October - November 2014 • Issue 132

Aircraft Technology
Engineering & Maintenance

The leading international magazine for the manufacturing and MRO sectors of commercial aviation

The PMA debate
Are attitudes changing to PMA parts?

Challenges ahead in North America

Metalmakers tackle composites head-on

Additive manufacturing moves forward

Engine parts - repair or replace?

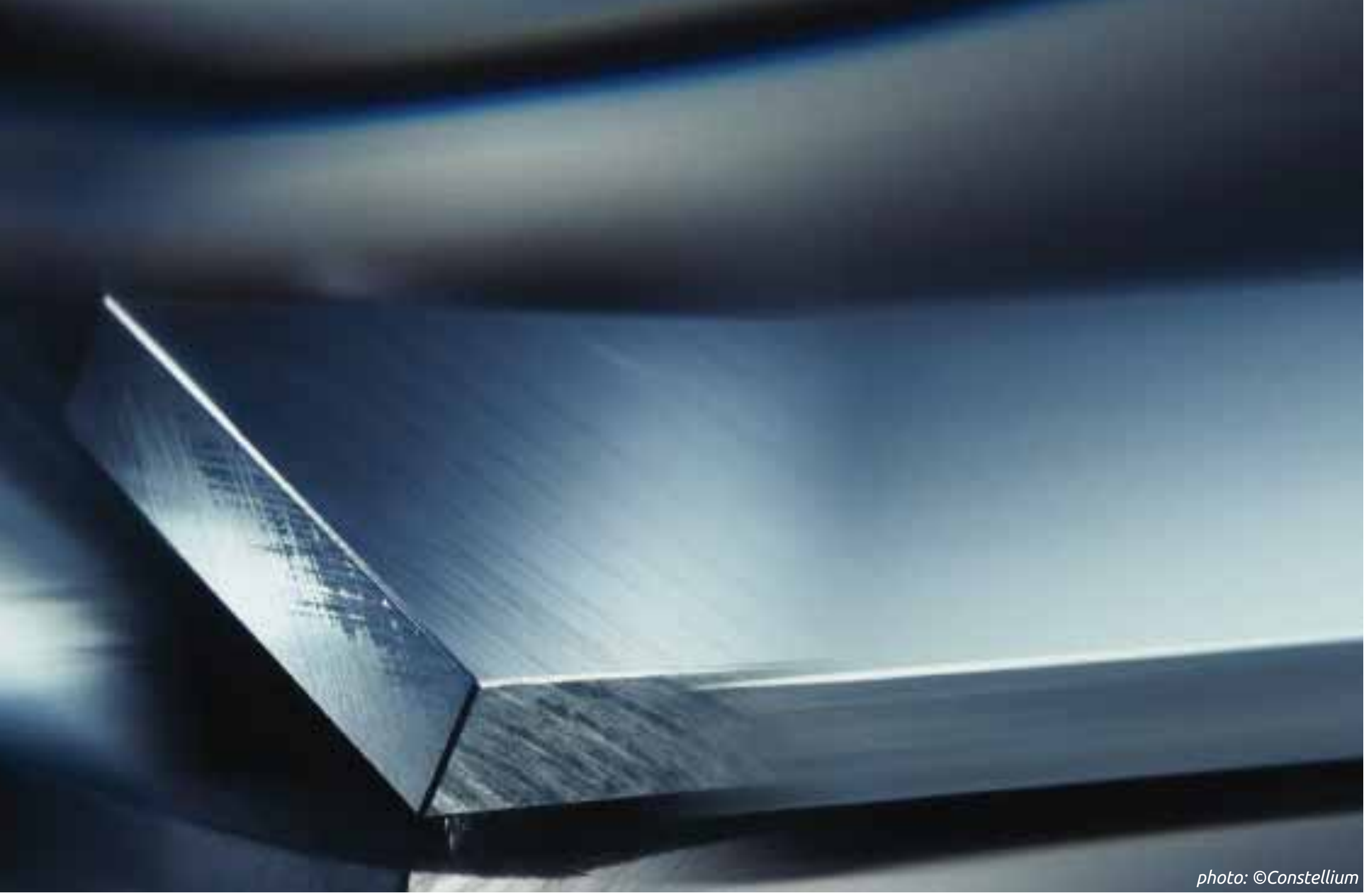
photo: ©Constellium

TECHNOLOGY & INNOVATION

Not-so-heavy metal

The use of composite materials in aircraft design has increased dramatically over the past 20 years, but metal manufacturers are making a comeback. *David Cook* examines how they are developing new alloys for the next generation of airframes and engines

At an Airbus suppliers conference in Munich last April Dr Christian Rueckert, Airbus' head of research and technology – materials and processes, described how the OEM had increased the amount of carbon fibre composites in its aircraft from 10 per cent by weight on the A330 (launched in 1987) to 53 per cent on the forthcoming A350. Meanwhile, the content of traditional metals such as steel and aluminium on the A350 stands at around 20 per cent each.

The reasons behind the dramatic surge in composite use in commercial aircraft design are well known: lightness and corrosion resistance combined with a price per kilo that has become more affordable as volume has increased. However, Rueckert made an important point, which is often overlooked in our fascination with new technology: 47 per cent of the A350 is made of metal and, as production levels increase over the next 10–15 years, the demand for aerospace metals to build nearly 6,000 new aircraft will put substantial demands on the metals industry. Some commentators suggest that beyond the end of the decade the percentage of composites used in the next generation of commercial aircraft will actually fall to below 50 per cent, giving predominance back to metals.

Taking on composites

The introduction of more composite materials into aircraft structures has been driven by rises in fuel prices. The price of oil has almost tripled in the past 15 years, from around $40 a barrel in the early 1990s to a peak of $140 a barrel and, during this time, anything which could be done to reduce weight was viewed favourably by OEMs, to the point where they were prepared to pay a premium for parts which offered a weight saving, or which enabled the replacement of existing metal parts by