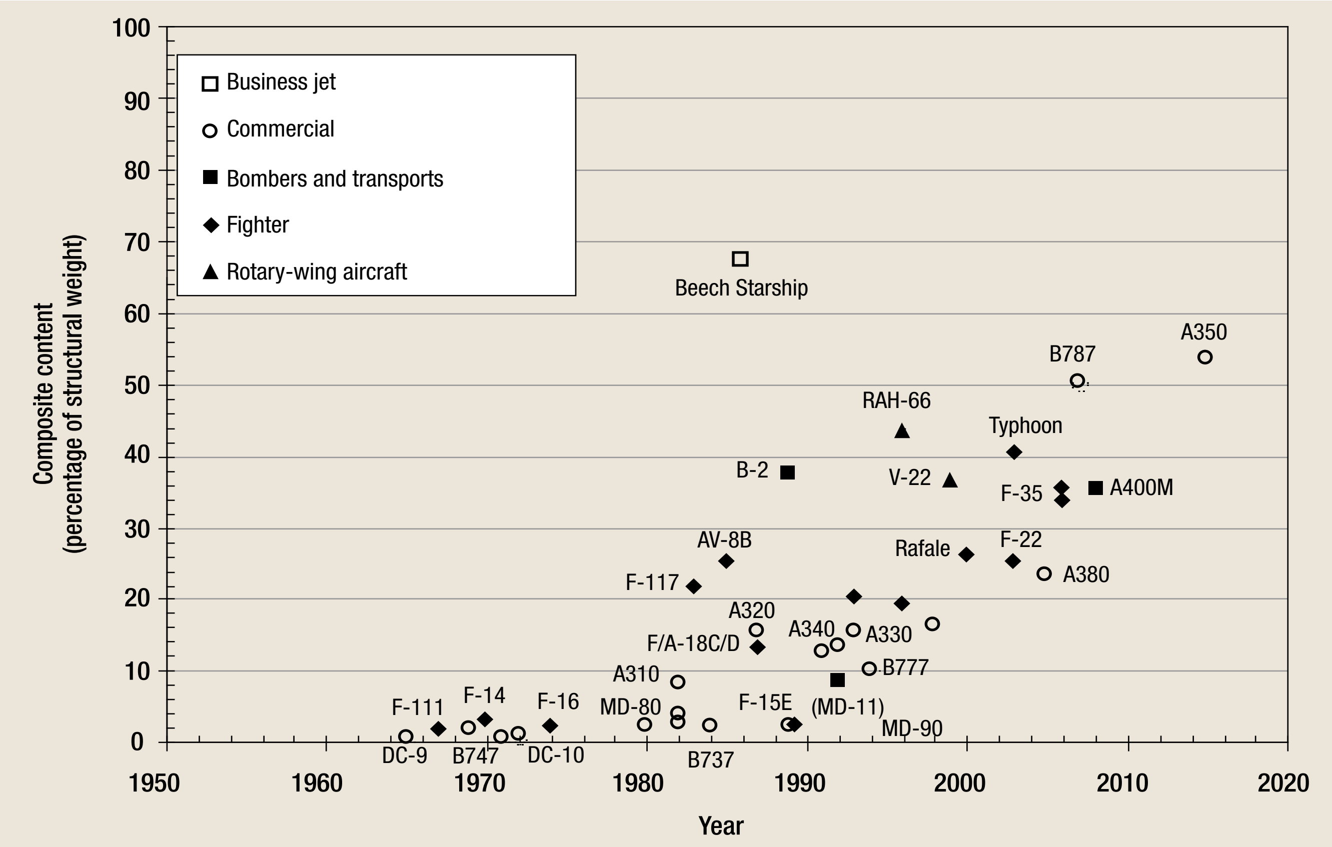

Figure 1: Change in composite use in aircraft over time.

