REUSABLE LAUNCH VEHICLE AEROSHELL MANUFACTURING CONCEPT

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ABSTRACT

Innovative Reusable Launch Vehicles concepts pose several challenging manufacturing issues, which have been considered during a feasibility study conducted recently at Alcatel Alenia Space. One of these aspects is related to the manufacturing of a light aeroshell structure, high temperatures resistant, affordable in a strict time schedule with a cost effective approach.
A conservative approach was taken into account in the final design, implementing some reliable technologies to ensure short development time and available know-how to avoid long term investments planning.
The main issue is related to the construction of a quite large structure, requiring innovative manufacturing facilities and complex research tools. The manufacturing and forming of large Titanium honeycomb panels, with very complex shapes, represents itself a challenge. A special vacuum oven brazing process was selected and a dedicated study on filler metals researches offered the chance to design a suitable product for this application.
The final assembly of the panels to manufacture the aeroshell is planned using laser welding technology. In this case the very small thickness of the skins, the difficult accessibility of the parts to be joined and the strict dimensional tolerances required by the final product for aero-thermodynamic reasons, represents interesting aspects which have been investigated.
The aeroshell manufacturing design implements technologies like Cutting, Forming and Descaling of titanium thin skins and honeycomb, Brazing of titanium honeycomb and skins to obtain sandwiches, Laser welding on sandwiches to obtain assemblies.
The paper offers an innovative perspective on re-entry vehicles aeroshell system, including the principles of design for manufacturability and technology transfer as key points to reduce mass, delivery time and costs of the final product.

1. INTRODUCTION

Space exploration requires safe, reliable, and affordable systems for the development of future Reusable Launch Vehicles (RLV).
Significant efforts have been conducted internationally in the technology development of advanced manufacturing techniques and joining processes.
The application of special metallic heat resistant materials in hot load carrying structures, like the aeroshell structures, has been investigated, facing the several challenges of the manufacturing.
The present feasibility study has been performed recently at Alcatel Alenia Space with the aim of preparing a manufacturing plan for a light aeroshell structure, high temperatures resistant, affordable in a strict time schedule with a cost effective approach.

2. THE AEROSHELL

The aeroshell's main purpose is to protect the capsule inside from the intense heating of the entry into the planetary atmosphere.
The aeroshell is covered with a Thermal Protection System (TPS), acting as a heat shield which protects from the heat and sustain the aerodinamic drag (Fig.1).

Fig. 1 - Spirit entering Mars atmosphere
(©NASA)

The concept presented takes into account the implementation of some reliable technologies to ensure short development time and available know-how to avoid long term planning.

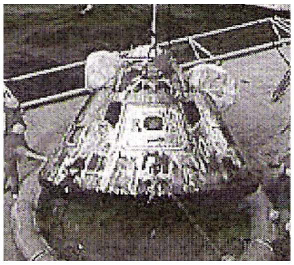

Fig. 2 – Apollo honeycomb heat shields (©AERONCA)

The aeroshell here considered is made of a titanium honeycomb sandwiched between titanium face sheets using a brazing process, and consists of several panels assembled together with a laser welding process in three main parts: apex cone, central airframe, lower airframe. These three assemblies are then integrated on the primary structure with mechanical fastening, taking care that appropriate insulation is provided between the two structures.

3. THE MANUFACTURING TECHNOLOGIES

The manufacturing of the aeroshell structure can be achieved implementing several different materials and technologies. A trade off among them suggested to keep the overall process highly reliable adopting well know processes, as the brazing one.
Considering the fact that there are some issues related to the relatively large dimension of the structure, it has been considered an investment in innovative facilities and advanced process simulation tools.
Also the forming of large Titanium honeycomb panels with a double curvature represents itself a challenge, and two options have been investigated.
In summary the technologies involved in the manufacturing process are:

Cutting, Forming and Deoxidizing
(on titanium skin and honeycomb).

Brazing
(on Ti honeycomb/skins
to obtain sandwiches)

Laser welding
(on Ti sandwiches
to obtain assemblies).

4. CUTTING, FORMING, DEOXIDIZING

The sandwiches are made of titanium skins and honeycomb which have to be prepared to assure appropriate shape, tolerances and cleanliness for the following brazing process.
All the materials, honeycomb and skins, require the deoxidizing for which it is needed a pool able to accommodate 3 m X 1.2 m panels.
Titanium skins don't need forming as they have a thickness of only 0,2 mm.
Titanium honeycomb (Ti3Al2.5V) is available in foils of the needed dimension, as it is possible to purchase 3mX2m foils. Honeycomb can be found already formed with double curvature, ensuring high mechanical properties, precise tolerances and a cell always perpendicular to the skin.

