
Project no. AST5-CT-2006-030852

Project acronym: MAGFORMING

Development of new Magnesium Forming Technologies for the Aeronautics Industry

Instrument: STREP

Thematic Priority: 1.4 Aeronautics and Space

# Publishable Final Activity Report

Period covered: from 01/08/2008 to 30/09/2009 Date of submission: 31/01/2010

Start date of project: 01/07/2006 Duration: 38 Months

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Project coordinator organisation name: PALBAM Metal Works

Revision version 1.0

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# Executive Summary

The main objective of MagForming project was to develop several forming technologies for Magnesium wrought alloys and to show their industrial feasibility in Aeronautics. The measure that was used for attaining the objective was the fabrication of several prototypes for each of the technologies; also refer to as Technology Demonstrators (TDs).

The consortium consisted of four SMEs, two Universities, one research organisation (EADS), three major aerospace companies (Airbus, Israel Aviation Industry and Liebherr Aerospace Toulouse) one major Magnesium supplier and one leading lubricant developer and supplier. It was coordinated by Palbam-AMTS from Israel.

Three administrative (WP1 Management, WP9 Dissemination & Exploitation and WP10 Assessment & Review) and seven technological workpackages constructed the consortium framework. Out of the technological workpackages WP2 concentrated in selecting the TDs and the Magnesium alloys for each technology, WP3 – WP7 concentrated in the different forming processes (forging, superplastic forming, pad forming, deep drawing and creep forming) and WP8 dealt with metallurgical investigation before and after the production processes.

Below are presented only main results conclusions of each technological workpackage (WP2 to WP7).

**WP2**

The following table describe the selected TDs and Magnesium alloys.

| **Process type** | **Selected Technology Demonstrators** | **Selected alloys** |
|---|---|---|
| large scale forging | A340 window frame | AZ31B, AZ80 |
| Medium scale forging | Air system compressor wheel | WE43, AZ80 |
| Small scale forging | A380 Door stop fitting | WE43, AZ80 |
| SPF – hydro/gas hot forming | G-150 Service door inner panel<br>Air system compressor scroll | AZ31B, ZK10<br>AZ31B-O, ZE10 |
| Deep drawing | Helicopter antenna support | AZ31B, ZE10 |
| Roll bending | Reference part | AZ31B, ZE10 |
| Pad/rubber forming | G-200 flap leading edge rib<br>Airbus pad forming reference part | AZ31B, ZE10<br>AZ31B, ZE10 |
| Creep forming | Integral welded fuselage panel with stiffeners | AZ31B<br>ZK10, ZK30 |

**WP3 Forging**

SMW Engineering was responsible for the large scale forged part while IFUM (from Hannover University) was responsible for the developing and manufacturing of the small and medium scale forged parts.

<u>Large Scale Forging – Window Frame</u>

Feasibility to forge a part like window frame from Magnesium alloy has been confirmed and the forging process parameters have been established.

Cost comparison showed that the production cost of making the part from Magnesium alloy is $15 vs. $55 using the current process and current material (7175 alloy), although obtaining the required properties for the part in Magnesium alloys will be problematic.

<u>Medium Scale Forging – Compressor Wheel</u>

The whole process chain from material characterization to the production of the part was performed successfully. The compressor wheel met the required high mechanical properties.

<u>Small Scale Forging – Door Stop Fitting</u>

The whole process chain from material characterization to the production of the part was performed successfully. The forging of the door stop fitting showed the feasibility of a forging process of a complex shaped geometry.

**WP4 SPF**

Service Door Inner Panel

Both AZ31 and ZK10 sheet achieved perfectly the final geometries. AZ31B alloy showed better superplastic behaviour versus both 6061 and 5052 Aluminium alloys.

Compressor Scroll

The SPF process, which was suggested for the production of compressor scroll, is feasible with Magnesium Alloy AZ31B.

The developed process seems to be more effective compared to the current process used.

The influence of the SPF process on fine microstructure as well as on the properties of the final product is acceptable.

**WP5 Pad Forming**

Leading edge Rib

IAI achieved the goal of pad forming a representative Magnesium alloy part as an alternative to an existing Aluminium part, with radii and joggles. The Magnesium required fewer stages for manufacture and consumed less energy.

ZE10 alloy achieved better results compared to AZ31B.

Overall, production cost of a Magnesium part is around 30% more expensive thank of Aluminium part.

Airbus Reference Part

Pad forming of the Airbus reference part at ambient temperature with the pad-forming process established for Aluminium sheet is feasible for thin Magnesium sheet material as well.

ZE10 alloy achieved better results compared to AZ31B.

Concerning material cost Magnesium sheet will be about 2.5 times more expensive per square-meter than standard Al 2024 sheet, but of course this is depending on the purchased amount of material, respectively the amount of sheet material produced in a certain quality.

**WP6 Deep Drawing**

Antenna Support

In general, AZ31B sheet responded excellent to deep drawing and SPF apart, as well as to the combination of the two processes.

**WP7 Creep Forming**

Integral Welded Fuselage Panel with Stiffeners

The creep forming of stiffened panels could be realized with AZ (AZ31 sheet and AZ31 profile) and ZK (ZK10 sheet and ZK30 profile) alloys, just by the use of vacuum and elevated temperatures.

The process steps were cut by more than 50% from the Aluminium to the Magnesium process.

# Project Execution

## *Objectives*

The S&T objective of MagForming was to develop the tools and methodologies for a complete family of advanced, semi-industrial, plastic and super-plastic forming technologies for Magnesium wrought alloys and show their industrial feasibility in Aeronautics.

The measure that was used for attaining the objective was the fabrication of several prototypes for each of the technologies mentioned in Table 3. These "Technology Demonstrators" or TDs were meant to prove the feasibility of the respective process route and aimed to be the cornerstone for subsequent full-scale industrial manufacturing processes.

The main objective, which was to develop tools and methodologies for the production of wrought Magnesium parts, was planned to be achieved by attaining the following sub-objectives:

1. Methodologies for the preparation of the raw material for plastic deformation. Such preparation should include, among others, solidification processes, rolling processes, extrusion and annealing processes, etc.
2. Study of the lubrication needs of the plastic forming of Magnesium. For example: Magnesium must be worked at high temperatures; therefore the lubricants must withstand high temperatures, unlike those for Aluminium.
3. The development of special heated dies with controlled temperatures and temperature gradients.
4. The development of cooling procedures, to attain the best qualities for the manufactured part, as required by the specifications and, at the same time, preventing damage from the press machine.
5. The development of a press loading application routine: level of force applied, temperature regime, duration of the application of force, process total speed etc.
6. Some minor geometric modifications, within the parts design, using modelling software, to make sure that the Magnesium part meets the specifications required by the end users.

Such being the case, the main target of MagForming was to develop several forming processes which are very popular in the aeronautic industry for Aluminium and other metals but are not yet transferable to wrought Magnesium.

## *Contractors involved*

The consortium consisted of four SMEs, two Universities, one research organisation, three major aerospace companies, one major Magnesium supplier and one leading lubricant developer and supplier.

The following table describes the participants' origin country and role in the project.

| **Participant name** | **Short name** | **Country** | **Organisation type** | **Role** |
|---|---|---|---|---|
| PALBAM Metal Works | PALBAM-AMTS | IL | SME | SPF, roll bending and deep drawing technologies |
| EADS Deutschland GmbH | EADS CRC | D | End user Research | Creep forming technology developer |
| Magnesium Elektron Ltd. | MEL | UK | Industry | Magnesium supplier |
| Airbus Deutschland GmbH | A-D | D | End user | End user and pad forming technology developer |
| Israel Aviation Industry | IAI | IL | End user | End user and pad forming technology developer |
| Liebherr Aerospace S.A.S. | LTS | F | Industry | End user |
| SMW Engineering | SMW-E | RUS | SME | Large scale forging technology developer and simulation |
| Chemetall GmbH | Chemetall | D | Industry | Lubricant developer and supplier |
| Ultratech Sp z.o.o. | Ultratech | PL | SME | Precision machining |
| Alubin Ltd. | Alubin | IL | SME | Magnesium extrusions supplier |
| Department of Metal Physics, Charles University, Prague | CUNI | CZ | University | Material investigation |
| Institute of Metal Forming, Leibniz University Hannover | LUH (or IFUM) | D | University | Small/medium scale forging technology developer and simulation |

Table 1: Participant of MagForming project

**Coordinator contact details:**

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## *Work Performed and Results*

MagForming project was constructed from 10 work packages as specified in the table below:

| WP no. | WP role |
|---|---|
| 1 | Management |
| 2 | Specifications |
| 3 | Forging |
| 4 | Superplastic forming |
| 5 | Pad forming / roll bending |
| 6 | Deep drawing |
| 7 | Creep forming |
| 8 | Testing and validation |
| 9 | Dissemination and exploitation |
| 10 | Assessment and review |

Table 2: Project's workpackages

## WP2

The first task of the project was to select the parts to be used as TDs of each technology. This was done under WP2 which was led by Airbus. The TDs were selected according to their feasibility to achieve the aeronautic requirements and the potential economic advantages in regard to the conventional solutions.

Then the available alloys and conditions (temper, semi-finished product form) were screened and the best suitable ones for the different TDs and special process requirements were selected.

| Process type | Selected Technology Demonstrators | Selected alloys |
|---|---|---|
| large scale forging | A340 window frame | AZ31B, AZ80 |
| Medium scale forging | Air system compressor wheel | WE43, AZ80 |
| Small scale forging | A380 Door stop fitting | WE43, AZ80 |
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| Creep forming | Integral welded fuselage panel with stiffeners | AZ31B<br>ZK10, ZK30 |

Table 3: Outcomes of WP2

## WP3

In WP3 three TDs were manufactured by forging technology: A340 window frame, air system compressor wheel and A380 door stop fitting.

### A340 Window Frame

<u>Work Performed</u>

The production of a window frame from Magnesium alloy has been done by SMW-E and included the following steps:

- Low-pressure casting to produce a cast pre-form for subsequent forging
- Per-form heat treatment
- Tools making (by Ultratech)
- Forging
- Heat treatment of the forging
- Machining of the forging (holes drilling)

Low-pressure casting into a metallic mould allowed obtaining a dense, fine-grained structure of the pre-form.

As regards to Magnesium alloys, using an inert gas to force the metal allowed to reduce the oxidability of the cast pre-form.

Pre-form dimensions and the main cross-sections shapes are determined by Finite Elements Analysis. The FEA was carried out using SuperForge software. Distributions of deformation, stress and temperature were investigated.

The main goals of the FEA simulations were to achieve:

- Optimal shape of the cast pre-form
- Pre-form's good deformability
- Uniform die filling
- Self-centering of pre-form

Thus obtained data was used to arrive at the optimal forging process parameters and for the dies development.

Some screenshots of the computer simulations are shown below.

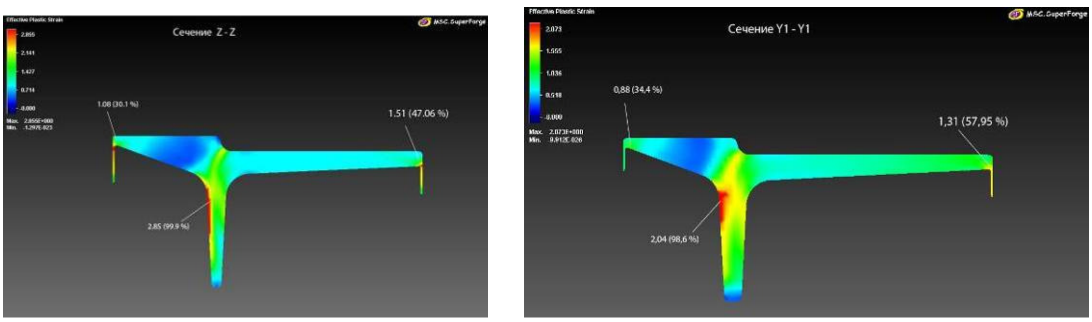



Figure 1: FEA simulations of the forging process

The drawing and the photo of the cast pre-form is presented on Figures 2 and 3.

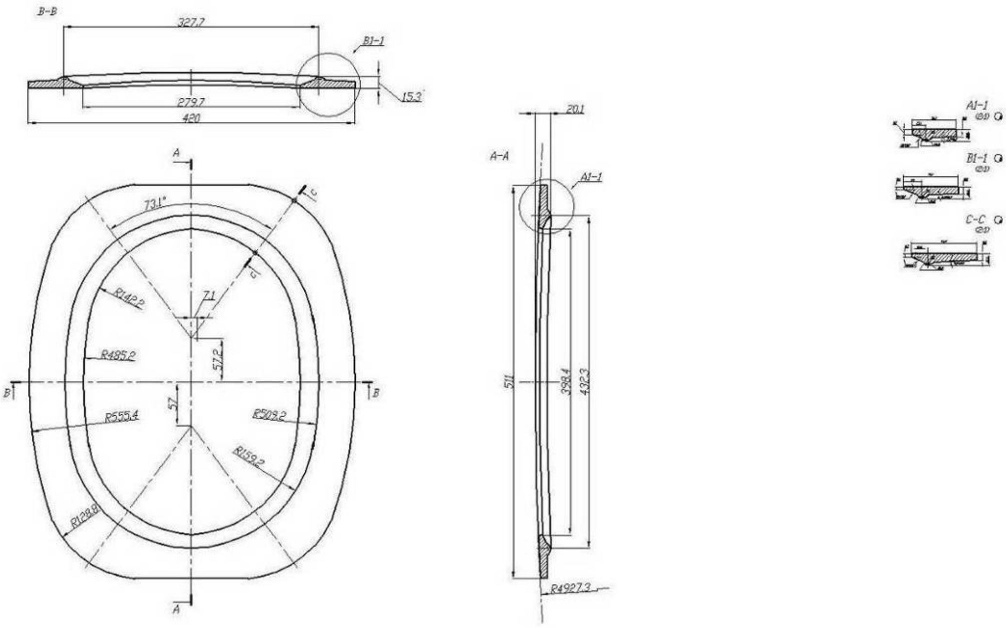



Figure 2: Cast pre-form drawing

Figure 3: Cast pre-form photo

Low-pressure casting technology suited well to produce pre-forms with cross sections close to rectangular shape with thicknesses within 3.5 to 15.5 mm and area of 800 $cm^2$. Therefore, considering a possibility of the pre-form shape adjustment, a decision was made to produce pre-forms by CNC milling from cast and rolled plates.

Magnesium Elektron manufactured and supplied 5 cast plates from AZ80 alloy and 5 rolled plates from AZ31 in H24 condition.

In order to achieve stable metal structure necessary for forging, all plates were subject to homogenization treatment.

Ultratech manufactured the quite complicated tools and dies for the forging process by their 5-axis CNC center FIDIA K 214, see Figure 4.

Chemetall supplied Gardolube L6300 lubricant for improvement of the forging process.

Figure 4: Some of the tools and dies for the forging process

Results

The actual forging took place in a closed die designed for 5000 ton press. The general tooling layout is presented on Figure 5. A sample of the window frame forging is shown on Figure 6.

