9. Aerospace Applications
Extending the Use of Titanium Alloys on A350XWB

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The constantly increasing expectations of Airlines in terms of environmental impact limitation, fuel consumption efficiency and reduced cost maintenance strongly incite AIRBUS to always push forward the limits of innovation on its airframes. Particularly, the new A350XWB is characterized by the massive use of CFRP on its fuselage structure. For both thermal dilatation compatibility and corrosion resistance, this introduction of CFRP induced the extensive recourse to titanium alloys and the related technologies. Indeed, their use has nearly doubled to reach about 20% of the structure weight compared to 10% on A380³⁻⁴. This paper deals with the structural applications of Titanium alloys on the different areas of the new A350XWB aircraft. In addition to the traditional applications on tail and landing gear that are reviewed, a particular attention is devoted to novelties on both pylons and fuselage. The reasons of the choices of the different alloys used are detailed in regards with the technical requirements. The advantages and the drawbacks of the associated forming and assembling processes are compared, in correlation with the main processing obstacles. Some innovative forged, cast and super-plastic formed parts are highlighted.

At last, the major stakes in terms of new metallurgical developments, research cooperative programs and typical processing problems of titanium parts are described.

Keywords: Aeronautics, Airbus, titanium

1. Introduction

Airbus is taking up a technical challenge with the new A350XWB. Airlines expect a cost effective aircraft integrating the most advanced technologies to save weight and environmental impact whilst also reducing maintenance costs. Carbon Fiber Reinforced Composite materials (CFRP) for the fuselage structure are a key innovation for the structure to achieve the top-level aircraft requirements on the A350XWB. This extensive use of CFRP, Figure 1, however, is only possible by the appropriate application of metallic materials and technologies, for instance to meet electrical conductivity or crashworthiness requirements.

![Figure 1. CFRP and Ti alloys structural weight evolution on Airbus aircrafts](image)

In particular, titanium alloys and related technologies appear as design effective solutions. New applications are confirmed on the A350XWB and their use is expected to reach 14% of the structure weight compared to 6% on A380³⁻⁴, as illustrated on Figure 2.

2. Titanium Alloys Features Toward CFRP-based Structure

Titanium is a relatively lightweight, corrosion-resistant structural material that can be strengthened greatly through alloying and through heat treatment for some of its alloys. Its advantages for specific applications include: medium density, good strength-weight ratio, excellent oxidation resistance at intermediate temperatures, low coefficient of thermal expansion, high toughness and good weldability. The mechanical properties of some titanium alloys are compared with those of reference aeronautical metallic materials on the Figure 3.

![Figure 2. Comparison of material breakdown between A380 and A350XWB](image)

More specifically, two key properties make titanium alloys highly compatible with CFRP structural design:

- there is no risk of galvanic corrosion at interfaces between Ti alloys and CFRP. This simplifies the design as no specific corrosion protections are required, reducing cost in manufacturing and eliminating the environmental impact associated with the surface protections and paints. In-service corrosion inspections and repairs are also reduced and thus the operability of aircraft increased.

- the coefficient of thermal expansion of Ti alloys is about half that of Al alloys. As CFRP have nearly zero thermal expansion in the fiber di-
reduction, the introduction of Ti alloys greatly reduces the problem of thermally induced loads at heterogeneous interfaces; these thermal loads being able to, often, significantly reduce the CFRP density, when used associated to Al alloys.

Another advantage of Ti alloys is linked to the elimination of some "banned substances". As a matter of fact, environmental legislation and restriction reject the use of chromate (the main protection of aluminium alloys) and cadmium (the main protection of steel). As titanium does not need any coating against corrosion and as it can be re-melted, it can thus be considered as "environmentally friendly" material.

Obviously all these advantages are not for free. There are several aspects to titanium alloys that must be evaluated before selection for a structural application:

- the high mechanical strength and toughness of titanium and very low thermal conduction, means titanium alloys are difficult to machine.

The Figure 4 shows a comparison of machining performances with those of aluminium alloys since 2007 to reduce prices and reserve sufficient production capacities for all Airbus and subcontractors needs[3].

- from manufacturing point of view, titanium alloys:
  - are susceptible to surface contamination at high temperature that imply intermediate and final processing to remove the brittle oxide layer.
  - have reduced hot processing window and limited possibilities for high strength alloys to be formed at room temperature without subsequent heat treatments. As a result, there are costly consequences with high buy to fly ratio, need for specific toolings and complex process routes to achieve the final microstructures and properties.
  - last but not least, titanium alloys have poor friction behaviour and dedicated coatings are recommended for some particular applications.

Even if these drawbacks have to be considered during design, especially for recurring costs and logistic, titanium alloys are extending their application fields by offering innovations or technological progress to A350XWB.

Strong technology developments were required to support A350XWB program, due to the fact that:

- many of its titanium components are very different and more challenging to process and to characterize than those made from Ti in the past.
- rapid development and validation to high readiness levels (robust and repeatable) were requested.