lighter composite equivalents. Currently the sector is seeing a fairly stable and benign fuel pricing environment (at around $80 a barrel) and, with the dramatic improvements in fuel efficiency offered by a new generation of engines, the trend today is for aircraft manufacturers to improve profit margins on the products they sell. As Rueckert stated in Munich: "For many years our objective was to outperform the direct competition in terms of order backlog and deliveries. Today the focus is much more on overall financial performance." Technology now has to buy its way onto an aircraft and if the advantages are not there then the OEMs will not use new technology simply for technology's sake.

The other side of the picture is that, having seen a significant share of its aerospace market lost to "black metal" (composites) the traditional metal suppliers have hit back, developing new and innovative products. The decision by Boeing to build most of the 787 fuselage out of composites

photo: ©Constellium

This machined fuselage is a prototype made from Constellium's aluminium-lithium based alloy Airware.

was not an easy one. Even at the time of the programme's design freeze new aluminium lithium alloys (Al-Li) were offering significant weight reductions at competitive price/weight ratios such that the choice for composites was not a foregone conclusion. Since then the metal manufacturers have continued to develop their technology and a number of new aluminium alloys are now available to aircraft manufacturers.

Two major aluminium manufacturers, Alcoa and Constellium, have been forging ahead with innovative new alloys for aerospace applications, most notably those alloys combining aluminium and lithium. Al-Li alloys were first developed in the 1950s, but initial applications were limited to military and space programmes where the requirement defined the product and little attention was paid to cost. Now, with improved manufacturing techniques and a more tailored approach to end-user requirements, an economic case can be made for using these products in commercial aerospace.

Al-Li is a generic term used to represent a range of alloys that also include ingredients other than aluminium and lithium (such as copper and zinc), and which provide a wide spectrum of mechanical and chemical properties. Consider, for example, the 2099 and 2199 products developed by Alcoa, in which the proportions of the various metals change dependent on the properties required.