Trial forging operation established the following:

1. The dies were fully filled by the metal, forging flash of 0.2 – 0.4 mm thickness uniformly distributed over the contour.
2. Dimensional thickness discrepancy in the forging cross-section is not more than 30% compared to the values on the drawing.
3. The surface quality when using lubricant supplied by Chemetall is in conformity with the drawing requirements.
4. Working temperature and forging speed were determined.
5. Forging force was no more than 3,000 ton.

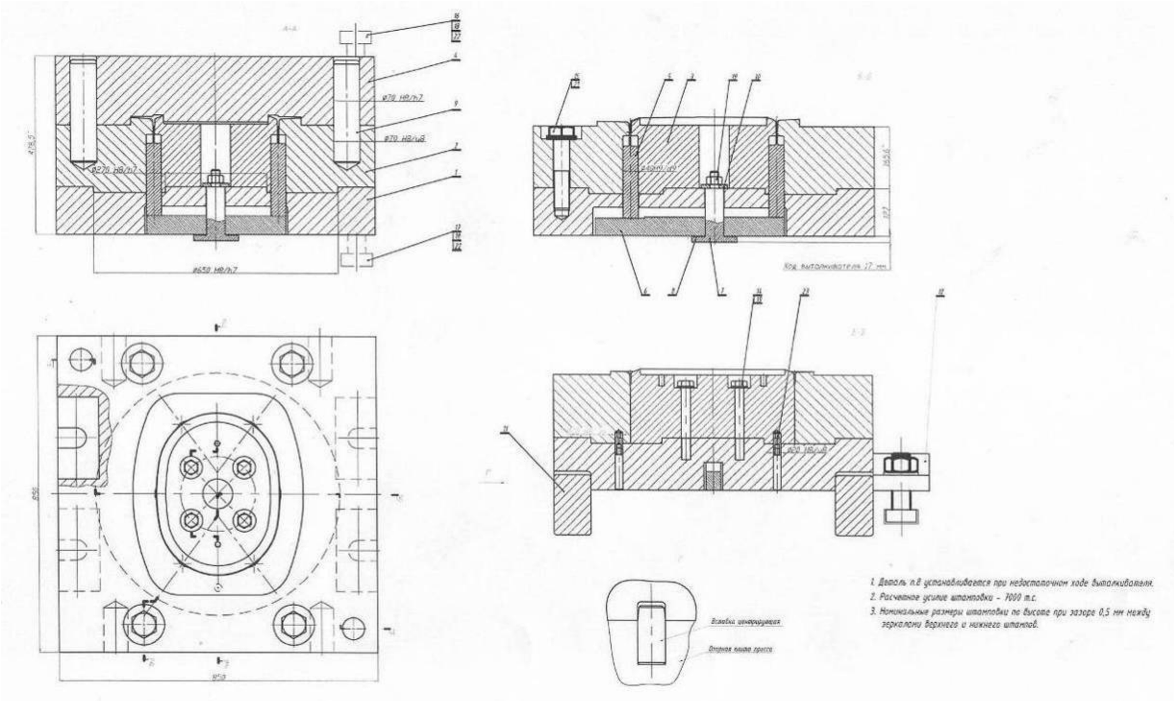


Figure 5: Tooling layout

Figure 6: Window frame forging (flash removed)

**Compressor Wheel**

Within WP3 the Institute of Metal Forming and Metal-Forming Machines (IFUM) was responsible for the development of the forging process as well as the design and production of tools and dies for the compressor wheel. The whole process chain from the material characterisation to the production of demonstrator parts was performed at IFUM and is described henceforth.

Input and Material Characterisation

The medium scale part was a compressor wheel for an air conditioning system (LTS*)*. Due to the high mechanical and thermal loads this part was forged out of the Magnesium alloy WE43. For the development of the forging dies and the tool design, IFUM obtained a 3D model of the compressor wheel. The pre-extruded semi-finished parts were delivered by MEL (WE43)

First step of the project at IFUM was the determination of the flow curves of the Magnesium alloy WE43. Upsetting tests under strictly controlled conditions at elevated temperatures between 280°C and 450°C were carried out on a servo hydraulic Plastometer. Specimens with a diameter of 11 mm and a height of 18 mm were tested, varying the parameters strain rate and temperature. During each upsetting test, temperature and strain rate was constant. By means of the detected load and path of the ram the required flow curves were determined. They show the true stress, true strain dependence on temperature and strain rate. The recorded data was used to calculate the required material data files for the numerical analysis of the forging process.

Development of Forging Dies and FE-Analysis

The obtained 3D model of the forging part was the basis for the tool design and the following FE-analysis. Initially CAD models of the forging dies were developed. Due to the elevated temperature of billets and tools up to 400°C the temperature related shrinking of the part after the forging process had to be considered. Therefore the dies were scaled up. Furthermore the geometry of the forging billet was developed. These initial models of dies and billet were transferred to FEA software. The numerical analysis was done with the software Forge3 (Transvalor S. A.). The following steps were necessary for the analysis:

- Import and alignment of the CAD data of forging dies and billet
- Meshing of the billet
- Specification of starting temperatures of dies and billet
- Definition of press kinematics and lubricant conditions
- Specification of material characteristics (flow curves)

The first numerical simulation of the compressor wheel showed that the form filling behaviour was not sufficient and load was unacceptable high even at elevated forging temperatures. In consultation with LTS a minor adaptation of the geometry was decided. This led to the anticipated reduction of press forces and a complete form filling. With the following FE-analysis the design process of the tools was supported in order to get information about optimal die and billet temperatures, the necessary forming force as well as the forming speed. Furthermore the geometry of the billet was adapted to the Magnesium forging process. Based on these investigations the die geometry was gained.

The forging dies were implemented in a tool guiding frame to ensure an optimal part quality within a close tolerance. Therefore adaptation parts and insulating plates were constructed for the connection of dies and tool guiding frame. Furthermore the required heating sleeves were determined for a maximum achievable die Temperature of 400°C.

Production of Dies and Process Development

The forging tools as well as the electronic devices for the heating sleeves were produced and assembled at IFUM. The tool for the compressor wheel has a weight of two tons and was designed for the maximum load of the hydraulic press of 12,500 kN. For the heating of the billets a convection furnace was used. To determine the billet temperature a reference billet equipped with thermocouples on the surface and in the centre was heated at the same time in the furnace. Figure 7 depicts the forging tool of the compressor wheel within a 12,500 kN hydraulic press.


Figure 7: Forging tool of compressor wheel

Due to the elastic deflection of the tools, the first step of the forging tests was the determination of the bottom dead centre of the ram to realise a complete form filling. The parts were forged with different parameters to investigate the influence of temperature and ram speed. Tool and billet temperatures were tested in a range of 300°C to 400°C. The ram speed was varied between 10 and 30 mm/s. The forging of the compressor wheel showed the best results at a temperature of 350°C. At higher temperatures the parts were sticking to the tool. At least five forging parts of the compressor wheel were forged under the same conditions. These parts were heat treated for 16 hours at 200°C after the forging process and delivered to LTS. The forging part of the compressor wheel is depicted in Figure 8.

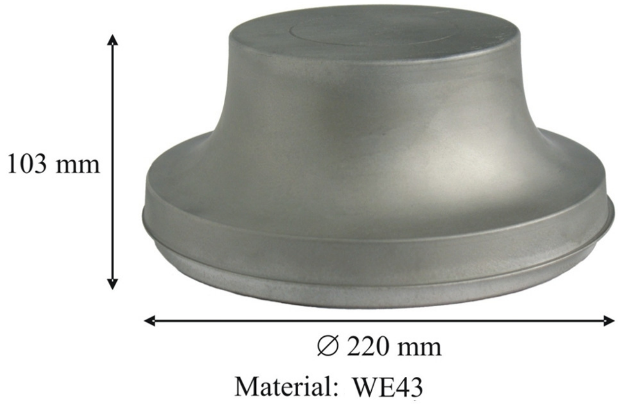



Figure 8: Small and medium scale forging part

LTS analysed the rough parts of the compressor wheel according to their quality standards, performed tensile tests and machined three compressor wheels out of the forging parts (Figure 9). The quality of the rough part is conforming to the requirements. With a yield strength of 291 MPa and a tensile strength of 338 MPa at room temperature and excellent mechanical properties at elevated temperatures, the forging part meets the requirements. The machined parts are tested on a dynamometer at high revolutions per minute for aerodynamic performance. At the time of writing this report the tests at LTS have not yet completed.

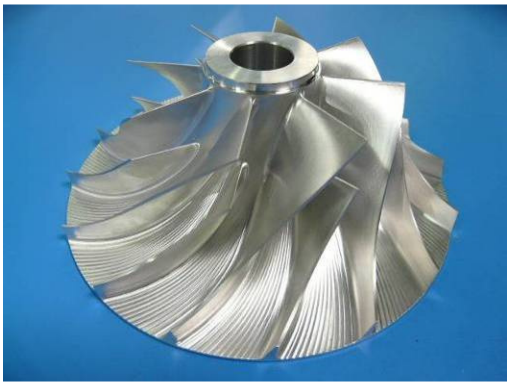


Figure 9: Machined compressor scroll (by LTS)

**A380 Door Stop Fitting**

Within WP3 the Institute of Metal Forming and Metal-Forming Machines (IFUM) was responsible for the development of the forging process as well as the design and production of tools and dies for the A380 door stop fitting. The whole process chain from the material characterisation to the production of demonstrator parts was performed at IFUM and is described henceforth.

Input and Material Characterisation

For the development of the forging dies and the tool design, IFUM obtained a 3D model of the door stop fitting. The pre-extruded semi-finished parts were delivered by Alubin. The chosen Magnesium alloy was AZ80.

First step of the project at IFUM was the determination of the flow curves of the Magnesium alloy AZ80. Upsetting tests under strictly controlled conditions at elevated temperatures between 280°C and 450°C were carried out on a servo hydraulic Plastometer. Specimens with a diameter of 11 mm and a height of 18 mm were tested, varying the parameters strain rate and temperature. During each upsetting test, temperature and strain rate was constant. By means of the detected load and path of the ram the required flow curves were determined. They showed the true stress, true strain dependence on temperature and strain rate. The recorded data was used to calculate the required material data files for the numerical analysis of the forging process.

Development of Forging Dies and FE-Analysis

The obtained 3D model of the forging part was the basis for the tool design and the following FE-analysis. Initially CAD models of the forging dies were developed. Due to the elevated temperature of billets and tools up to 400°C the temperature related shrinking of the part after the forging process had to be considered. Therefore the dies were scaled up. Furthermore the geometry of the forging billets was developed. These initial models of dies and billet were transferred to FEA software. The numerical analysis is done with the software Forge3 (Transvalor S. A.). Following steps are necessary for the analysis:

- Import and alignment of the CAD data of forging dies and billet
- Meshing of the billet
- Specification of starting temperatures of dies and billet
- Definition of press kinematics and lubricant conditions
- Specification of material characteristics (flow curves)

The first numerical analysis of the door stop fitting showed that a one step forging process with a single die set is possible. With the following FE-analysis the design process of the tools was supported in order to get information about optimal die and billet temperatures, the necessary forming force as well as the forming speed. Furthermore the geometry of the billet was adapted to the

Magnesium forging process. Based on these investigations the die geometry of the door stop fitting was gained.

The forging dies were implemented in a tool guiding frame to ensure an optimal part quality within a close tolerance. Therefore adaptation parts and insulating plates were constructed for the connection of dies and tool guiding frame. Furthermore the required heating sleeves were determined for a maximum achievable die Temperature of 400°C.

Production of Dies and Process Development

The forging tools as well as the electronic devices for the heating sleeves were produced and assembled at IFUM. Figure 10 depicts the forging tool of the door stop fitting within a 4,000 kN hydraulic press. For a better overview the insulation of the heating sleeves was removed. For the heating of the billets a convection furnace was used. To determine the billet temperature a reference billet equipped with thermocouples on the surface and in the centre was heated at the same time in the furnace.

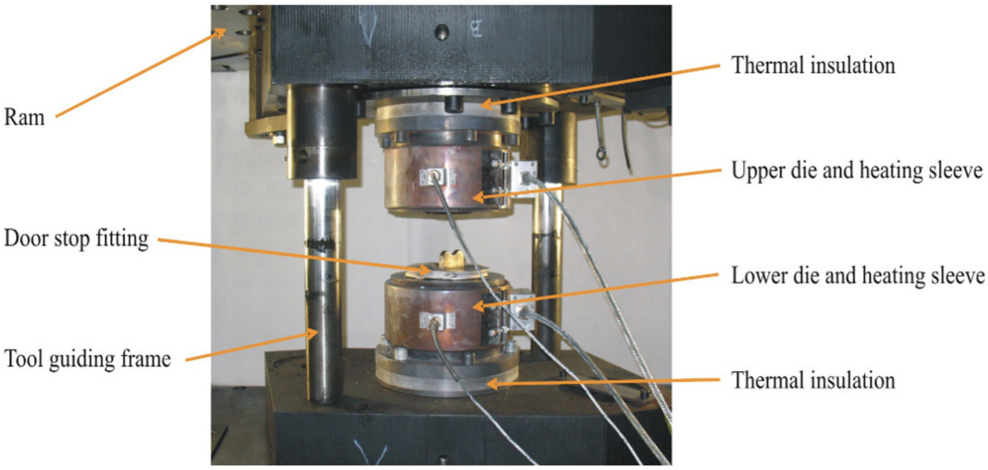



Figure 10: Forging tool of door stop fitting

Due to the elastic deflection of the tools, the first step of the forging tests was the determination of the bottom dead center of the ram to realise a complete form filling. The parts were forged with different parameters to investigate the influence of temperature and ram speed. Tool and billet temperatures were tested in a range of 300°C to 400°C. The ram speed was varied between 10 and 20 mm/s. Due to the complex shape, the forging process of the door stop fitting was challenging. Lower temperatures led to an incomplete form filling. At higher temperatures the forging part stuck to the tool. Finally the part was forged at a temperature of 300°C. The forging part of the door stop fitting is depicted in Figure 11.

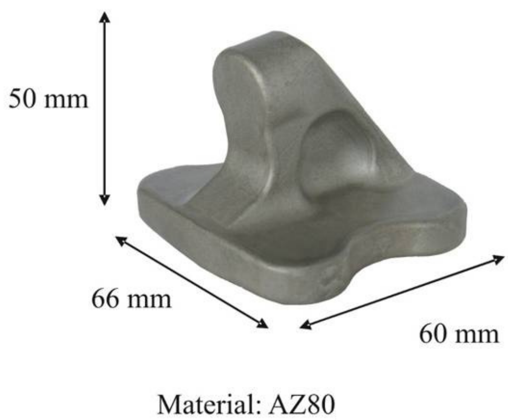



Figure 11: Small and medium scale forging part

## WP4

In WP4 two TDs were manufactured by SPF technology: G-150 service door inner panel and air conditioning system compressor scroll.

**G-150 Service Door Inner Panel**

PALBAM-AMTS was responsible for the production of the G-150 service door inner panel. Requirements and drawing (Figure 12) have been provided by IAI, the producer of the Gulfstream G-150 Aircraft. The original raw material of this part is Aluminium 6061 or 5083 sheet.

MEL supplied the material for the superplastic process: Magnesium sheet alloy AZ31B-O (fully annealed) and ZK10.