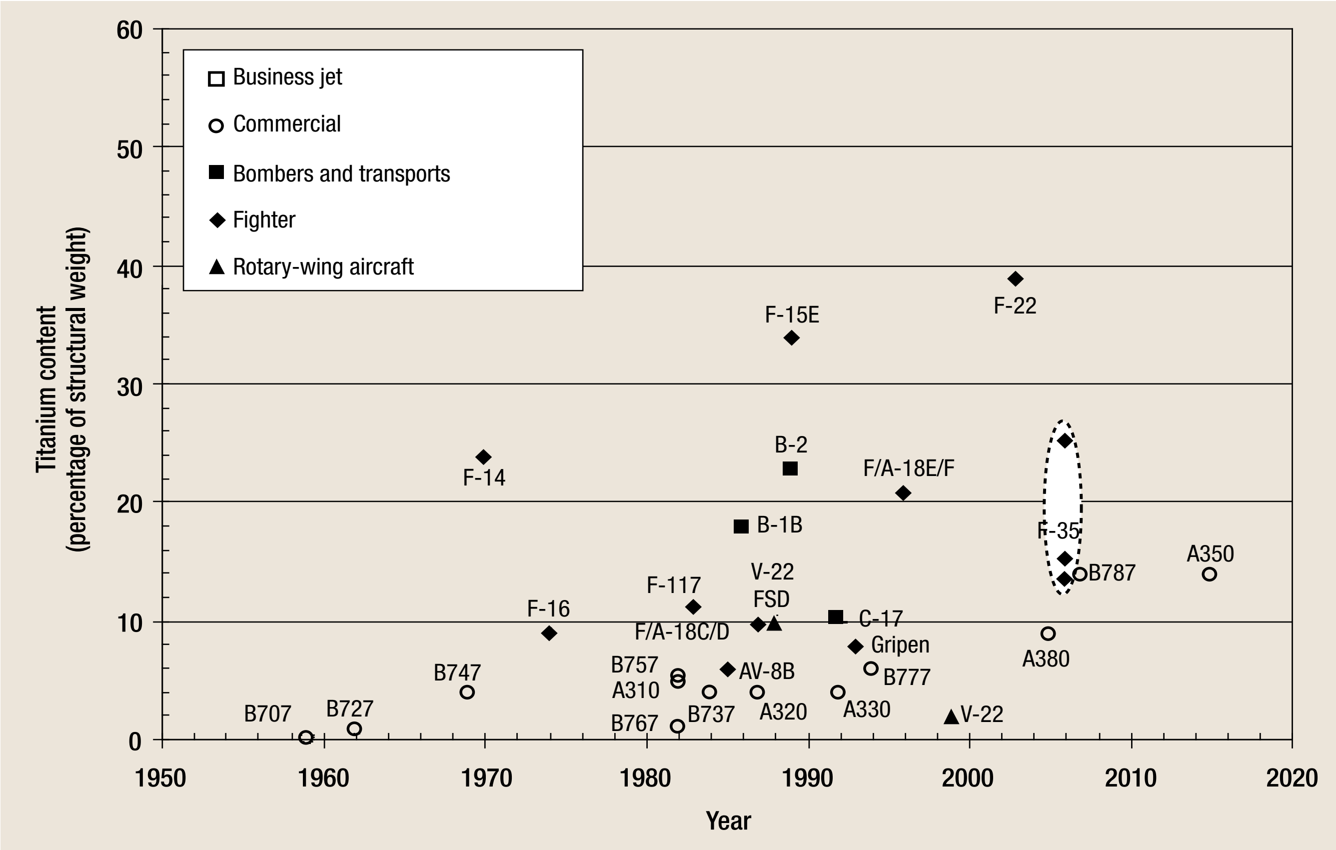

Figure 2: Change in titanium use in aircraft over time.

wood. Cutting the fibers cleanly is key, especially at the hole exit, and requires high shear geometry and high cutting speeds. CFRP is also highly abrasive, so a very hard cutting tool material is required—preferably diamond.

Titanium also needs a high shear geometry, but at the higher cutting speeds needed for composites excess heat is generated, potentially workhardening the titanium in the stack and reducing the aircraft component's fatigue life. In addition, titanium has chemical affinity to most tool materials. Thus, for the most part, cobalt-HSS and carbide have been the primary cutting tool materials used for titanium. However, these materials do not have the wear resistance needed for extended tool life when machining composites. When the cutting edge, dulled by the abrasive composites, tries to cut titanium, workhardening occurs, then tool failure. There have been some promising results machining titanium with PCD, but greater toughness is desired to resist chipping. Besides composite and titanium, aluminum or stainless steel may be in the stack, each with its own cutting requirements.