The main objective in creating these alloys is to reduce weight and lithium is introduced into the aluminium to reduce the overall density of the material. Another important consideration, however, is fatigue crack growth (FCG). FCG considerations have an important impact on the mass of material used in a structure. The more a material is resistant to fatigue the less of it is needed within a component, particularly within the supporting structure and so a "virtuous spiral" is created by using FCG-resistant material which can bring about further significant reductions in weight.

Alcoa carried out a trade study with one major OEM concerning the lower wing skin design of its new aircraft programme. In a paper entitled *New aluminium lithium alloys for aerospace applications*, the firm compared the lower wing skin of an aircraft with one created from a new Al-Li alloy and reported that weight reductions of up to 18 per cent could be achieved simply because of the lower density of the new material. Furthermore, by modifying the material ageing process and tailoring the mechanical properties of the structure to optimise FCG performance, a lighter material with slightly lower strength could be used, giving an overall weight saving of 25 per cent. Significant advantages would also be noted in terms of the aircraft's structural inspection requirements and corrosion monitoring programme due to better fatigue resistance.

Constellium, another major metals supplier to the aerospace industry, has developed its own products to respond to the challenge. Its "Airware" technology, is based on Al-Li alloys that also incorporate copper and silver, can offer a five per cent reduction in weight due to the reduction in material density and a 25 per cent weight reduction where the materials' properties are taken into account during the part's design. Materials such as Airware are particularly suitable for stretch forming, often without additional heat treatment, making them particularly suitable for the complex curved shapes which are often found in aerospace structural design. Airware products have been selected by Airbus for the A350, Boeing for the 787 and Bombardier for its C Series aircraft family.

Both metal suppliers are convinced of the future role these products will play in aerospace and other industries. Alcoa is investing more than $90m in new Al-Li production capacity in the US, while Constellium is spending more than $120m on Airware production facilities in France.

Another metal making a comeback in the aerospace supply chain is titanium. Reputedly difficult to work with and expensive, prices of raw titanium have fallen by around 75 per cent in the past 10 years, mainly due to important changes in the ore refining process. This now makes it economically viable for some remarkable applications. In recent years aircraft interior furnishings have become the preferred domain of composites and thermoplastics. However, the first aircraft seat to weigh in at less than 5kg per passenger has recently been certified by Expliseat and its structure is made exclusively from

Newly developed friction stir welding techniques use low heat combined with forging pressure to produce welded joints, minimising distortion of the metal.

titanium. While similar products are being produced in composite materials, Expliseat were the first to beat the 5kg per passenger goal.

A familiar friend

There are, of course, other reasons why metals retain a great deal of attraction for aircraft manufacturers. Carbon composites have come a long way since their first use in aerospace in 1944, but they do not appear to have delivered the full range of benefits which it was believed they would offer 20 years ago. Furthermore, metals have been used in aerospace for longer; the industry understands metals better, is more comfortable with metals and, as such, the certification of metal structures is probably simpler than an equivalent composite structure.

In the same way, development of new metal products, such as alloys, are simpler as engineers feel more comfortable with a material they understand. Production processes remain very similar from one metal type to another and so the development of a new alloy does not require a massive change in industrial infrastructure. Compare this with the billions of dollars spent on new composite manufacturing facilities in recent years.

Another significant factor in metals' continued popularity is ease of manufacture. Molten metal can be poured into a mould to produce extremely complex shapes. Forging can be used to shape metal while introducing specific structural properties, and fatigue resistance can be introduced into the metal through heat treatment or additional processes such as shot peening, which is now being completed with lasers. Such procedures and processes are well established and so lend themselves easily to automation which drives down costs and lead-times. While composite manufacturing has embraced automation for large, regular shaped components such materials still require labour-intensive manufacturing procedures, especially for complicated shapes demanding hand layup of preforms or prepreg plys.