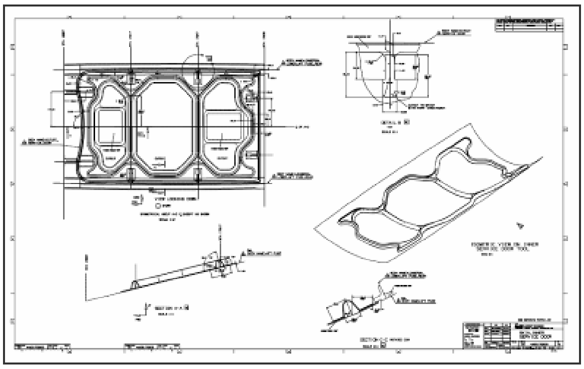


Figure 12: IAI drawing of the door panel

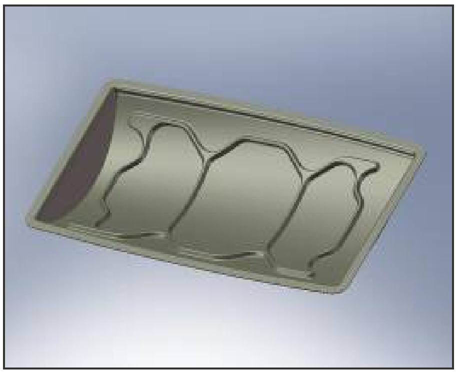


Figure 13: AMTS 3D solid model

Work Performed

The production of service door inner panel from Magnesium alloy included the following steps:

- Creating a 3D solid model out of the drawing (Figure 13).
- Materials selection.
- Design and manufacturing of small scale SPF tool (Figures 14 and 15).
- SPF process studying (small scale test): degree of deformation/thinning as a function of process schedule and temperatures.
- Design of door inner panel shaped dies. Process Simulation.
- Design of tooling set for full scale forming. Design review, drawings release.
- Production of forming tools (PALBAM workshop).
- SPF experiments. Process optimization. Results. Conclusions.

Design of Small Scale SPF Tool and Manufacturing of Small Scale SPF Tool

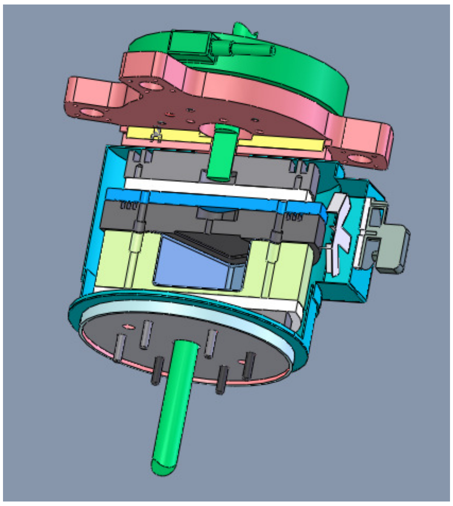


Figure 14: Tooling Assembly on the press (left) and assembly of small scale SPF process Tool (right)

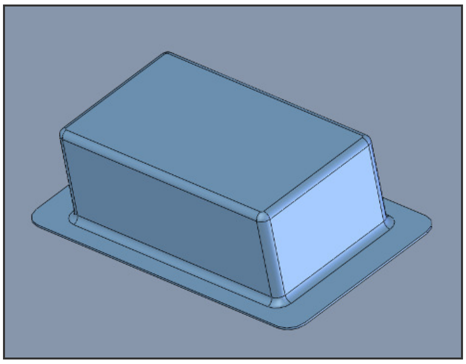


Figure 15: Experimental part model (left) and deformed Magnesium part (right)

SPF Process studying (small scale test): Degree of Deformation/thinning as a Function of Process Schedule and Temperatures

We started with a 3D rectangular box, which its dimensions are 240 x 135 x 90 mm and flange radii of R8. The geometry is challenging since the theoretic deformation ratio, for isotropic final shape, is above 200%. Steel dies have been continuously heated, by artificial convection within a closed chamber, in order to avoid temperature differential through active areas.

Materials which have been examined: Aluminium alloys 5052 and 6061, Magnesium Alloy AZ31B.

For the AZ31B sheet, M values, as well as grain size of the bulk material, have been measured. The average M factor has been calculated to exceed 0.3. Grains size of approximately 15µm was found.

SPF cycles have been operated in varied procedures. Obviously, tests used to be stopped together with the first crack along the work-piece.

For reference, we operated back pressure, during some of the forming cycles, in order to avoid growth of cavitation, typical phenomena for Aluminium SPF.

Interim Conclusion

- Magneisum AZ31B showed better superplastic behaviour versus both 6061 and 5052 Al alloys (as expected).
- At a certain thermal condition and an average strain rate it is possible to achieve more than 230% (!) 3D plastic strain.

Design of Service Door Inner Panel Shaped Dies. Process Simulation

Simulation inputs:

- AZ31B-0 Magnesium sheet, 2 mm thickness
- Loading flow stress for different temperatures (up to 300ºC) E = 0.46 GPA
- Gas pressure versus time curve

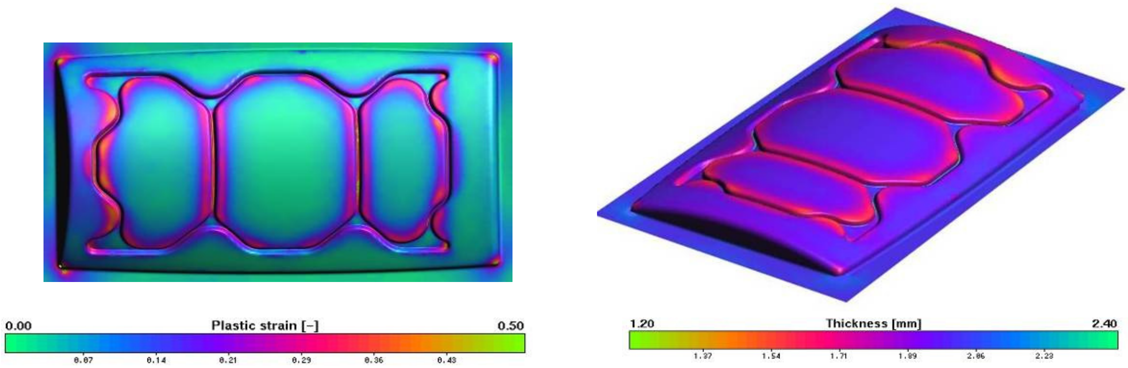



Figure 16: Simulation output: deformation report (left) and thickness report (right)

The above simulation (Figure 16), which was done at LUH with AUTOFORM software, showed feasibility of the forming process and provided confidence toward tool making.

It appeared that we found slightly above 60% multidirectional plane deformation.

Considering anisotropic factor, strength directionality and homogeneity we might expect 90% in-plane deformation.

Design of Tooling Set for Full Scale Forming; Design Review; Drawings Release

Designing of full scale SPF tooling system for the service door inner panel was based on the following data:

- Maximum gas pressure of 12.0 bars/170PSI, keeping stable pressure for 2.5h
- Maximum temperature: 550ºC
- Loaded surface area: 0.95m$^2$
- Press tables must not exceed 70ºC

Full scale SPF machine was designed. The design program contained a heat flow numeric simulation.

Production of Forming Tools

All production of the forming tools and accessories as well as quality inspection, finishing and assembly, were done in-house, at PALBAM Workshop.

- Technologies involved in the manufacturing of hot forming tools were:
    - heavy duty machining shop

- 5 axes machining centers
- sheet metal bending
- welding and assembly
- mechanical polishing
- electronic controllers installation
- heating elements coiling

<u>SPF Experiments; Process Optimization; Results</u>

All the SPF experiments were done at PALBAM forming shop, using the 10,000KN hydraulic press (Figure 17).

Figure 17: PALBAM's 10,000KN hydraulic press

2mm Magnesium sheet blanks were cut by laser beam out of AZ31B and ZK10 alloys. 2 mm Al sheet 6061 and 1.5mm Al 5083 have been taken as a reference. A pressure function was operated (time versus pressure value).

Temperatures were measured in 4 different locations.

Each cycle the formed part was examined for cracks initiations/thinning at the acute radiuses.

<u>Results</u>

Both AZ31 and ZK10 sheet were preformed quite well and achieved perfectly the final geometries.

The maximum deformation obviously appeared upon the formed corners, which created the stiffeners strips. The maximum strain ratio did not exceed 85% at those areas (Figure 18).

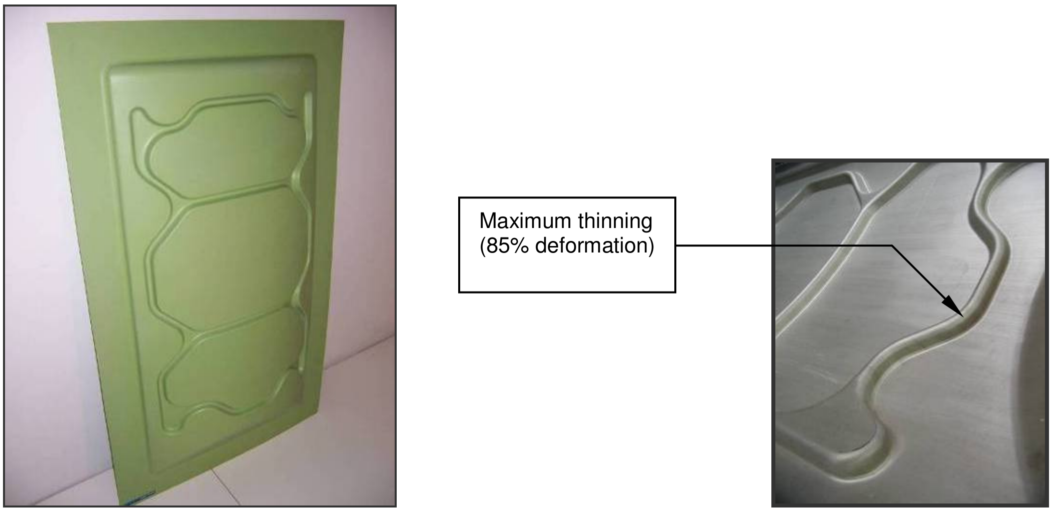



Figure 18: The produced service door inner panel (left) and a zoom on the thinning area (right)

**Air Conditioning System Compressor Scroll**

PALBAM-AMTS was responsible for the production of the LTS air conditioning system compressor scroll.

Today the product is manufactured from Aluminium Alloy A357 by permanent mould casting. It is assembled out of two slices, while the minimum wall thickness is 3 mm (see drawing in Figure 19). The end user made some experiments with stainless steel sheet forming, in order to save weight by reducing structure thickness.

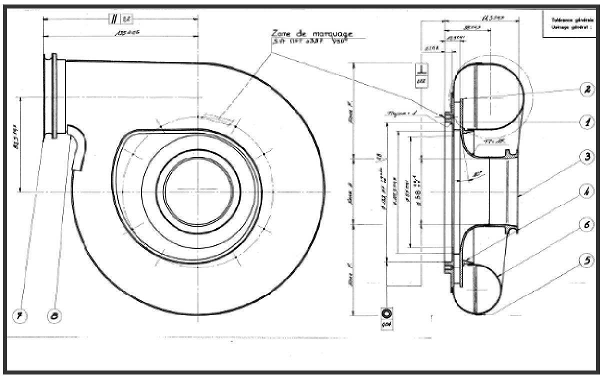


Figure 19: LTS drawing of the compressor scroll

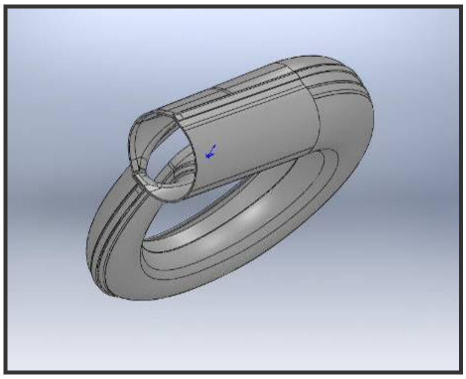


Figure 20: AMTS 3D solid model

<u>The End User Requirements</u>

- Cutback of compressor scroll weight without increasing the parts production and assembly costs.
- Loads: 1 bar internal pressure at service condition.

In order to follow the above requirements, it was decided to consider deep drawing, as an alternative production process.

The first step was to simulate the deep drawing process using 2mm Magnesium sheet AZ31B alloy. The simulation was done at LUH by AUTOFORM software (Figure 21).

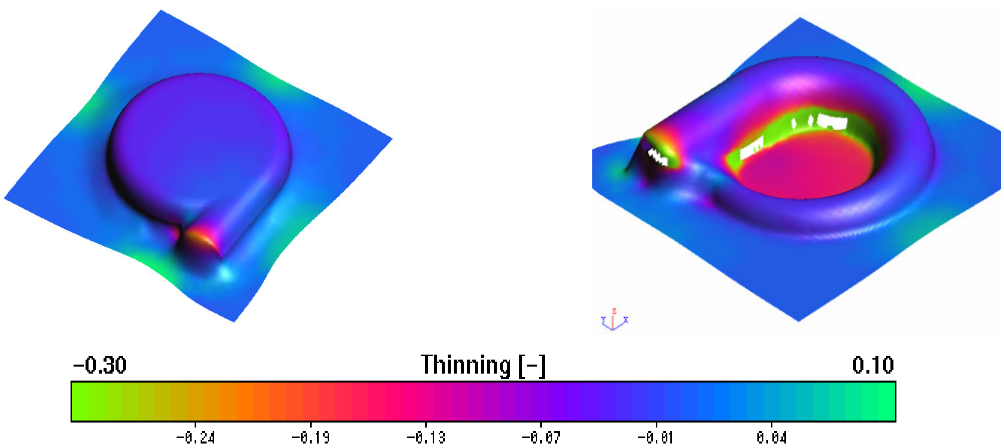


Figure 21: Deep drawing thinning – bottom scroll basin (left) and upper scroll basin (right)

Following numeric simulations for Magnesium deep drawing of two separate shells, which showed difficulties in accomplishing the complex geometries, it was decided to try using SPF process in order to overcome both technological and cost issues. First it was decided to produce the bottom part by deep drawing and the upper part by SPF, but a second design review reached the conclusion that a full SPF process would meet best the requirements.

SPF Process

The female die, for the one problematic Scroll slice, has been designed (Figure 22) and the shape installed into the forming simulation.

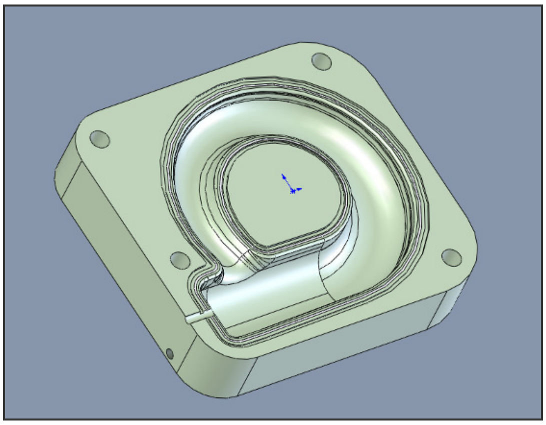


Figure 22: 3D solid model of compressor scroll female die

From the forming simulation images, of the more deformed scroll basin, one can easily notice that there are two critical zones (Figure 23) which expected to have high thinning values and might contain cracks caused by the final forming phase. The critical zone no. 2 is less problematic, in a matter of final product, since it is going to be removed during the final machining.