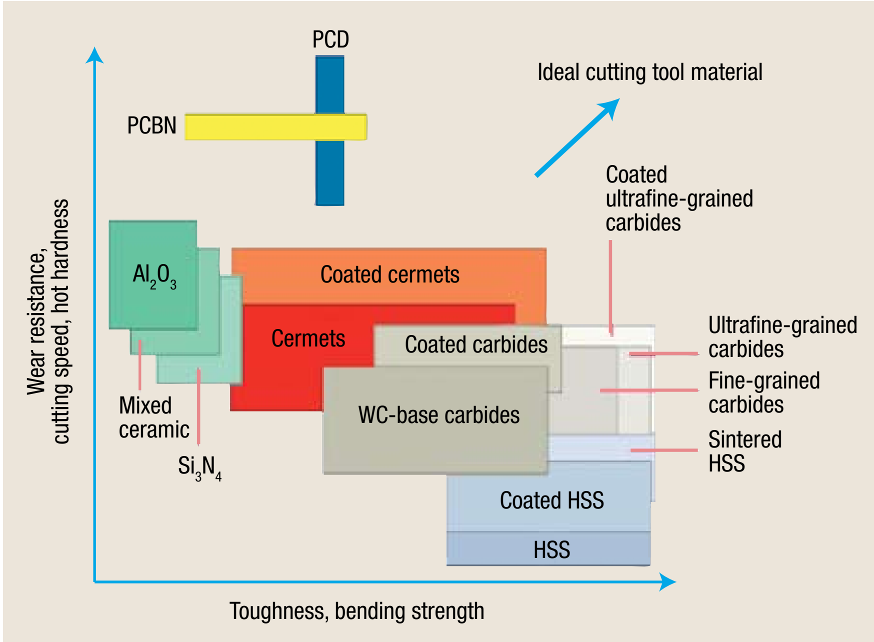

Figure 3: Hardness-toughness relationship for cutting tool materials.

Areas for Improvement

Figure 4 shows the improvement in material-removal rates for roughing and finishing titanium over time as machining technology improved. One can see that titanium machining improvement has leveled out and there is a need for new technology to enable further improvement. This improvement is vital considering the substantial increase in the percentage of titanium and composites in aircraft structures.

Following are areas where improvements may be made in tool materials for drilling composite/metal stacks:

- Harder, tougher grades,
- Functionally gradient material (to tailor properties to different areas on a tool),
- Nanotechnology (nanostructure),
- Different compositions (e.g., non-cobalt binder),
- Self-lubricating capability (to enable dry or near-dry machining),
- Lower material cost,
- Lower tool manufacturing and refurbishing cost, and
- Improved attachment methods.

Material Development Cycle

Once a material having suitable properties has been identified, several other things must be considered for it to be a viable cutting tool material for production use. One can view the development of a cutting tool material as following these basic steps:

1. Concept development
   - Synthesis of material envisioned in theory
   - Verification of properties
2. Trial use: Selected cutting tools made from material and tested
   - Inserts
   - Round tools
3. Establishment of applicability of material
   - Types of tools
   - Workpiece materials
   - Speed and feed range
4. Commercialization
   - Volume production in a cost-effective manner
   - Education of sales force to promote product.

The timeframe for this process can be quite lengthy, especially if the technical issues are difficult to solve, as shown in Figure 5 for superhard coatings.

One can see that there may be many impediments in this process, so connecting the supplier with the right application for the cutting tool material is the key for successful commercialization. The next question is, "Is the market large enough to make it worthwhile?"

How Large a Market?

The forecast for the next 10 years is that there will be a general increase in aircraft production (Figure 6). The

