INMA – Innovative manufacturing of complex Ti sheet components

Contract No. 266208
From 01.09.2010 to 28.02.2014
FP7-Transport

Mariluz Penalva
Tecnalia Industry and Transport
Production Systems
There are **high costs** and **long lead times** associated to the production of titanium sheet metal parts in the aircraft (hot zones in airframe, cold zones in the engine) because of **forming technologies** based on the use of **dedicated tooling** (cold/hot stamping, SPF)

- High tooling costs
- Iteration between design and industrialization phases
- Frequent design evolutions
The INMA project aims to lead to cost reduction and increased flexibility when manufacturing titanium (or other difficult-to-deform materials) sheet metal parts by introducing the asymmetric incremental sheet forming technology (AISF) into the production chain.

The AISF technology shows the potential to produce complex sheet metal parts without dedicated tooling. Thus, the development costs are reduced and agility and flexibility are gained during the design phase for prototyping or the production of spare parts and very low volume series.
AISF of titanium

Process data
Simulation
Material data
Geometric accuracy
Hot forming

Forming experiments
FE modeling
Material testing
KB techniques
Heating means and methods

Technology gaps
Technology enablers

Concept application and validation by fabricating 2 demonstrator parts (1 for aeroengine, 1 for airframe)
Empirical data and practices are needed for the development of AISF of Ti alloys

- The maximum wall angle have been obtained for alloys of interest under cold and hot forming conditions
- Specific forming tool concepts have been identified and designed
Process data (2/2)

- Tool paths for different representative shapes have been generated
- Part quality criteria have been checked
- Tool path up-scaling has been done
- Successful spinning practices have been identified
Material data (1/2)

- Non-traditional tests and criteria to characterize specific material formability under AISF have been defined.

Properties of Ti being deformed under AISF have to be characterized.
- Static (tensile) testing and metallographic analysis were done on cold and hot formed material specimens.

Comparison of the alpha-case layer thickness at both surfaces in A1 area of the P2 part (direction along tool traverse direction).

Graphical presentation of the surface roughness measurement results – P3 part: maximum height $R_z$.

Micro-hardness measurement results – P2 part: comparison of the average values from both directions for each sample.

Strength relief of specimens extracted from H, A, E and B areas.

Part P2: Ti-6Al-4V (Grade 5) – microstructure – zones A, C, J, OA; examples of micrographs from the samples from of chosen zones; observation: direction (red arrows).
The aim is to provide a solution to hot form TiGr5

- Hot tensile and compressive tests have provided the adequate temperature working range
- Hot forming tests have confirmed material testing results on formability
Two opposite heating concepts (localized hot spot, homogenous temperature) have been implemented and assessed.

Maximum temperature tends to stabilise.
FE process models can speed up the AISF development for Ti alloys through reliable process predictions.

- Upscaling of FE model for complex and large shapes
- Implementation and validation of small scale FE model
- Coupling of FE model with heating
The developed FE model could successfully be transferred to the simulation of a scaled down realistic part within the scope of a case study

- Validation has been conducted in terms of process forces, strain distribution and geometrical correlation

Four approaches (sub modeling, sub structuring, mesh adaptivity and tool elimination) for calculation speed up for upscaling have been investigated

- The first three methods lead to a reduction of computing time to low levels around 0.25 of the time required by an ordinary reference AISF model and provide relatively accurate results
- tool elimination has some potential for further solution time reduction but might require a case-by-case optimization

The thermal and structural simulation capabilities are successfully combined and applied on the case of simultaneously local heating and ISF forming of a test shape.

- Experimental data and FE model show good agreement

Combination of thermal and structural simulation capabilities during homogeneous heating of the sheet is still in progress
The poor geometric accuracy of Ti parts produced using AISF with no tooling needs to be solved.
A number of mechanisms have been proposed for representing 3D geometries (original CAD and real shape)

Two knowledge-based models have proposed (intelligent process model 1 and 2)

It has been demonstrated that by using the proposed intelligent process models the material springback can be predicted with high accuracy

One of the knowledge-based model has been evaluated showing that springback can be reduced by using corrected cloud data
Aeroengine demonstrator (in progress)

The target is to produce a realistic Inconel part that meets design tolerances by applying process empirical know how and FE simulation.

- There is a clear progress in geometric accuracy.
- Surface finish is slightly over the design tolerance yet.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Zone</th>
<th>Ra (um)</th>
<th>Average Ra (um)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>3.77</td>
<td>3.87</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>3.97</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>2.47</td>
<td>2.62</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>2.77</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>central</td>
<td>1.93</td>
<td>1.71</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>1.48</td>
<td></td>
</tr>
</tbody>
</table>

Tool step down
Airframe demonstrator (to be launched)

The target is to validate significant improvement in geometric accuracy when forming TiGr5 without dedicated tooling by applying homogeneous heating and Knowledge Based error compensation.
Demonstration (3/3)

The demonstrators will serve as the basis for the AISF technology evaluation

<iostream>

1. Assessment

- NRC (tooling) and overall reduction in costs
- Tight geometric tolerances
- Green technology (low energy consumption)
- Small machine environment
- Raw material consumption
- Quality/aspect ratio
- Suppress or reduce post-forming additional operations (e.g. hand reworking)

2. On going for end-user’s decision

- Competitive against existing solutions or alternatives
- Defined potential target pieces
- Integration inside plant workshop

</iostream>
The INMA project aims to provide a low cost and agile forming technology to shape titanium and difficult-to-deform materials based on the AISF process:

- A vast empirical know-how on Ti forming using AISF has been produced
- FE models have been set up to support the process know-how acquisition
- Material properties data have been produced
- A knowledge-based model allows modifying the CAD in order to decreased geometric distortion due to springback
- An homogeneous temperature heating method has been set up for TiGr5

During the last stage of the project 2 demonstrator parts are being fabricated by applying the implemented concepts

By the end of the project Airbus and WSK will assess and validate the developed technology based on the fabricated demonstrators
Acknowledgements

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 266208