Regarding zone no. 1, an intercooler which would reduce the deformation degree at the problematic area was designed and implemented.

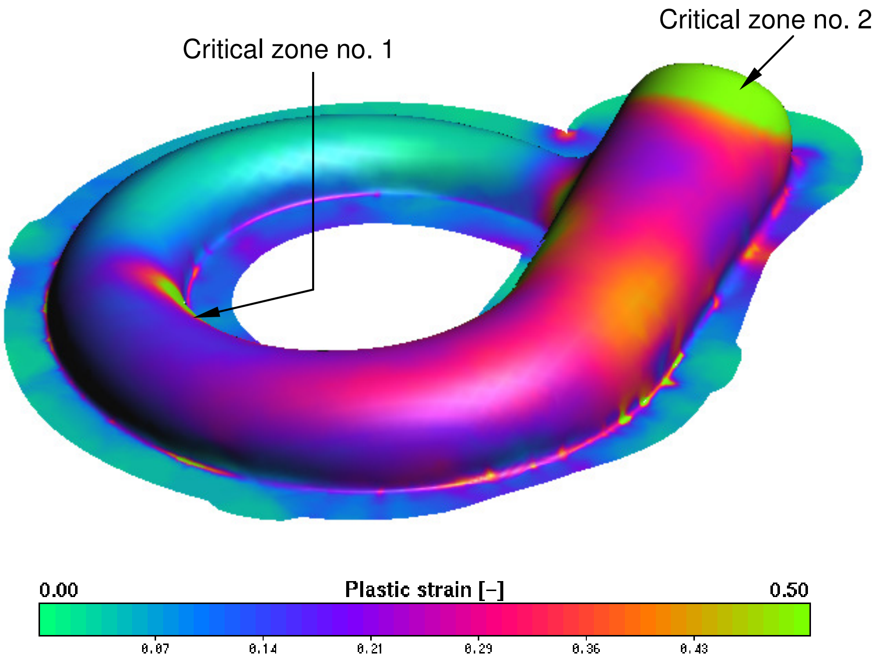



Figure 23: Critical zones in the compressor scroll upper part as simulation predicts

Tooling System Manufacturing

The SPF tools segments, including shaped steel dies, heated generators and closed furnace, were manufactured, in-house, at PALBAM metal shop.

All the assembly and installation on the press and the insulation of the pressured gas injectors were also applied by PALBAM technicians.

Figure 24: Machined compressor scroll female die

SPF Process

These are the basic parameters used for the SPF process:

- Process temperature range: 350-400°C
- Gas pressure: maximum 6 bar
- Schedule: 90 min. (gas pressure and time-set monitoring function)

Results

The material was fully filled the dies and the original geometry was obtained (Figure 25).

Some specimens were taken out from the formed scroll for a basic tensile test (Table 4) and in order to evaluate the microstructure. In addition, some transverse cuts were done in order to examine the wall thinning through the critical zones.

Minimum wall (maximum thinning) which has been found through the critical areas was 1.18mm.

Figure 25: As formed Magnesium compressor scroll

| **Sample** | **Type** | **Tensile properties** | | |
|---|---|---|---|---|
| | | **Yield stress, MPa** | **Ultimate strength, MPa** | **Elongation, %** |
| 3S-1 | sheet, longitudinal | 200 | 291 | 13 |
| 3S-2 | sheet, transverse | 180 | 271 | 7 |
| 5S-1 | Scroll | 165 | 258 | 16 |
| 5S-2 | Scroll | 167 | 265 | 14 |
| 5S-3 | Scroll | 173 | 266 | 12 |
| ASTM B90/B | sheet temper “H24” | 200 min | 269 | 5 min |
| Spec minimum | sheet temper “O” 1.5-6.0 mm | 105min | 220 min | 10 |

Table 4: Mechanical properties of AZ31B sheet and the compressor scroll

Figure 26 shows the similarity between the part model and the actual produced part made of Magnesium.

Figure 26: The compressor scroll, 3D solid model designed by LTS (left) and Final shape produced by PALBAM-AMTS (right)

## WP5

In WP5 two TDs were manufactured by pad forming technology: G-200 flap leading edge rib and Airbus pad forming reference part. Also a roll bending part was manufactured.

### G-200 Flap Leading Edge Rib

Work Performed

IAI chose a representative Aluminium part to be replaced by Magnesium. The part was accepted by the consortium members and defined as the IAI reference part.

IAI selected two Magnesium alloys to be examined in this project, AZ31B-H24 and ZE10A-F. The materials were received from MEL as pre-cut sheets in the following dimensions: 350x220x1.5 mm. Lubricants for forming improvement received from Chemetall: Gardolube L6301 S (1kg).

In the first stage of the work, chemical analysis was taken to verify the composition of the alloys, and mechanical testing was performed on the two alloys.

In the second stage, bending tests were performed (at PALBAM workshop and with their help) in a wide range of temperatures and radii to estimate the best parameters for the pad-forming process.

Metallurgical examinations were performed on the bent parts to look for any cracks, crack initiations and/or modifications in the alloys structure.

Initial pad-forming tests were first made on a part similar to the reference part to evaluate the process – time and temperature before forming.

IAI performed the pad-forming according to the parameters that were established in the initial tests. Those parameters did not yield the desired results on the reference part, therefore IAI decided to enlarge the radii.

Comparison between Magnesium and Aluminium in the pad-forming process, economic and ecologic aspects were done.

Results and Discussion

The part that was chosen by the consortium was the 'Inboard Flap – Leading Edge Rib' (Figure 27) of the business jet G-200. The selected Magnesium alloys which were received from MEL were milled and prepared in accordance to the flat pattern drawing (Figures 28-29).

Figure 27: Suggested Aluminium part to be replaced by Magnesium alloy

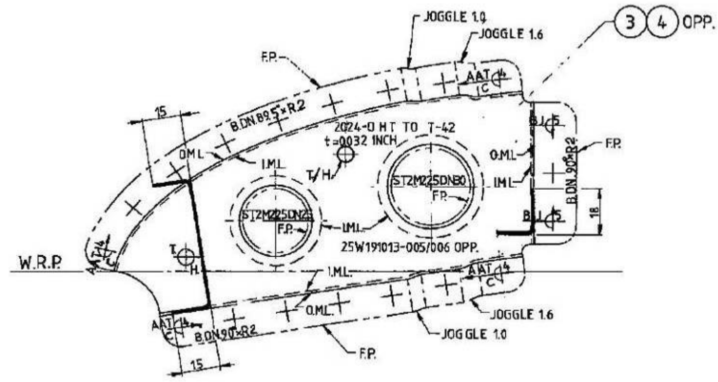



Figure 28: Flat pattern drawing of the chosen part – leading edge rib


Figure 29: Magnesium flat patterns sheet after milling ready to be pad-formed, (left) ZE10A-F; (right) AZ31B-H24

Chemical analysis was done on the two alloys and compared to ASTM B-90 (in the case of AZ31B-H24) and metal specification received by MEL (in the case of ZE10A-F). The chemical analysis was carried out twice from each sheet. Results are given in table 5 below.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| AZ31B-H24 (ASTM-B90) | | | | | | | | | | |
| Element | Al | Zn | Mn | Ca | Cu | Fe | Ni | Si | Other | Mg |
| Min. | 2.5 | 0.7 | 0.2 | --- | --- | --- | --- | --- | --- | --- |
| Max. | 3.5 | 1.3 | 1.0 | 0.04 | 0.05 | 0.005 | 0.005 | 0.05 | 0.3 | Bal. |
| Received | 3.14 | 1.08 | 0.43 | 0.001 | 0.005 | 0.01 | 0.002 | 0.002 | --- | Bal. |
| ZE10A-F (Magnesium Elektron – Material Specification) | | | | | | | | | | |
| Element | Zn | Cu | Fe | Ni | Zr | Re | Other | Mg | --- | --- |
| Min. | 1.0 | --- | --- | --- | 0.02 | 0.12 | --- | --- | | |
| Max. | 1.5 | 0.008 | 0.004 | 0.001 | 0.2 | 0.22 | 0.3 | Bal. | | |
| Received | 1.21 | 0.003 | 0.02 | 0.0025 | 0.027 | 0.2 | 0.05 | Bal. | | |

Table 5: Chemical analysis of AZ31B-H24 and ZE10-F received from MEL

Tensile tests were performed according to ASTM E8 for each alloy in two directions (longitudinal and transverse) at room temperature (RT) and after exposure to elevated temperature (Table 6).

| Alloy | Test conditions | Direction | UTS MPa (ksi) | TYS MPa (ksi) | Elongation % |
|---|---|---|---|---|---|
| AZ31B-H24 | RT | L | 290.7 (42.2) | 219.6 (31.9) | 13.8 |
| | | | 292.7 (42.8) | 216.8 (31.5) | 12.8 |
| | | T | 314.9 (45.7) | 259.5 (37.6) | 15.2 |
| | | | 312.1 (45.3) | 260.1 (37.7) | 14.5 |
| | RT after exposure to 300℃ & 10min | L | 258.0 (37.4) | 155.4 (22.5) | 17.6 |
| | | | 256.5 (37.2) | 152.2 (22.1) | 18.9 |
| | | T | 266.4 (38.6) | 181.3 (26.3) | 17.8 |
| | | | 264.4 (38.3) | 181.5 (26.3) | 17.4 |
| ZE10A-F | RT | L | 233.8 (33.9) | 164.8 (23.9) | 21.1 |
| | | | 236.4 (34.3) | 164.8 (23.9) | 21.3 |
| | RT after exposure to 300℃ & 10min | L | 204.7 (29.7) | 114.1 (16.5) | 18.3 |
| | | | 206.3 (29.9) | 116.4 (16.9) | 19.2 |
| | | T | 198.6 (28.8) | 95.8 (13.9) | 20.8 |
| | | | 195.0 (28.3) | 90.2 (13.1) | 21.6 |

Table 6: Tensile test results

Bending tests have been performed (at PALBAM) according to ASTM E290 for each alloy in two directions (longitudinal and transverse) for wide range of temperatures, radii and heating time (Figures 30-31).

The recommended procedure based on the results of over 60 trials is: pre-heat the alloy to 250℃ – 300℃, wait for at least 5 minutes and bend quickly before the temperature drops under 225℃.

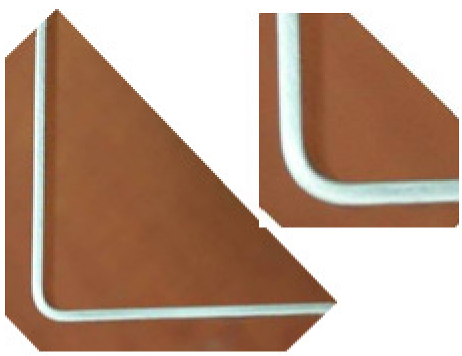


Figure 30: Successful bending to R2

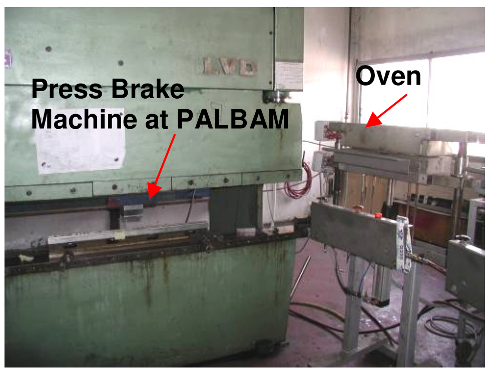



Figure 31: Press Brake machine for bending

Metallurgical examination of the bent area to look for cracks, crack initiations and/or inner structure modifications has been done. No significant cracks reviled.

Pad Forming

Preliminary pad-forming tests performed on test part (Figure 32) to estimate the parameters for the process. Consequently, the process parameters chosen as optimal for the pad-forming were heating up the tool without the sheet to 300°C for 10 minutes, placing the Magnesium sheet in the tool and heating for two more minutes.

Comparison between Aluminium part and Magnesium part is shown in Figure 33.

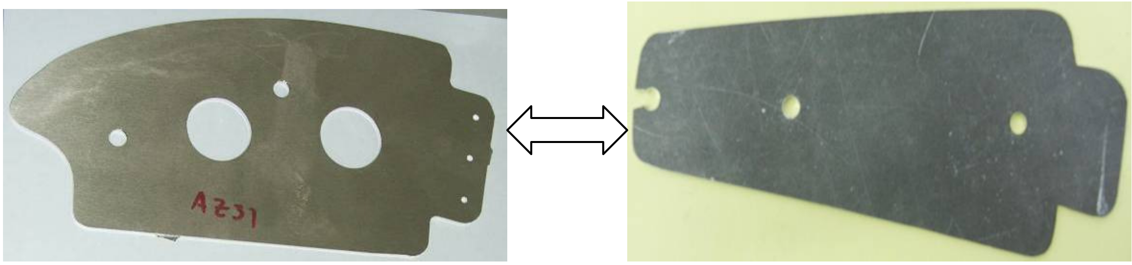



Figure 32: Test part (left), chosen for test runs of pad-forming and the chosen serial part (right)

Figure 33: Comparison between original Aluminium test part (left) to Magnesium part (right)

Forming of the chosen part with the test model parameters was unsuccessful (Figure 34), probably due to the double curvature nature of the part. After more tests we concluded that in order to overcome the cracks that were developed, bigger radii were required. Consequently, we placed on the tool a formed Aluminium part to enlarge the bending radii by the Aluminium thickness (Figure 35). The results obtained were divided: Successful bending of ZE10A-F (Figures 36-37) and unsuccessful bending of AZ31B-H24 (Figure 38).