"Alcoa reports that weight savings of up to 18 per cent could be generated by using one of its Al-Li alloys rather than a traditional metal."

Meanwhile, there have been phenomenal improvements in metallic manufacturing processes to reduce cost, improve lead times and reduce environmental impact. Gone are the days when parts were machined out of a solid block of metal, leaving as much as 90 per cent of the metal on the machine shop floor. Most metal forgings are produced using "near net shape" processes, which means that the blank is very close to the final shape required by the manufacturer. Structures can now be machined very quickly, using sophisticated five-axis, computer-controlled machines, removing the minimum amount of metal, reducing cycle times and minimising scrap.

Structural assembly processes have also evolved allowing welding of different metals to one another. Friction stir welding (FSW), for example, uses frictional heat combined with forging pressure to produce welded joints between solid pieces of metal. Due to the low welding temperature, mechanical distortion is minimised. FSW has been used in some limited aerospace applications but, in the not-to-distant future, complex integrated structures are expected to be built using these welding processes and complete aircraft sections will be joined by FSW welding. The advantages can be quantified in two ways. First, through weight savings, from not needing to use traditional fasteners such as nuts and bolts, and second through faster build times for large structural components due to ease of assembly. A similar technology, linear friction

Titanium, as used in this casting for a jet engine, is making a comeback into the aerospace supply chain thanks to changes in the ore refining process.

welding, is particularly suited to welding titanium structures.

The manufacturing technique which is generating most headlines at the moment is additive manufacturing (see p.46). This technology has developed out of other manufacturing processes where metal alloys are sintered or formed using lasers as a heat source. Additive manufacturing takes the process one step further by integrating the powdered metal and the laser into a machine which repeatedly passes the laser through the powder, building up layers of metal at each pass. GE uses a direct laser melting machine to manufacture fuel nozzles for the new CFM LEAP engine by guiding an optical laser head through a bed of metal powder, building up successive layers of melted metal 20 microns thick. While the process takes 120 hours to complete GE claims that the new nozzle is 25 per cent lighter than an equivalent nozzle made using traditional processes and five times more durable because it is made as a single piece and not from 20 separate parts.

An essential element in developing the additive manufacturing process was the availability of a suitable alloy. Cobalt-chromium alloys have been used in artificial human joints for decades and have proved to be light, tough and corrosion resistant. Furthermore, they are capable of withstanding temperatures of more than 980°C. The fact that these alloys are already widely used, means that they are readily available and relatively cheap. The only real challenge for manufacturers was to find a way to turn the base alloy into a suitable powder.

Building power plants

Alongside airframes and interiors, engines have received a lot of attention from composite manufacturers as OEMs seek to reduce weight and improve fuel efficiency. Carbon fibre, either in a simple cross-ply layup or a more sophisticated 3D weave has replaced steel and titanium as the material of choice for the fan blades in the latest generation of civil aircraft engines and is also being used in major structural components such as fan cases and high-pressure (HP) compressor cases.

Where carbon-fibre composites cannot compete with metals is in those areas of the engine subject to high temperatures. While some military engine makers are looking at the possibility of using sophisticated composite materials capable of withstanding temperatures up to 300°C, this would allow them to be used for blades only as far back as the third stage of the HP compressor. As engine OEMs drive for greater fuel efficiency, so the demand for new, high temperature metals has become stronger and the alloy manufacturers have responded to the call with their own forms of metal composites.

In the same way that organic composites use carbon fibres as reinforcement in a matrix of resin so metal composites use metal filaments in a matrix of another metal to produce a structure with significantly improved mechanical properties such as strength and fatigue resistance while reducing weight. An aluminium, titanium or magnesium matrix, reinforced with boron or silicon fibres can triple the component's strength while generating a 60 per cent weight reduction compared with an equivalent conventional aluminium component.