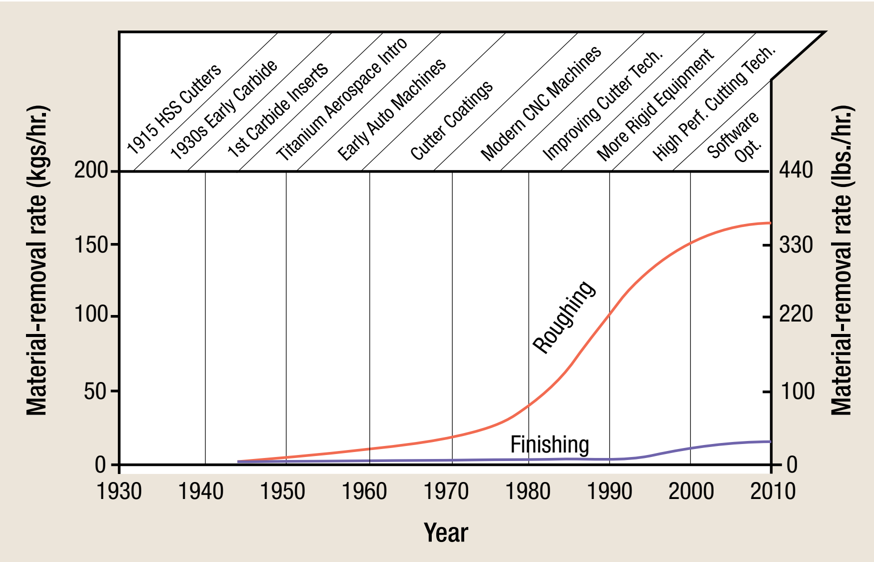

Figure 4: Improvements in titanium machining over time.

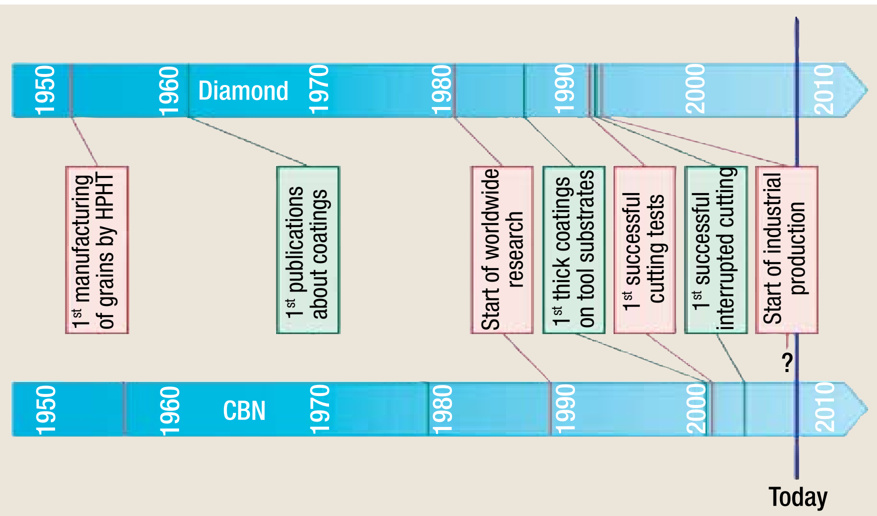

Figure 5: Chronology of superhard cutting tool coatings.

following shows the number of aircraft that need to be built over the next several years, based on current orders:

Commercial:

- 2007 deliveries: Boeing, 441 ($29.5 billion); Airbus, 453 ($23.9 billion)
- 2007 orders: Boeing, 1,413; Airbus, 1,341
- Backlog of orders (as of December 2007): Boeing, 3,427; Airbus, 3,421. Details on two models are as follows:
  - 787 Dreamliner: 857 planes on order as of February 2008 with a peak production rate of at least 10 per month
  - A350: 370 planes on order as of February 2008 with a peak production rate of 13 per month
- Current market outlook (2007 to 2026): 22,700 to 28,600 commercial aircraft, valued at $2.6 to $2.8 trillion. Details on two subcategories are as follows:
  - Freighters: There is current demand for 1,980 units, with total demand for the 2007-2026 period expected to be 4,000 units. About 870 of the freighters will be new, with the rest being converted passenger aircraft.
  - Regional jets: There is current demand for 2,886 units, with total demand for the 2007-2026 period expected to be 3,700 units.

Military:

- F/A-18E/F: Projections call for 581 U.S. Navy fighters through

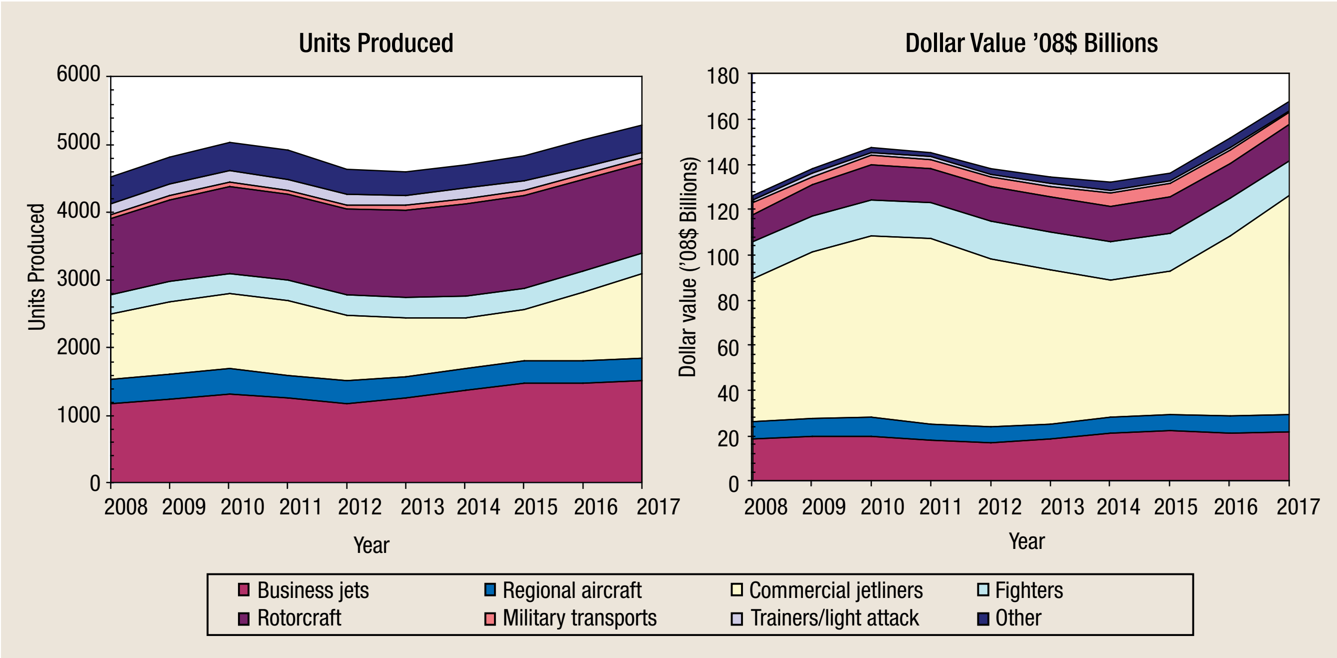

Figure 6: Teal Group's world aircraft forecast.

2012 valued at $57 million each with a peak production rate of 48 per year.

- F-22: 183 fighters ordered through 2010 (U.S. only), valued at $150 million each with a peak production rate of 32 per year.
- Eurofighter Typhoon: Projections call for making more than 700 fighters through 2016 (about $51 to $58 million each) with a peak production rate of 52 per year.

- F-35: Projections call for total global demand of 3,173 fighters through 2035 (about $50 million each) with a peak production rate of 48 per year.

Improved Cutting Tools

There are several current examples of improved cutting tools for aerospace applications.

Example 1: A fiber-reinforced composite parts supplier for commercial aircraft was only able to drill 150 to 200 holes in 0.200"-thick material with a brad-point, solid-carbide drill before the drill had to be replaced due to unacceptable fiber breakout. With a new CVD diamond-coated carbide drill, the supplier was able to drill up to 2,200 holes. Even though the cost of the new drill was 15 times that of the old drill, the cost per hole was reduced by 80 percent due to the longer tool life and increased machine time from fewer tool changes.

Example 2: Lockheed was getting less-than-desirable tool life and edge quality when trimming composite wing skins for the F-35. A new CVD diamond-coated cutting tool was developed, which increased tool life from 9 linear feet at one-third the material thickness to 57 linear feet at full material thickness. This allowed machining of a wing skin with two tools instead of 24, resulting in a cost benefit of $80,000 per aircraft and estimated savings/cost avoidance of $222.6 million over the projected build of 2,783 F-35 aircraft for the U.S. market.

Example 3: The upper deck floor beams for the Airbus A380 are made of CFRP and are attached to aluminum frames on the fuselage. The original uncoated solid-carbide drills used on this CFRP and aluminum stack lasted only 90 holes. Switching to a diamond-coated carbide drill provided more than 500 holes per drill.

As a hypothetical example, assume one had an application where there were 90 holes of a particular size in a composite/titanium stack. If a drill cost $150 and lasted 20 to 30 holes, there would be extra time spent changing the drill three to five times during the application, as well as possibly needing extra motors with drills already set up in them so production interruptions would be minimal. If a drill lasted at least 100 holes, even if it cost twice as much or more, there would be cost-per-hole savings and flow time reductions.

Considering the growing market for aircraft that use more composites and titanium and the push for reduced assembly flow time, improvement opportunities are great. The time for cutting tool companies to provide a product that generates real improvement is now. **CTE**

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