Fig. 3 – Titanium honeycomb (©INNOVENT)

In this case it is possible to purchase honeycomb which is produced on the base of our design requirements. It is obtained joining small machined pieces with special welding processes. Conical shapes can be provided for the upper and middle stage, more complex ones, to be used for the lower stage, have to be produced developing a process with the supplier.
A second option is to procure flat honeycomb and then to form it, developing an in house ad hoc forming processes.

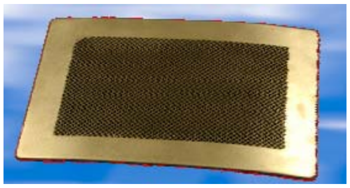

Fig. 4 – Titanium honeycomb panel (©INNOVENT)

Activies undergoing will provide information on some honeycomb samples (size: 50 mm X 50 mm, cells dim: 1/32" ÷ 1") to verify the brazing process and the mechanical properties of different cell size and configurations. In this case the honeycomb is furnished electrochemically polished.
The honeycomb panels have then to be cut to perfectly fit the final shape, as the brazing process requires an high level of precision on the contact surfaces to ensure that the bonding occurs at the border of each cell.

5. BRAZING

The joining processes like welding produce a melting and solidification of the base metal to create the connection between two parts.
The brazing process instead maintain the two parts in the original status and sees the melting of a filler, which with capillarity phenomena distribute itself in the gap between the pieces.
The main advantage of this process is that it works at lower temperature than the welding one, and it doesn't decrease the mechanical properties of the base metal.
The brazing process can be performed locally or globally, depending on the requirements and on the extension of the joints. Several methods can be applied, but it is considered the global brazing method in oven.
The driving factor in this case is that the global brazing process ensures a more uniform temperature distribution in the volume and produces a more precise joint geometry on large panels. The brazing in oven usually works in a controlled atmosphere (with an inert gas, e.g. Argon) or in vacuum.

Fig. 5 - Brazed Sandwiches

5.1 Brazing process

The aeroshell manufacturing requires a brazing process that has been designed to fulfil the following requirements:

1. *compatibility* of materials and filler metal
2. strict *tolerances (*minimum gap allowable for appropriate brazing is 0.25 mm)
3. high *degassing*
4. appropriate *thermal cycle*

The skins and the honeycomb are made of Ti 3Al 2.5V alloy, so it is recommended to apply a Ti based filler metal, to ensure homogenous joints and to produce a high rate of solidification, avoiding brittle behaviour.
To maintain strict tolerances during brazing it is important to perform the brazing of both the honeycomb surfaces at the same time, and the gap between surfaces have to be lower than ¼ mm.

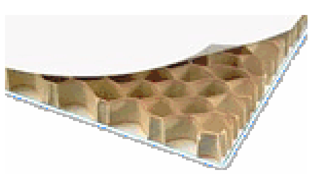

Fig. 6 – Titanium sandwich

The wall of the honeycomb cell has to be thick as much as possible, and at least 0.5 mm, because the filler metal can be chemically aggressive on the surfaces, producing distortions which can lower the mechanical properties.
It is required that the honeycomb used for Space application allows an high level of degassing and this is even more important in case of a brazing process is used for the manufacturing of the sandwiches.
The thermal cycle is crucial to obtain high performance brazed panels. Some other details have then been investigated to better define the eutectic temperature of the filler, cooling temperature available on the oven, mass of panels and tools, configuration of the overall system in the oven.

5.2 Filler metals

The composition of the filler metal depends on the materials involved in the process (Ti3Al2.5V) and on the temperature range determined by:

- operational temperature of the aeroshell: ~ 300 ºC
- β transformation temp of titanium alloy ~ 900 ºC

Several alloys have been considered in different forms: paste, powder, foils. Foils have been excluded for the very complex shape of the brazed joint and the difficulties to maintain tolerances. In the other forms some have been selected for a preliminary investigation:

- PASTE: Ag Cu (~ 780 ºC) and Ag Cu Ti (~ 900 ºC)
- POWDER: *Ti 37.5 Zr 15 Cu 10 Ni* (~ 850 ºC), US.

The brazing filler metal would be applied according to the physics, in fact the paste brazes thanks to capillarity. It is placed on the surface of the materials manually or with an automatic injector, then the assembly is dried at almost ambient temperature and finally the sandwich is placed into the oven for brazing. This solution ensure precise tolerances on the distribution of the filler and on the final joint geometry.