3. Applications of Titanium Alloy Technologies

3.1 Fuselage Door Surroundings, Main Landing Gear Support and Center Wing Box Frames

For the first time, titanium alloys will be used for these applications with the major characteristic that very big and/or long die forgings must be developed and industrialized. In areas with low space allocations, high loads transfer and CFRP environment, Ti6Al-4V in beta annealed temper was chosen against aluminium alloys based on damage tolerance performances. As an illustration, the Figure 5 compares some specific mechanical properties of common aeronautical metallic alloys.

The choice of the beta annealed temper for the gear beam, see Figure 6, instead of the alpha-beta temper, permitted 150kg of weight savings knowing that the weight of the final part is 380kg.

TA6V alloy has also be selected for large forgings for wing applications, particularly at the interface between wing and pylon. For those applications, β temper
was selected in relation with the local requirements in terms of fatigue crack propagation resistance and toughness.

Specific material properties

- TA6V
- 15-5 PH
- Ti6Al-4V
- T84
- T7452

Figure 5. Comparison of specific mechanical properties of different metallic materials

Figure 6. 4m long Gear beam of MLG of A350XWB

Figure 7 shows other very long forgings for door surroundings (18 per aircraft). It must be point out that the buy to fly ratio of these new parts are very important since Ti6Al-4V is much more difficult to forge than aluminum alloys. It has huge impacts on:

- cost: initial raw material, machining
- logistic: supplier capacities
- stress validation: A and B values for die forgings with the highest sections ever required for this temper.
- manufacturing: the risk of deformation after machining must be anticipated.

Figure 7. 4m to 5m long doorframes from A350XWB (here frame for door 2)

For some CWB (Center Wing Box) frames, the buy to fly ratio has been minimized by combining extrusion process and Hot Stretch Forming. The industrial validation demonstrated very good process efficiency from forming point of view with no consequences on material design properties and no deformation after machining despite the nearly 4.5m long extrusion with local thickness between 12 and 15mm. The Figure 8 illustrates the shape of the blank and of the final part.

Figure 8. Comparison of the extruded blank formed and the final part for frame 46

3.2 Crashworthiness Frames

A drawback of CFRP structures toward crashworthiness is their limited capacity to absorb the impact energy of this design case. Therefore, metallic frames have been proposed as shown by Figure 9.

Figure 9. Titanium frames for crashworthiness in lower part of the CFRP fuselage

The selection of titanium alloys is connected to their intrinsic corrosion resistance that permitted to avoid inspections for this issue until final design service goal.

Particularly, the Ti3Al-2.5V titanium alloy has been proposed because it combines the following advantages:

- availability in form of sheets or coils ready for qualification
- intermediate price between commercially pure titanium and Ti6Al-4V
- higher possibility for cold forming, that reduces manufacturing costs.

3.3 Rear Fuselage End (RFE)

Even if the use of CFRP on both horizontal plane (HTP) and vertical tail plane (VTP) is not a novelty related to A350XWB program, the use of Ti alloys on the RFE has been widely extended on this part of the aircraft.

For instance, the HTP center joint is made of an assembly of TA6V forged products at α/β and β tempers (Figure 10).

Another example is the APU Muffler Exhaust, for which the working temperature is the main driver for the design; a combination of TA6V and T40 alloys has
been selected in relation with this constraint, for skin, frames and stringers in this area of the RFE.

Figure 10. A350XWB’s HTP center joint made of an assembly of several TA6V α/β and TA6Vβ forged parts

3.4 Engine Pylon
Innovations are continuously implemented on the pylon structure. With A380, it was the massive use of beta-annealed parts including the biggest Electron Beam Welded, EBW, part that ever flew on Airbus aircraft (see Figure 11).

A350XWB is not an exception. Due to very low space allocation in conjunction with high loads to transfer and a challenging weight target, a new attachment concept have been selected by the Wing/pylon development team to finally save 615kg per wing by:
• selecting front engine attachment at fan location
• replacement of rear pylon box by two pyramid for rear wing attachment
• fail safe front attachment for wing integrated to the lateral panel by EB welding.

It results in a very new design for pylon as illustrated on Figure 12.

4. Research & Developments
As mentioned earlier, the main limitations of titanium use are the raw material cost, the buy-to-fly ratio generally associated to the design of Ti blanks and their low manufacturability (machinging and drilling); Airbus & EADS Innovation Works current R&D efforts are thus focusing on those topics.

4.1 To Improve Buy-to-fly Ratio
Improving the buy-to-fly ratio and minimizing machining are ways to reduce the cost of Ti structure.

Among the different techniques to reach these objectives, the replacement of large forgings per a combination of thin extrusion and welding is of special interest for Airbus. Such is especially the case of Linear Friction Welding (LFW).

LFW is a solid state process for joining materials together through intimate contact of a plasticized interface, which is generated by frictional heat produced as one component is moved under pressure to another. The main advantages are that it doesn’t require shielding gases and the nugget doesn’t go through liquid state (see Figure 13).