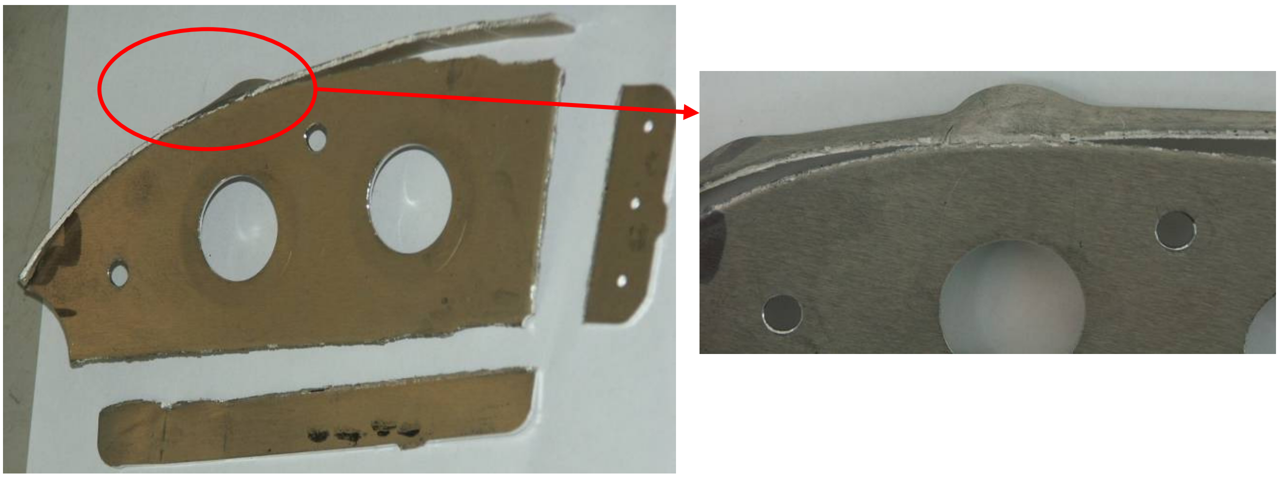


Figure 34: Unsuccessful pad-forming using the initial test parameters

Figure 35: ZE10A-F placed on pad-formed Aluminium sheet to enlarge bending radii

Figure 36: ZE10A-F after success pad-forming on Aluminium sheet (final radii of R3.5)

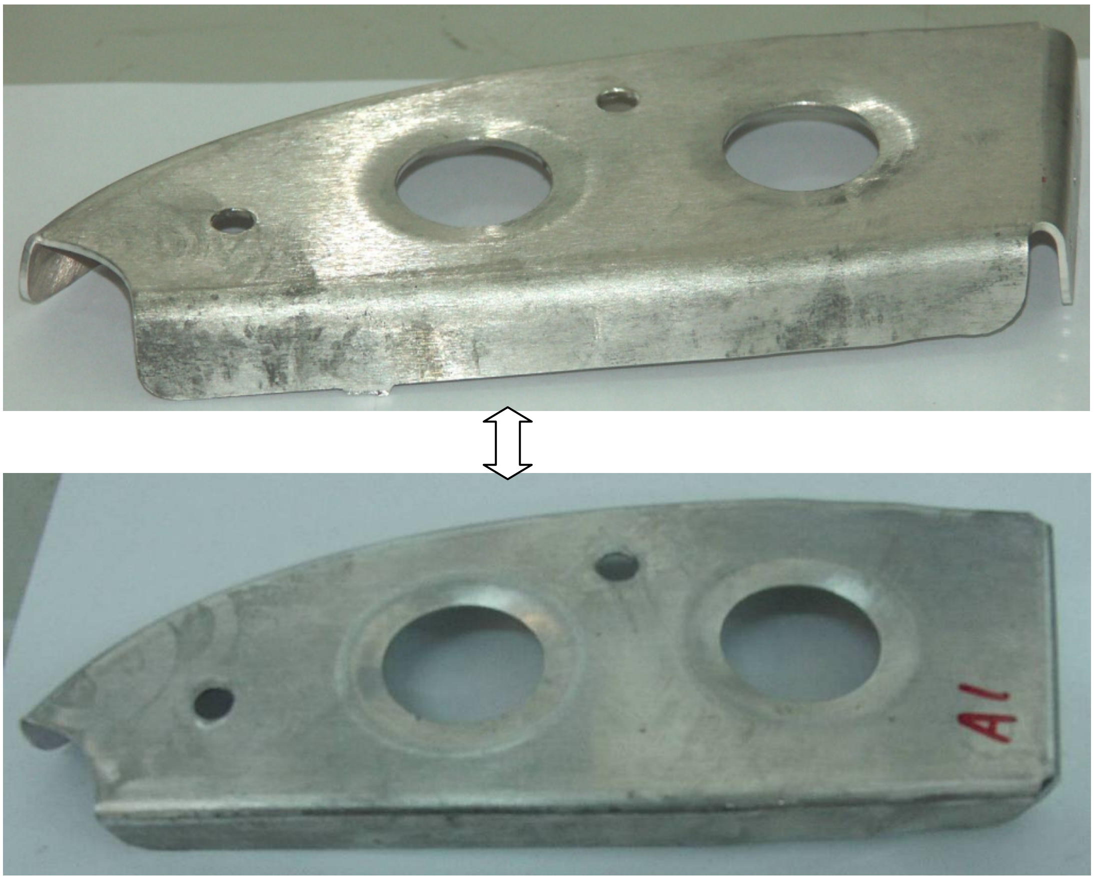



Figure 37: Comparison between success pad-forming of ZE10A-F (up) to original Al part (down)

Figure 38: Unsuccessful pad-forming of AZ31B-H24 with the enlarged radii

**Airbus Pad Forming Reference Part**

Work on Pad Forming of Magnesium Sheet Alloys AZ31 and ZE10

The objective of Airbus to jump in additionally into WP5 was to assess the suitability of Magnesium sheets by simply applying the production environment conditions for pad-forming of Aluminium parts (tools, temperature and other manufacturing process parameters) to selected Magnesium alloys. As a result a first indication of the feasibility of the room temperature process for Magnesium is envisaged, as the part (Figure 39) serves at Airbus as a reference for new alloys and with the achievement of some of the features an estimation of potential parts could be performed.

Materials Supply

Airbus received from MEL sheets of ZE10 and AZ31B in 2 mm thickness. The processing was done without lubricants.

Pad Forming

The flat blank and the detailed part are displayed in the following picture:

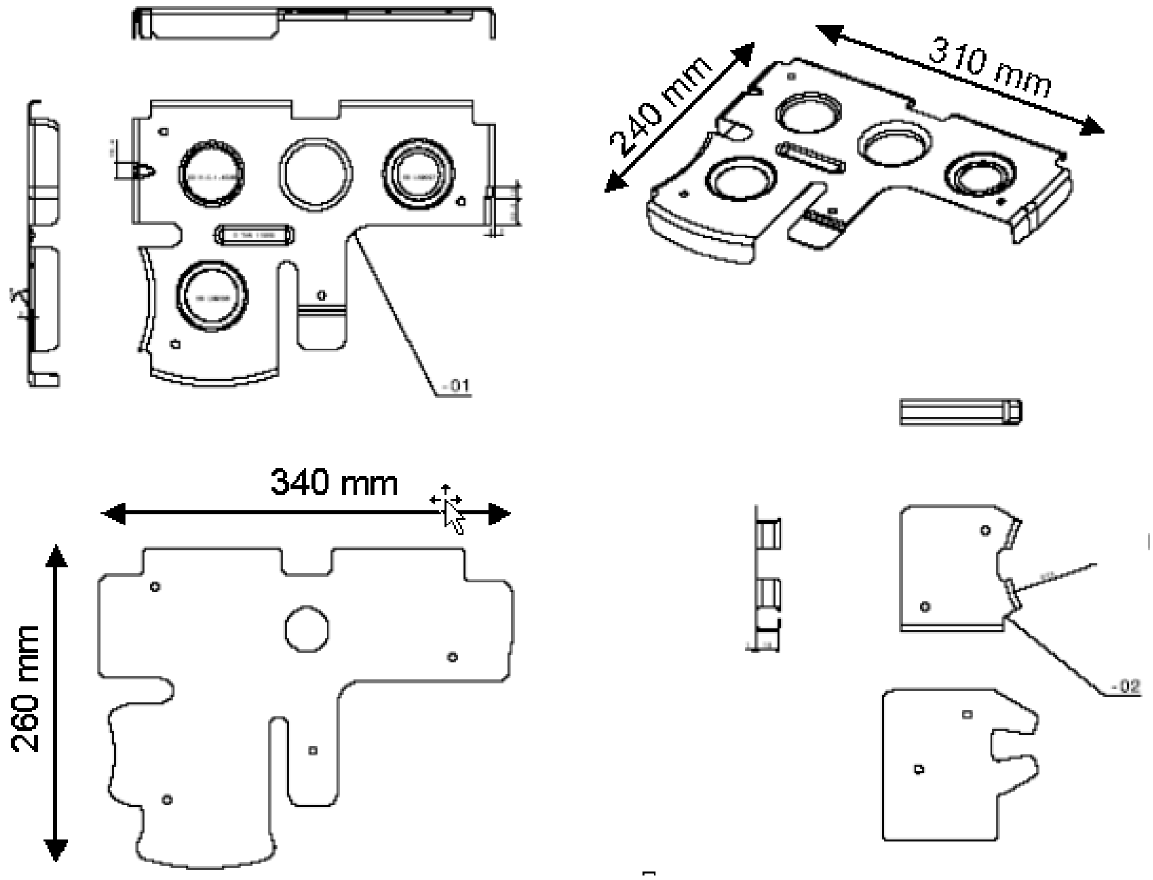



Figure 39: Airbus reference part (top) and blank (bottom)

In the first step the shape of the blanks were machined from both alloys at the original thickness and the Airbus process for Aluminium parts was applied without lubricant and with the wooden tool, see Figure 40.

Figure 40: Wooden tool for Airbus reference part for pad-forming of Al parts

Results on Pad Forming of Magnesium Sheet Alloys AZ31 and ZE10

AZ31:

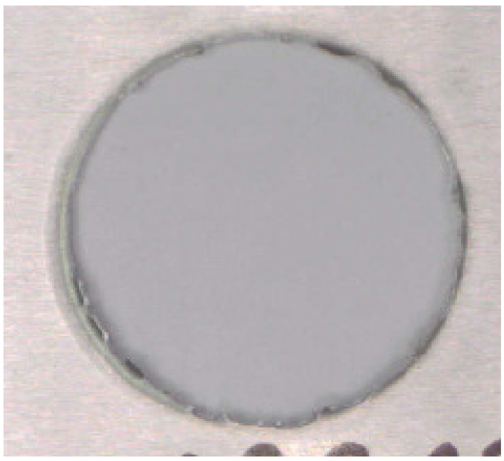
The results of the pad-forming of AZ31 sheets of 2 mm can be seen in the following pictures:


Figure 41: AZ31B (2 mm) part with broken flanges, crimps and cracks

Following pictures show details of deformed areas, revealing poor deformation behaviour of AZ31 under these conditions:

Upper flanges broken off

Lower flange broken off



Joggled areas reveal cracks and broken rim over full circumference of crimped hole

Figure 42: Flanges broken over full length and cracks in joggles and crimped areas.

Due to this results the pad-forming of AZ31 under the manufacturing conditions at Airbus for Aluminium parts are not feasible at all for Magnesium and will not be evaluated further.

ZE10:

The results of the pad-forming of ZE10 sheets of 2 mm thickness can be seen in the following pictures:

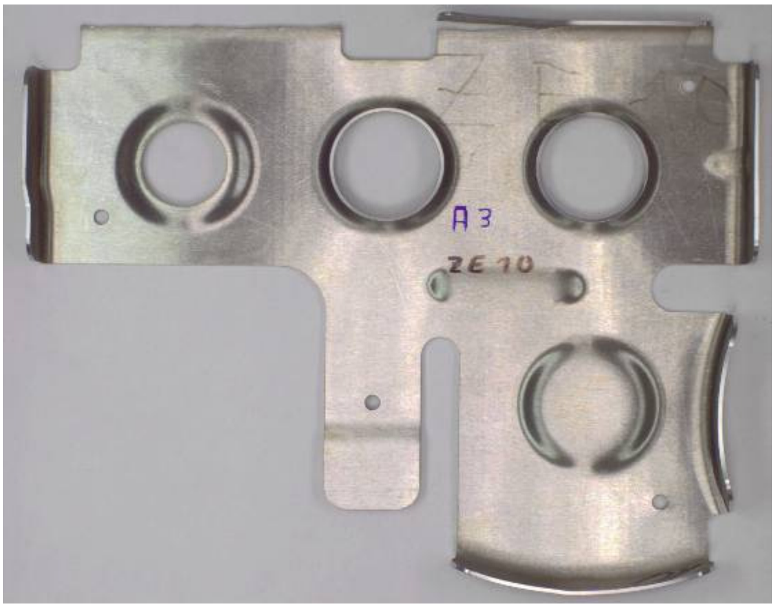
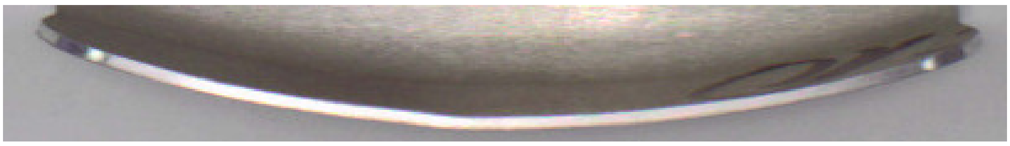



Figure 43: ZE10 (2 mm) part with broken flanges, crimps not cracked

Deformed areas are shown in the following pictures in higher magnification and display the deformation behaviour of ZE10 under these conditions:

Upper flange broken and partly adherent



Lower flange show only a small crack in the mid area on the convex side


Detailed view reveals no cracks in crimped areas

Figure 44: Details of deformed areas show rather good deformation behaviour compared to AZ31

Based on these results it was decided to make a further trial with reduced thickness. Hence the thickness of the blanks was reduced to 1.4 mm in the areas of the flanges. The results of the pad-forming of ZE10 sheets of 1.4 mm thickness can be seen in the following pictures:

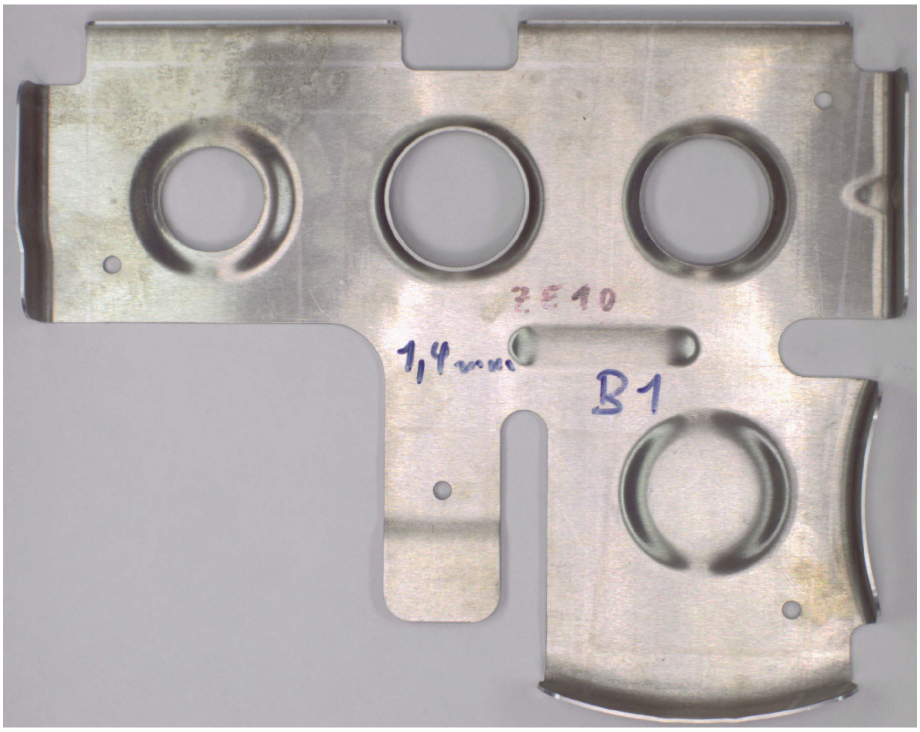



Figure 45: Flange area reduced to 1.4 mm – no cracking in the angles

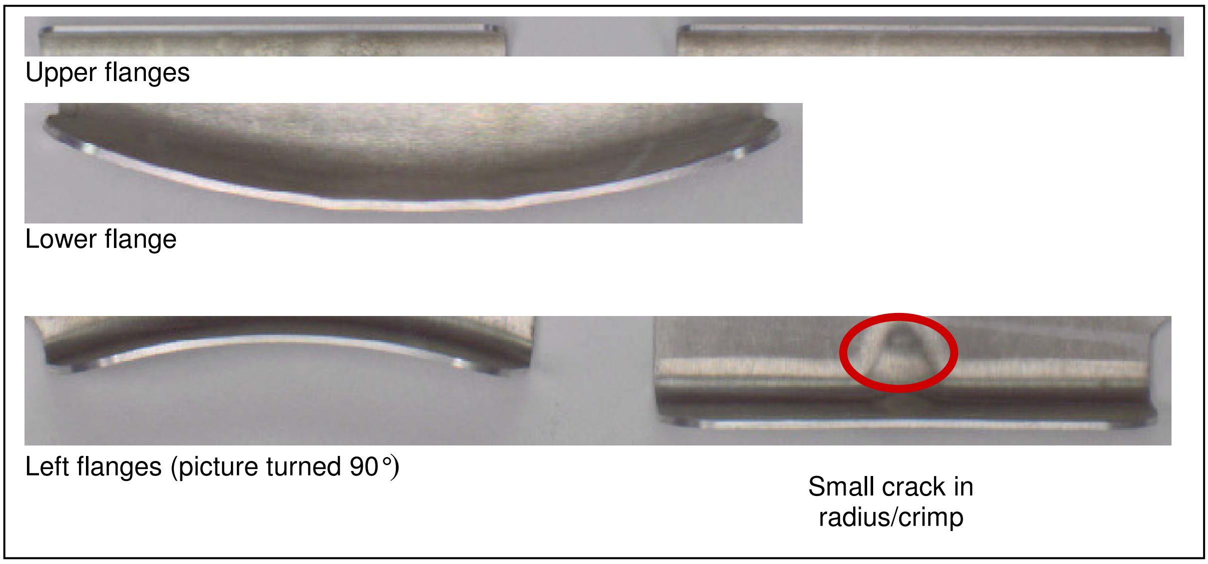



Figure 46: Detailed view on flanges of part with reduced thickness

The pad-forming process on blanks with reduced thickness in the areas to be bended (flanges) revealed much better deformation behaviour, resulting in no cracks in these areas, except for the inner side of the combined bent/crimped area indicated above. Consequently the ZE10 material is assessed to be suitable for the used pad-forming process on similar parts, although detailed further investigation/optimisation in regard to a real part will be needed, i.e. adjusted radius-thickness ratio.

**Roll Bending**

Work Performed

The Fuselage side panel of the IAI G-100 aircraft was selected to demonstrate the roll bending technology. Soon it had become evident that the part was not applicable, so Palbam-AMTS decided to simulate the roll bending process on cylindrical envelope as preparation to production of gas/fuel vessels or tubing accessories of aircraft interior systems. The objective was to perform a roll bending process at room temperature, which is limited due to the HCP crystalline structure of the magnesium.

In order to roll bend relatively small radii (~Ø200 mm) it was necessary to prepare combi-elastic rolling system. Therefore, base roll with envelope made of elastomer had been designed and produced. The designated roll was installed on the automatic rolling machine which can contain up to 400 mm sheet width (Figure 47).


Figure 47: Elastomeric roll

First production of cylindrical envelopes was carried out using AZ31B-O (full annealing) magnesium sheet 3.2 mm thickness (figure 48). The result: good geometric shape visually.

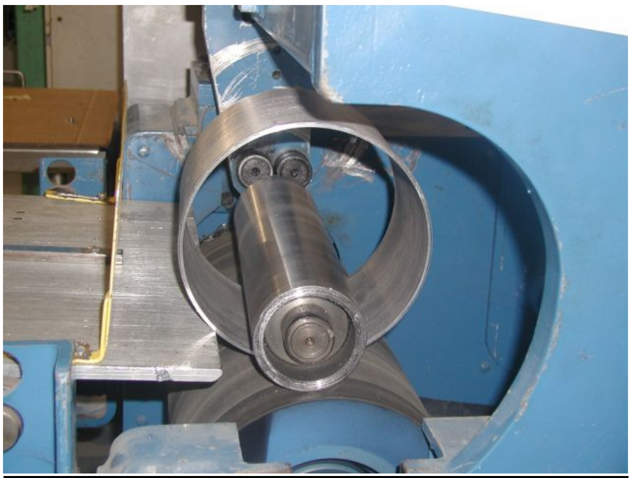


Figure 48: Rolled cylindrical envelope made from AZ31B-O 3.2mm sheet.

Palbam-AMTS performed roll-bending experiments on selected sheets which were received from MEL. These were ZE10 and AZ31B with a gauge thickness of 2 mm.

Results

Rectangular slices were cut in the initial rolling direction. The length was determined in accordance with the final desired rolling radii. These were rolled at ambient temperature using the rolling bench (Figure 49). The mandrels were chosen according to the final radius of curvature selection. For the experimental process it was decided to role to a diameter of 150 mm and 200 mm. These were achieved usually using 1 to 2 mandrels (with different sizes) in order to finalise the rolled sheets with a narrow as possible opening (sufficient for further welding). Samples for examination were not extracted from these since they were processed rapidly at room temperature, eliminating the possibility of severe strain hardening.

Figure 49: Cold rolling bench

Figure 50 show the roll bent 150 mm and 200 mm cylinders which demonstrate possible tubing accessories. It appeared that since the bending was done against elastomer made roll, no evidence for surface damages was observed during the trials.

Figure 50: Rolled ZE10 and AZ31B. Diameters 150 and 200 mm

## WP6

In WP6 one TD was manufactured by deep drawing and SPF technology: antenna support.

### Antenna Support

The antenna support is a 1.5 mm formed sheet part.

It is a Helicopter external part, presently made out of Aluminium alloy, through joining of several sheet segments together by TIG arc welding.

Requirement Provided by the End-User

| | Typical UTS(MPA) | YS(MPA) | El (%) |
|---|---|---|---|
| **AL 5086 –H112** | 269 | 131 | 14 |

Table 7: Required mechanical properties

External part, corrosion resistance criterion: 2000 hours SST.

The end user provided the drawings and PALABM-AMTS created the 3D model (Figures 51-52).

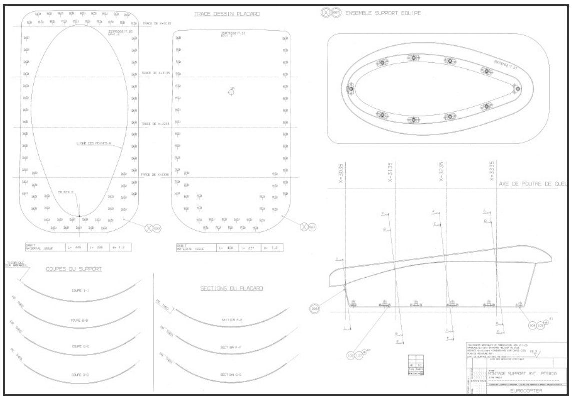


Figure 51: End-user drawing montage

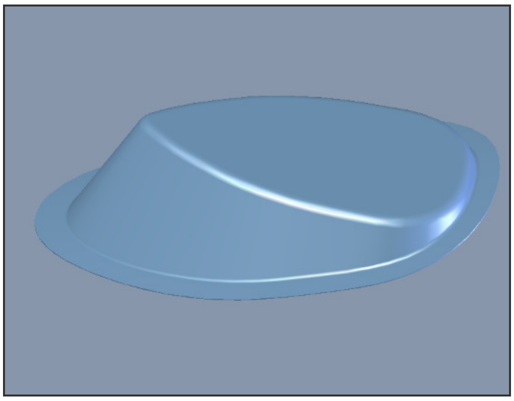


Figure 52: AMTS 3D Solid Model
Part dimensions: 610 x 365 x 170mm.
Skin thickness ~1.5mm.

The initially suggested manufacturing process was a single forming step through conventional deep drawing.

Numeric simulation, of the deformation degree caused by deep drawing process (Figure 53) showed difficulties in achieving the required geometry by a single step.

Double stage process, which contains severe plastic deformation in addition to the conventional drawing, found to be suitable in order to produce the antenna support out of just one sheet segment.

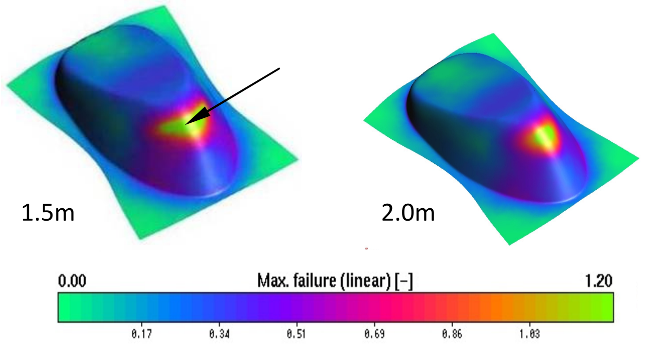



Figure 53: FE simulation which predicts failure (marked arrow) in case of a single step conventional.

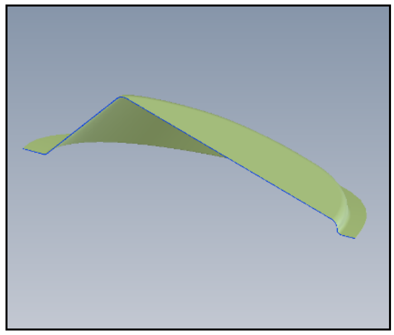


Figure 54: 3D solid section of final with shape

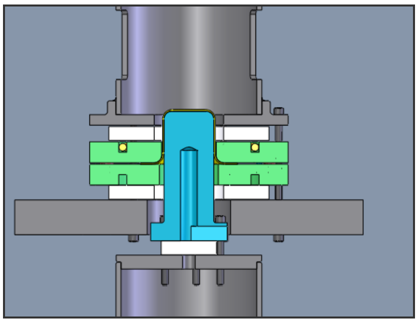


Figure 55: Stage 1 – deep drawing

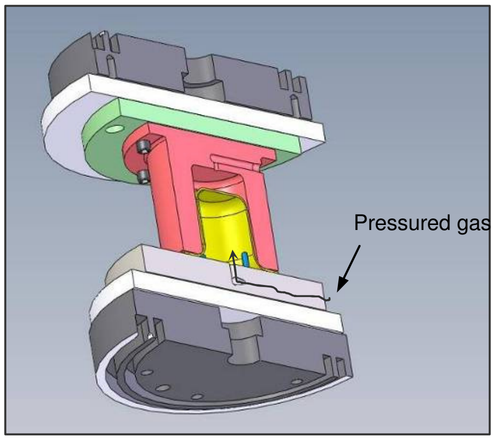



Figure 56: Stage 2 – SPF

Design of a two stage process has been started with cup tests in order to evaluate the influence of the initial drawing phase on the microstructure and hardening of the deformed material (Figures 55 and 56).

Material

The conclusions of the cap test lead to the selection of AZ31B Magnesium sheet as the raw material for the downstream process.

Magnesium Alloy AZ31B in the form of rolled sheet found to be suitable for both conventional drawing (high strain rates) and superplastic forming (creep mechanism, low strain rate). MEL supplied the material in H24 condition.

Deep drawn shape is shown in Figure 57. The non-flat surface (double curvature surface) is marked in indigo line and arrows.

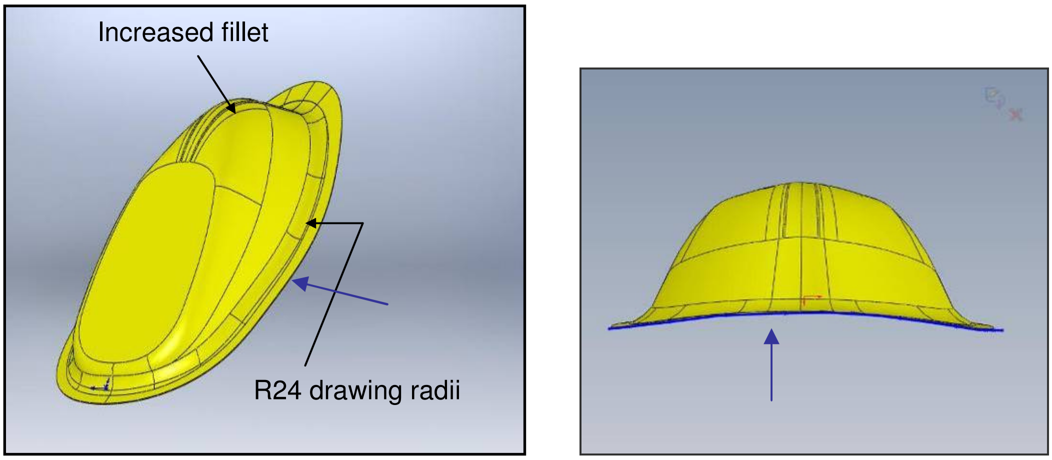



Figure 57: Deep drawn shape

The drawing stage has been evaluated by FE simulation which predicted the feasibility of the process, see Figure 58.

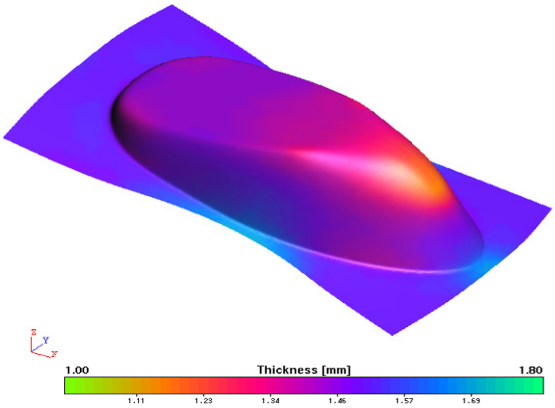



Figure 58: Deep drawing simulation – thickness report

<u>Tooling Systems for Two-Stage Process</u>

Two different tooling systems, for each one of the forming stages, were designed and produced at PALBAM workshop.

As it shows in Figure 58, the deep drawing blank holder should have non-flat surface, in order to create the initial shape of the part. Therefore the tooling preparation cost, in such a case, is a bit more massive.

The dies for both forming operations were produced out of SAE 4340 steel blocks.

Figure 59: Deep drawing male die machining

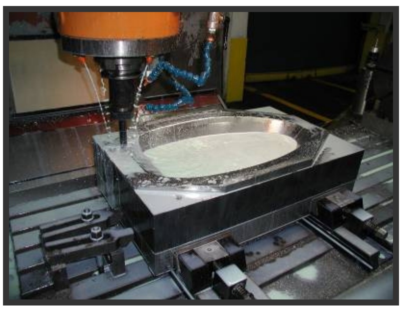


Figure 60: SPF female die machining

The procedure should go step by step, which means, first the deep drawing being accomplished and then the drawn part is installed within the SPF tool, for the final forming.

The performance of the processes contained a few cycles, which intended to optimize the forming parameters:

- Temperatures, press force, schedules and fluid pressure.
- The experiments were done at the range of temperatures, between 180℃ to 500℃.
- The deep drawing process took about 6 minutes each blank, including lubrication and pre-heating.
- The complementary SPF process time frame has been examined within two periods: 30 minutes and 90 minutes.