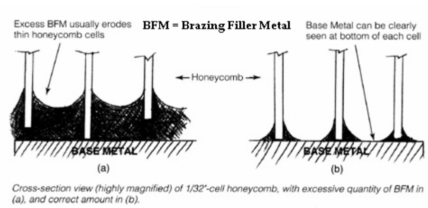

Fig. 7 – Effect of filler on the brazed joint

Another option considers instead the use of a brazing powder, which is placed on the pieces after having distributed the adhesive. This solution is largely adopted in aerospace components brazing and a compound for Ti alloys is already commercially available.

5.3 Oven

It is possible to realize the brazing process in oven having an Argon atmosphere or in vacuum, depending on the quality of the joints which are required by the specific applications.
The vacuum maintain a better clean condition and produces very high quality joints at level $>10^{-5}$ bar. For this reason the vacuum oven brazing was chosen as the ideal solution for this specific application.
The cooling after brazing has been recommended to occur in a convective environment, to increase the control of the oven parameters and the temperature gradient. This is obtained with the rapid insufflation of Argon in the chamber when filler has already reached the solidus temperature. For the development phase it is possible to use in house facilities which allow to perform testing on 1.5 m X 1.5 m panels.

Fig.8 – Brazing oven (©COFI)

6. LASER WELDING

The final assembly of the panels to manufacture the three part of the aeroshell is planned using a welding technology. The YAG laser welding has been identified as the most suitable process to assemble the Titanium brazed sandwiches, because it is compatible with requirements like the very small thickness of the skins, the difficult accessibility of the parts to be joined and the strict dimensional tolerances required by the final product for aero-thermodynamic reasons. Moreover the laser has a great advantage over other welding processes as it concentrate the energy in a very narrow path, reducing the thermal affected zone to the minimum, ensuring higher mechanical properties of the airframe.

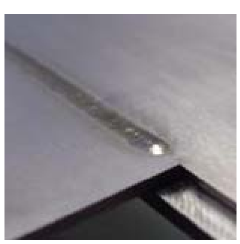

Fig. 9 – Laser welded sample

In fig. 8 are shown specimens 1mm thick which have been welded with 1 Kw YAG laser for preliminary tests, which proved that this process has the lowest thermal dispersion, producing at 10 mm from the weld seam a temperature of ~ 250 ºC. The low temperature is also very important to avoid damages to the brazed joints which have been created in the step before.
It is also known that the mechanical properties of the titanium skins at 0,1 mm from the welding are comparable to the base metal.

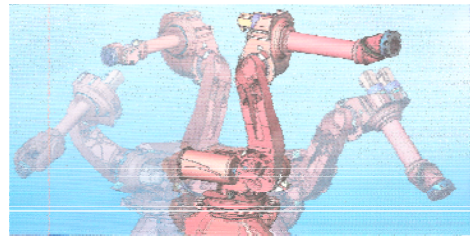

Fig. 10 – Laser welding facility (©COMAU)

Another advantage of the laser process is its flexibility, as it works transmitting the power through optical fibers. For this reason it offers the possibility of multiple welding and just changing the optics it can be used for laser cutting.

7. TESTS AND CONTROLS

The concept is suited for aerospace applications, especially for the ones in which a high temperature and strength-to-weight ratio is required. Brazed structures have also a good energy absorption capability and can withstand combinations of aerodynamic, acoustic, and thermal loads. To validate the processes described it is advisable that a test campaign might develop and validate control methods for the overall aeroshell and its subsystems. The “technologies and processes” laboratory is dedicated to characterize sandwich panels through:

Non Destructive Inspections

- Ultrasonic inspection
- Eddy currents
- X-Rays

Destructive tests

- Metallurgical characterization
- Tensile tests
- Susceptibility to stress corrosion cracking

The panels has to be checked with NDI to verify eventual cell deformations, while the brazed joints has to be examined to exclude partial disbonding. Destructive tests are more focused on the laser welded joints to determine the eventual presence of volume defects, cracks and inclusions.
The “structures” laboratory characterizes, through macro tests (Modal analysis, mechanical properties of the structure, etc..), the final assembly and validates the final configuration of the flight unit.

8. CONCLUSION

Honeycomb structures are widely used in Space engineering thanks to their unique characteristics of strength and mass. The efficiency of the honeycomb depends upon the material, cell form, and technological processes. Therefore new method of honeycomb structures' optimization, honeycomb filler specially made for each structure, and technology of efficient skin-to-honeycomb bonding allow to implement new possibilities of the honeycomb structures' weight reduction.

This aeroshell manufacturing design implements technologies like Cutting, Forming and Descaling of titanium thin skins and honeycomb, Brazing of titanium honeycomb and skins to obtain sandwiches, Laser welding on sandwiches to obtain assemblies.

The aeroshell manufacturing concept presented might then offers an innovative perspective on re-entry vehicles system, including the principles of design for manufacturability and technology transfer as key points to reduce mass, delivery time and costs of the final product.

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