Welding seams obtained by LFW are generally characterized by a very limited extension of the heat affected zone (Figure 14) and good mechanical properties (Table 1). Indeed, the mechanical resistance is near of that of the bare material and above all, tensile failures appear outside the weld.

Figure 12. New pylon design

Figure 13. Illustration of the principle of LFW and picture of butt joint weld

Figure 14. Cross sectional microstructure of a Linear Friction Welded TA6V
Table 1. Tensile properties of a Linear Friction Welded TA6V/TA6V joint

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<th>YS (MPa)</th>
<th>UTS (MPa)</th>
<th>A (%)</th>
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<tr>
<td>LFW TA6V/TA6V</td>
<td>965</td>
<td>1010</td>
<td>15</td>
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After such good behaviour at laboratory scale, a seat track design was selected as demonstrator. The design of the current extruded blank, weighing 11kg, m⁻ prior to machining, is displayed on the Figure 15 (left side). The presence of blades on each side of the central web makes this section being difficult to extrude in Titanium and thus results in the increase of its section, and thus its liner weight.

Figure 15. Ti seat tracks extruded blanks as example of combination of thin extrusion and LFW

Welding the blades per LFW (as illustrated on the Figure 15, right side) allows to extrude thinner section and to reduce its linear mass down to 5.5kg · m⁻¹. It results in cost savings, not only in terms of buy-to-fly improvement, but also through the reduction of the milling cycle.

Another way to reduce the buy-to-fly ratio of titanium part is to develop/extend the use of casting. The example of surrounding door was already mentioned previously. These parts are currently produced by die-forging, that results in very high buy-to-fly ratios. An alternative solution could be the production of these parts by casting, such is the purpose of a collaborative Chinese-European project labeled COLTS, aiming at developing the casting of such large components.

4.2 To Reduce Weight

The beta-metastable VST5531 was introduced for pins between wing and pylon on A380, with a weight saving of 15kg in replacement of steel⁷. Another interesting track for a larger introduction of these alloys is related to their good specific mechanical properties at intermediate temperatures, as illustrated on Figure 16.

![Figure 16. Comparison of specific property (ultimate tensile stress / density) of various metallic materials](image)

For instance, the replacement of Ni based alloys, such as Inco718 on some parts per beta-metastable alloys, such as Ti17 and Ti5553 alloys, may result in important weight savings (up to 25% on some parts, see Figure 17).

![Figure 17. Change of design between Inco718 and Ti17 on some pylon parts](image)

However, additional testing regarding the long-term thermal stability of these beta-metastable Ti alloys are still currently in progress to confirm their potential for Ni based alloys replacement.

4.3 To Reduce Production Cost

As already mentioned previously, due to high buy-to-fly ratio of parts and the poor machinability of Ti alloys, mechanical machining represents an important portion of the final cost of Ti aeronautical components. The TIMETAL®54M, from Timet, is presented as an alpha-beta alloy with superior machinability and strength comparable to that of Ti-6Al-4V.

As high damage tolerant properties are required for some applications, the correlation between the microstructure and the mechanical properties of this alloy is currently investigated.

The microstructures obtained for different heat-treatments are displayed on the Figure 18, in regards with some mechanical properties (Table 2).
Figure 18. Microstructure of Ti54M after α/β annealing (top) and β annealing (down right: furnace cooling; down left: air cooling)

Table 2. Variations of mechanical properties of Ti54M obtained from different heat treatments (Courtesy of Forges de Bologne)

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<tr>
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<th>UTS (MPa)</th>
<th>A (%)</th>
<th>Kt (MPa√m)</th>
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<tr>
<td>α/β annealed</td>
<td>910</td>
<td>18</td>
<td>114</td>
</tr>
<tr>
<td>β annealed Air cooling</td>
<td>910</td>
<td>11.7</td>
<td>98</td>
</tr>
<tr>
<td>β annealed Furnace cooling</td>
<td>875</td>
<td>11.6</td>
<td>110</td>
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These results, coupled by different additional tests, such as FCP (Fatigue Crack Propagation) measurements, allow envisaging the introduction of Ti54M for some applications, in replacement of TA6V. The gain would there mainly stand in the reduction milling cycles.

At last, different others new alloys are under investigation either for tubes or other applications where high formability are required. Different alloys can be mentioned for their cold formability:

- ATI 425 from ATI
- VST3331 from VSMPO
- SSAT 350 from Sumitomo

5. Conclusions

Titanium alloys play a major part in the structure of A350XWB so that the overall design achieves the challenging performances expected by the airlines.

The dynamism in this metallic domain is not only limited to new applications, innovations are also proposed in conventional use areas.

Successes related through the examples of this article are mainly based on the important involvement of experienced people in all domains (stress, design, manufacturing, materials, etc) with strong multi-functional communication effort.

Improvements and further innovations are prepared by reinforcing the titanium supplier cooperation and defining accurate research activities to reduce buy to fly, improve machining and develop new alloys or assembly process (welding, fasteners...).

REFERENCES

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