Two-Stage Process Results

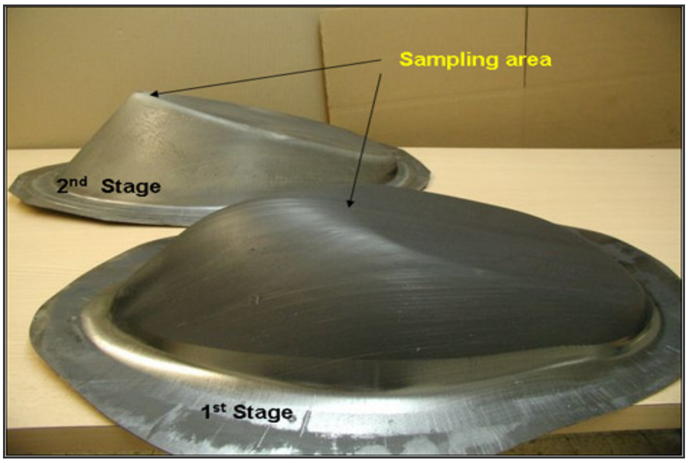



Figure 61: Two-stage process results

During the processes cycles it was necessary to examine:

- Thinning: reduction in sheet thickness as a result of stretch forming, see Figure 62
- Microstructure: dynamic recrystallization, grain growth, directionality of grains
- Mechanical properties

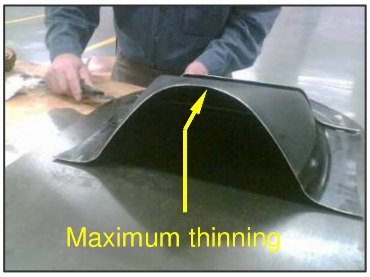



Figure 62: Two-stage process results

The tensile properties of the part in different stages of the production process are given in Table 8.

| Sample | PALBAM designation | Test location | Tensile properties | | |
|---|---|---|---|---|---|
| | | | YS, MPa | UTS, MPa | Elongation, % |
| Initial sheet | - | transverse | 225 | 295 | 13.0 |
| Initial sheet | - | longitudinal | 248 | 330 | 13.0 |
| 2 min heated sheet/N-D | - | transverse | 168 | 273 | 23.0 |
| 2 min heated sheet/N-D | - | longitudinal | 190 | 270 | 15.5 |
| Deep drawing | C8 | 1 - bottom | 170 | 274 | 20.0 |
| Deep drawing | C8 | 2 - bottom | 164 | 265 | 18.0 |
| Deep drawing | C8 | 3 - wall | 162 | 276 | 21.1 |
| DD + 30minSPF | C1 | 1 - bottom | 166 | 257 | 16.2 |
| DD + 30minSPF | C1 | 2 - bottom | 140 | 242 | 21.0 |
| DD + 30minSPF | C1 | 3 - wall | 151 | 240 | 18.7 |
| DD + 90min SPF | C4 | 1 - bottom | 167 | 256 | 18.7 |
| DD + 90min SPF | C4 | 2 - bottom | 149 | 255 | 18.0 |
| DD + 90min SPF | C4 | 3 - wall | 161 | 269 | 18.7 |
| ASTM B90/B | N/A | sheet temper “H24” | 200 min | 269 max | 6 min |
| Min Value | | sheet temper “O” | 100 | 210 | 12 |

Table 8: Tensile properties

## WP7

In WP7 one TD was manufactured by deep drawing and SPF technology: integral welded fuselage panel with stiffeners.

### Integral Welded Fuselage Panel with Stiffeners

Description of Work Performed

The objective of WP7 was to manufacture a selected aeronautic application by a creep forming process, achieving a set of selected requirements and properties. EADS CRC was responsible for the tasks below:

Design and Production of Tools and Dies

EADS CRC should do first the determination of optimum forming parameters of several sheets and profiles, as well as in welded areas. EADS CRC should also carry out accompanying simulations of the creep forming process. The chosen design and process parameters should follow the simulation results. The WPL should organise a design review to assess the economic feasibility to proceed with the production.

Creep Forming Process development

The stiffened structure creep forming and assembly should be carried out by EADS CRC (Figure 63). The objective was to weld the flat stingers on the flat skin by laser beam welding (LBW). Friction stir welding (FSW) may be used to join several smaller panels to larger ones. As a second step the single or double curvature should be realised with the integral stiffened panel by creep forming with suitable parameters. The selected component was a generic component representing a typical stiffened aircraft fuselage panel with a double curvature.

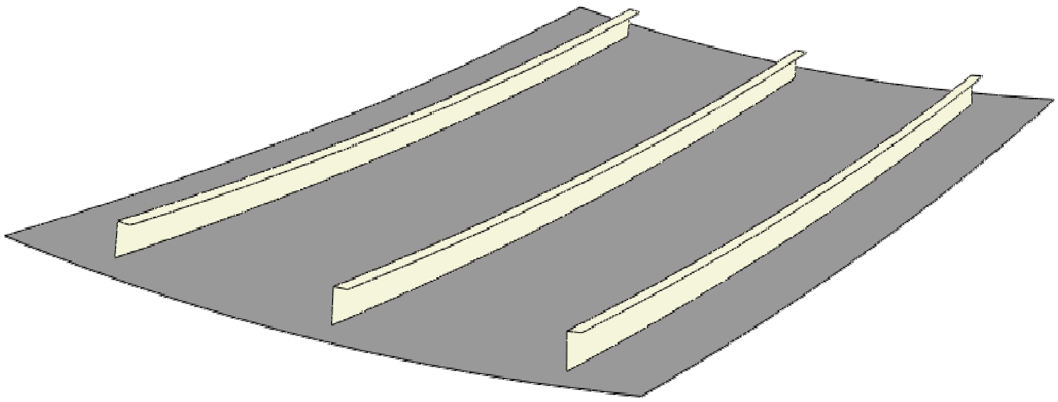


Figure 63: Drawing of stiffened panel configuration

Results

Material:

Since a welding process was considered here, the suitable alloys could be AZ31B as well as AZ80A or AZ61. ZK10 and ZK30 were recommended especially for creep forming but had to be investigated concerning weldability first.

MEL supplied AZ31B and ZK10 sheets in the thickness of 2 mm. Alubin provided the extruded L-shaped profiles that were welded on the flat panel.

Design and production of tools and dies:

For creep forming, the equipment that was used is rather simple. It was performed just with a single die, Figure 64 (drawings of component and tool are shown in Figure 80), heating equipment and an agent to form the material (i.e. vacuum). The tool had the machined outer contour of the panel (Figure 63) and could be connected to a vacuum pump to hold and deform the sheet by use of vacuum (Figure 65). Accompanying simulation of the creep forming process for magnesium was carried out by EADS CRC, together with a partner. The design of the shape of the die and the setting of the process parameters followed the results obtained by computer simulation. By the end of the design stage, the WPL conducted a design review to assess the economic justification of proceeding with the production of tools.

Figure 64: Creep forming die

Figure 65: Creep formed demonstrator panel fixed in the tool

Process Development:

First, the determination of optimum forming parameters for several kinds of sheets and profiles as well as in the welded area was done by EADS CRC on small samples. Tensile tests at different temperatures as well as stress relaxation tests were carried out and used for development and calibration of the material models used in the simulation. The simulation was used to predict the relaxation depending on temperature and time (Figures 66 and 67) and finally to predict the spring back after cooling and removing from the tool (Figures 68 and 69). All process steps were predicted according to the manufacturing in the labs of EADS CRC. The process parameters were selected to obtain a perfect geometry fit and as low spring back as possible.

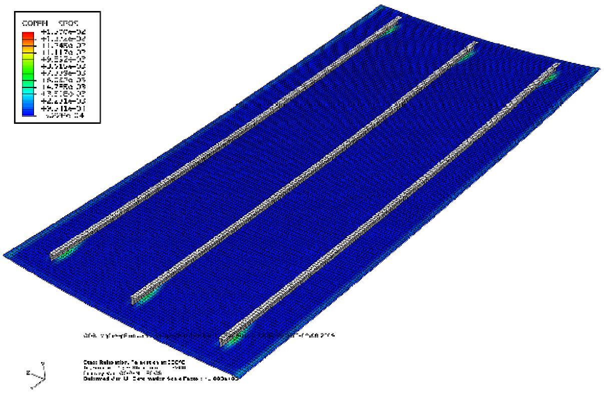


Figure 66: Tool clearance after relaxation, under temperature and vacuum

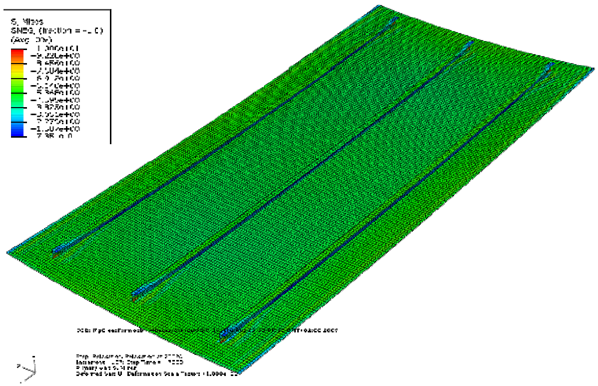


Figure 67: Stress distribution after relaxation, under temperature and vacuum

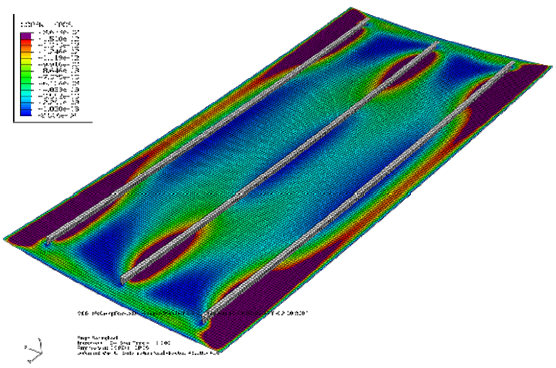


Figure 68: Tool clearance after spring back

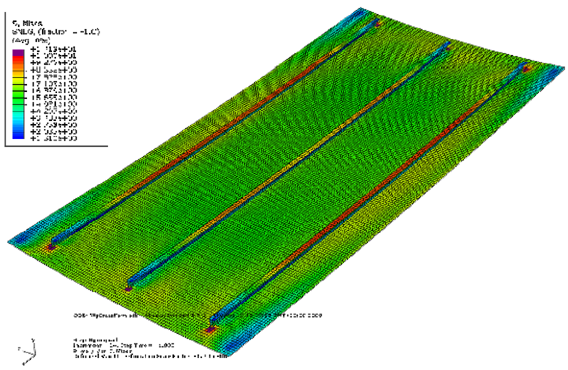


Figure 69: Stress distribution after spring back

Manufacturing of a demo part:

Contrary to series 6xxx aluminium alloys, for magnesium alloys, the practice was to weld the flat stringers on the flat skin by laser beam welding (LBW), see Figure 70. Friction stir welding (FSW) was used to join several smaller panels to larger ones, see Figure 71. As a second step the single or double curvature was realised with the integral stiffened panel obtained by creep forming. Creep forming enables large panels to be deformed into double curvatures by pressing them on to a jig with weights/vacuum and heat treating them in a furnace to induce creep (Figure 72). An advantage of the process is that there is no or very low spring back in the part following forming, allowing very precise tolerances to be achieved. Figure 65 shows the set up of a jig with a formed panel in place. It was decided to work without any lubrication due to the autoclave surrounding and the necessary vacuum.

The prototype part (Figure 73) was a demonstrator fuselage panel from Airbus, fabricated by EADS CRC. The panel was stiffened by a series of ZK30/AZ31 stringers welded to the ZK10/AZ31 sheet using two Nd-Yag lasers from both sides with a power output of 2.3 kW and 3.5 kW (Figure 74). The stringers were extruded by Alubin. EADS has developed laser beam welding and friction stir welding of magnesium alloys as part of the AEROMAG and MagForming programs. Furthermore FSW (Figure 75) was used to weld the skin sheets in longitudinal direction together to larger panels using a welding speed of about 1 m per min.

A large driver for the fabrication of the Airbus stiffened panel via laser beam welding (LBW) and creep forming was manufacturing cost saving. The original fabrication method in AA2024-T3, using stretch forming and riveting involves 22 manufacturing steps with a lot of intermediate heat treatments and riveting steps. The 2$^{nd}$ generation of the panel was fabricated from AA6013-T6 using stretch forming and LBW with 16 steps. The potential production route for magnesium alloys only requires 9 steps (i.e. contour milling - inside milling - cutting of stringers - edge process for stringers - stringer fixing – LBW - placement in forming tool - creep forming - surface protection) to complete the panel.

Figure 70: LBW of flat panel before creep forming

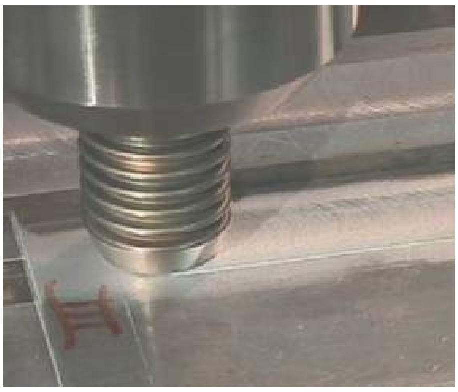


Figure 71: FSW of flat panel before creep forming

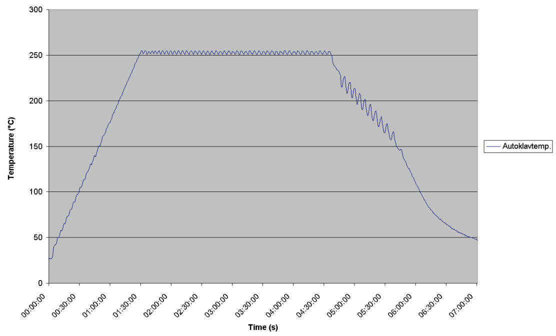



Figure 72: Temperature profile during creep forming

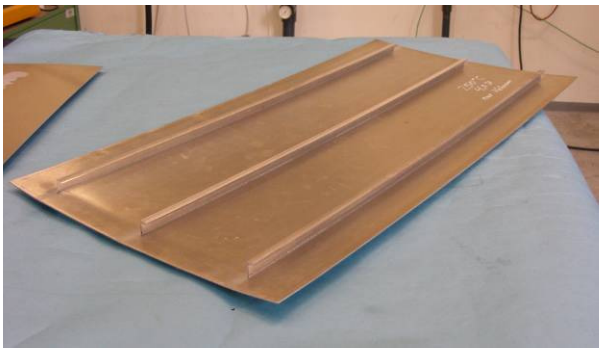


Figure 73: Fotograph of creep formed panel

| | Tacking | Welding |
|---|---|---|
| Laser power | 0,5 kW | 0,9 kW |
| Speed | 4m/min | 4m/min |
| Ray angle | 22° | 22° |
| Focus distance | 0,4 mm | 0,4 mm |

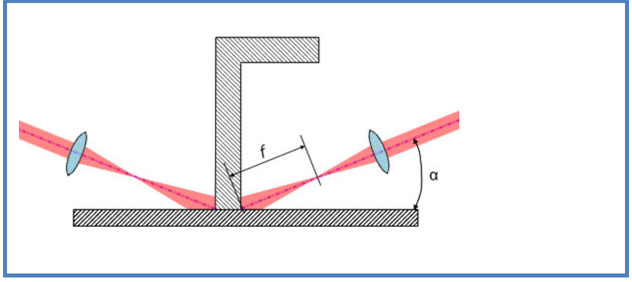



Figure 74: LBW set-up and parameters

**FSW tool**

Conical threaded pin with 3 flanks and 3.5 mm pin diameter; 10 mm shoulder, Tool turning counterclockwise; Tool angle 2°

**Welding parameters**

Rotational speed = 1000 rpm

Welding speed = 900 mm/min; Force = 8,5 kN

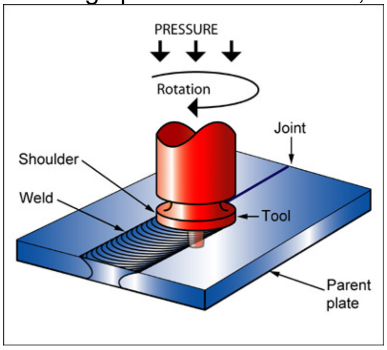



Figure 75: FSW set-up and parameters

Properties of components:

The formed parts have been tested in two different ways. One aimed at verifying the dimensions of the panel and the goal of the second was to verify the mechanical behaviour of the material after the forming process. The panels tested after forming were made of ZK10 alloy for the sheet and ZK30 for the stringers. AZ31 was used for a second batch of creep formed panels.