The material attracting the most interest at the moment is titanium aluminide, or TiAl, where a titanium matrix is reinforced with aluminium fibres. This material will be used extensively in the HP compressor and low-pressure

Next-generation aircraft programmes could see a reduction in the amount of composites and an increase in the use of new metal alloys.

"An aluminium, titanium or magnesium matrix, reinforced with boron or silicon fibres can increase a component's strength by a factor of 200 per cent compared with an equivalent conventional aluminium component."

(LP) turbine blades and disks of the CFM LEAP engine, allowing higher operating temperatures while at the same time giving longer fatigue life and, consequently, lower engine maintenance costs. Experiments are continuing to find other potential applications for these types of materials. As early as 2007, Snecma tested a LP turbine shaft made up of a titanium matrix reinforced with silicon carbide fibres, expecting to see a 50 per cent increase in shaft strength compared with conventional steel shaft and a significant reduction in weight.

Perhaps the most surprising engine technology development in recent months has come from Alcoa, which has signed an agreement with Pratt and Whitney to supply aluminium fan blades for the new geared turbofan (GTF) family of engines. While GE and Rolls-Royce have plumped for carbon-fibre blades, Alcoa explains that the low rotational speed of the GTF fan reduces the tensile strength requirement of the blade from 200,000 — 400,000psi to 100,000 – 150,000psi — well within the capabilities of its new Al-Li alloys. These alloys are significantly cheaper than carbon fibre and Pratt and Whitney claims that the ability to form a much thinner trailing edge on the metal blades contributes to a two per cent improvement in aerodynamic efficiency compared with an equivalent carbon-fibre blade. These blades should also be easier to repair than those made from composite materials, allowing the sort of cropping, blending and smoothing operations usually associated with traditional metal blades, but which are impossible on a carbon-fibre blade.

Future outlook

The rising cost of oil and its associated products, such as carbon fibres and resins, have allowed new metals to compete with composite materials and regain some of the ground lost over the past 20 years. This is not to say that the metals industry is immune from geopolitical influences; metal ores are natural resources which are very much in demand. The conflict in Ukraine, for example, has created unease with regards to access to titanium as Russia is a major supplier. A number of aerospace manufacturers, particularly engine manufacturers, have confirmed they are building up stocks of titanium as a direct result of the political situation.

International labour costs and skills shortages are also influencing the metals sector, particularly with regards its competition with composite materials. Aerospace composites are still a high-tech product and are labour intensive, which could make manufacturing in countries with low labour costs attractive. However, a high scrap rate caused by poor quality workmanship could destroy the business case. On the other hand, metal manufacture is a traditional industry well understood and mastered across the world; this provides metal manufacturers with greater opportunities to outsource to developing countries, with lower overheads and minimal risk, than composite makers.

Another important aspect in this equation is the ability to recover and recycle materials. Manufacturers are more conscious than ever of the need to save energy and materials where possible. While metals are eminently suitable for recycling, the situation with carbon-fibre materials is much more complex. Alongside environmental considerations, the ability to recycle ensures the most efficient use of materials, particularly those which supply is not guaranteed. Some metallic elements used in the manufacture of aerospace components are so difficult to procure and refine, that sometimes the best way of securing raw material is to buy scrap components. Rhenium is one such example. This rare metal is used in the manufacture of aircraft engine turbine blades and some OEMs have put in place buy-back programmes to secure scrap blades as a source of rhenium to supply their manufacturing processes.

Composite suppliers may have gained significant market share in terms of aircraft structures and engine components in recent years, but metal suppliers have not been sitting idly by. They have responded with new materials and manufacturing techniques allowing them to offer exciting new products to the aerospace industry to the point where the next generation of commercial aircraft may well see metal reclaiming its position as the preferred material for aircraft manufacture. To meet the challenge of building more than 6,000 aircraft in the next 10–15 years, the metals industry will need to adapt and protect itself from geopolitical disruption by finding new sources of raw materials, such as from reclaimed parts. In many ways the metals industry is behaving in the same way as its products: the more you work it, the tougher it gets!