Mechanical properties control:

This step aimed at characterizing the material after the forming step to control if the process did not alter the material properties. The test compared an unformed panel (P7) with two creep formed panels (P9 and P10). The parameter studied was the different creep forming time. The specimens were only taken in the longitudinal direction and tested at room temperature. Figure 76 shows that there are no differences between the panels and the parent sheet material. Therefore, the creep forming process can be considered as not modifying the mechanical properties of the material for the investigated alloys.

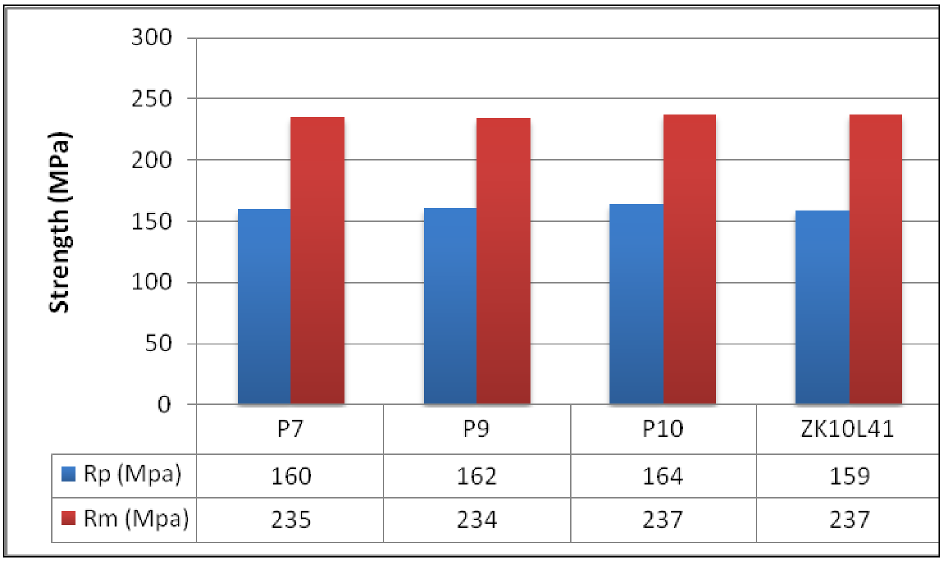
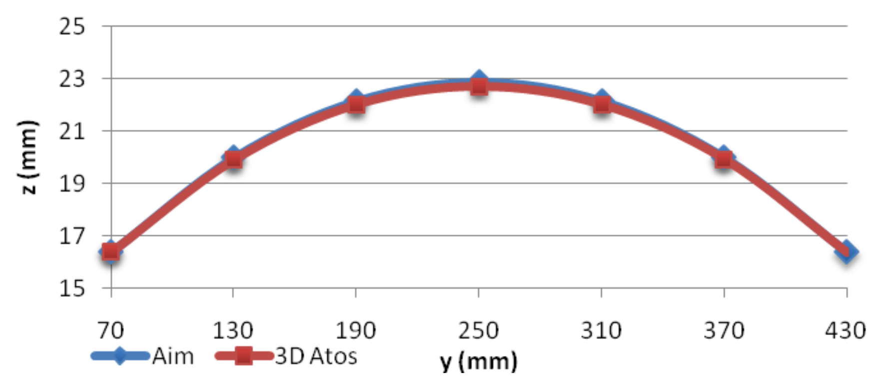



Figure 76: Static strength values of parent material and different panels

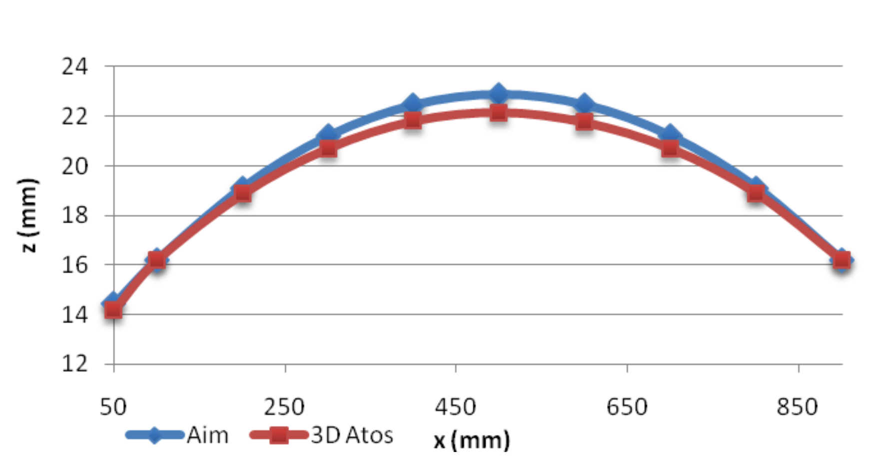
Dimensional Control:

This step goal was to control if the creep forming process was applicable for the selected alloys and the chosen parameters. The 3D measurements have been done using Atos by GOM. Atos is a 3D digitizer, which uses the principle of optical triangulation by observing projected fringe patterns with two cameras. This system is commonly used for quality control and reverse engineering. The measurement result was a mesh of about 30,000 points for each panel. For a better understanding of the results, the points have been taken on curves oriented in the two directions (longitudinal and circumferential) of the panels. The points taken out of the mesh have been compared to the same points on the 3D model of the die used for the creep forming. The measurements are presented along three curves on each panel for each direction. The aimed curvature in the longitudinal direction is 12,000 mm and the curvature in the circumferential direction is expected to be 2500 mm. In Figures 77 and 78 the dimensional accuracy is shown in two directions for one panel as an example.




| | | Atos - Aim |
|---|---|---|
| 70 | 16,37 | 0,00 |
| 130 | 19,90 | -0,08 |
| 190 | 22,00 | -0,14 |
| 250 | 22,69 | -0,17 |
| 310 | 22,00 | -0,14 |
| 370 | 19,92 | -0,06 |
| 430 | 16,37 | 0,00 |

Figure 77: Panel 10 extracted curve at position x=500mm




| | | Atos - Aim |
|---|---|---|
| 50 | 14,17 | -0,25 |
| 100 | 16,19 | 0,00 |
| 200 | 18,87 | -0,24 |
| 300 | 20,71 | -0,48 |
| 400 | 21,81 | -0,63 |
| 500 | 22,16 | -0,70 |
| 600 | 21,75 | -0,69 |
| 700 | 20,70 | -0,49 |
| 800 | 18,90 | -0,21 |
| 900 | 16,19 | 0,00 |

Figure 78: Panel 10 extracted curve at position y=250mm

Figure 79: Creep formed panel made from AZ31 sheet and AZ31 stringers joined by LBW; Longitudinal joints realized by FSW.

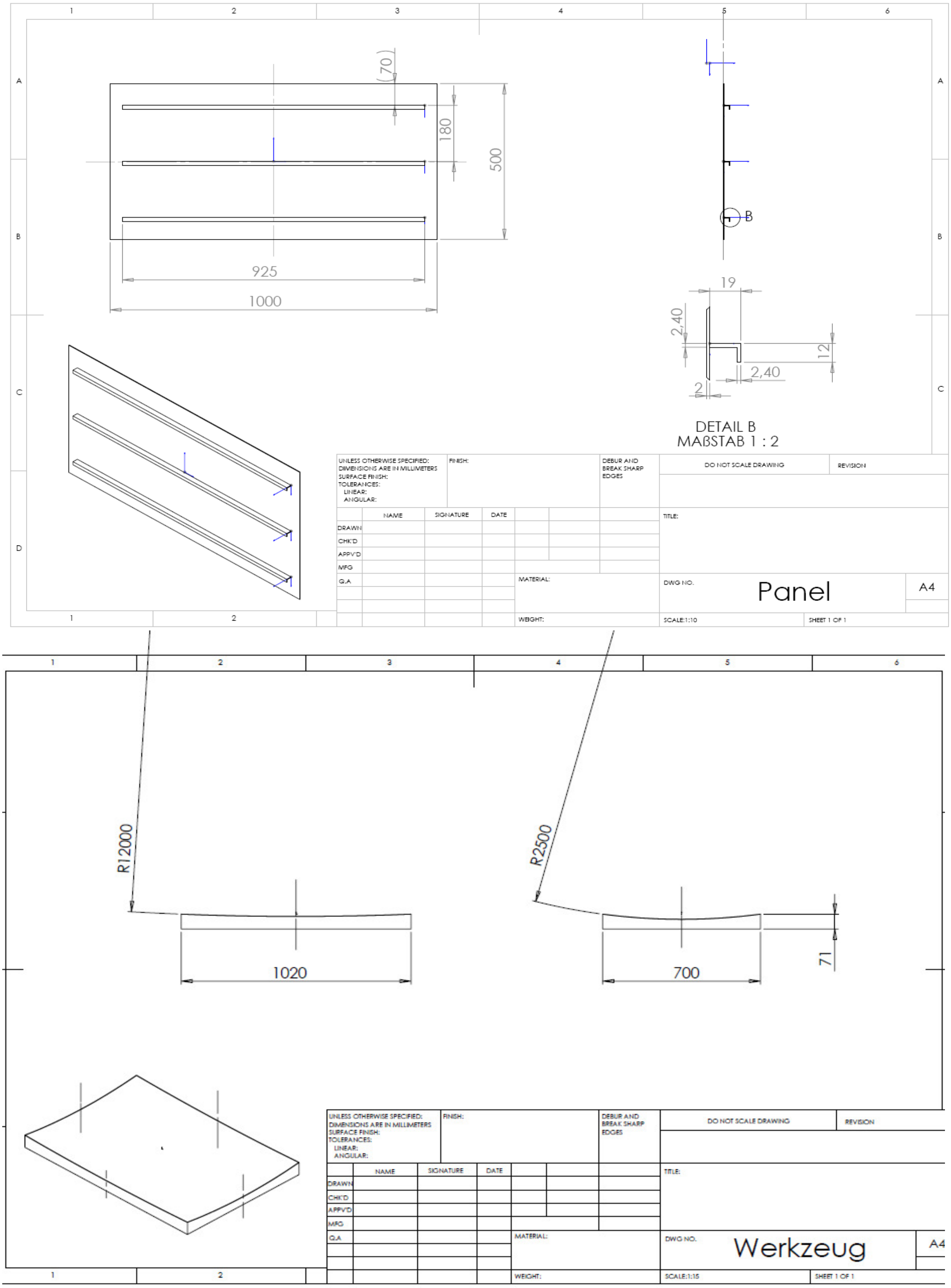



Figure 80: Panel (top) and tool (bottom) drawings

## WP8

CUNI, acting as the metallurgical laboratory of MagForming project, investigated the semi-finished material supplied to the different workpackages by MEL and Alubin in order to understand the material prior to the forming processes and to find special parameters which facilitate simulation and production processes.

Some of the issues investigated were: flow curve, yield and ultimate stress, thermal analysis, critical conditions for superplastic forming, optimization of thermal processing and testing of raw material after optimized thermal treatment, SEM micrographs of fracture surfaces, analysis of phases, observation of microstructure, analysis of chemical composition, identification of processing temperature. This was done mainly for the forging, SPF and creep forming processes.

In the third period, mainly the finished technology demonstrators were tested. The description of work connected to respective WPs follows:

In WP3: Optimization of pre-process thermal treatment of the raw material for forging. Tests of forged window frame: mechanical properties (strength, ductility, isotropy, homogeneity), microstructure by light microscopy and SEM.

In WP4: Further optimization of process parameters by determination of critical conditions for superplastic forming in sheet material.

In WP5 and WP6: Mechanical tests of samples from formed demonstrators, documentation of microstructure.

In WP7: Mechanical tests of samples from formed demonstrators, documentation of microstructure and comparison of the properties with the material presently used.

The outcomes of WP8 are given in each workpackage results.

## *Discussion and Conclusions*

## WP3

Window Frame

Feasibility to forge a part like Window Frame from Magnesium alloy has been confirmed which fulfils the main objective of MagForming project.

Forging process parameters have been established.

Cost comparison showed that the production cost of making the part from Magnesium alloy is $15 vs. $55 using the current process and current material (7175 alloy), although obtaining the required properties for the part in Magnesium alloys will be problematic (Tables 9 and 10).

| **Operation** | **Airbus** | **SMW-E** |
|---|---|---|
| 0. Initial material | rolled plate, 7175 alloy | Mg ingots, master alloy |
| 1. Producing perform for subsequent forging and equipment involved | punching in a 630 ton press | low-pressure casting,<br>casting machine |
| 2. Preparing perform metal structure for forging | ---- | homogenization,<br>chamber oven |
| 3. Forging<br>3.1 Heating<br>3.2 Forging<br>3.3 Flash cutting | chamber oven<br>2000 ton hydraulic press<br>630 ton press | 5000 ton hydraulic press |
| 4. Heat treatment<br>4.1 Hardening<br>4.2 Ageing | chamber oven<br>chamber oven | ----<br>chamber oven |

Table 9: Window frame process comparison

| **#** | **Cost item, $/each** | **Airbus** | **SMW-E** |
|---|---|---|---|
| 1 | Initial material | 60.0 | 10.0 |
| 2 | Returned material | -13.5 | - |
| 3 | Equipment amortization | 0.70 | 1.05 |
| 4 | Electric power | 0.22 | 0.25 |
| 5 | Labour | 3.0 | 1.6 |
| 6 | Overhead expenses | 4.5 | 3.2 |
| | TOTAL | 54.92 | 16.1 |

Table 10: Window frame cost comparison

Compressor Wheel

Within WP3 IFUM developed a forging process for an aeronautical application. The whole process chain from material characterization to the production of the part was performed successfully. The compressor wheel meets the required high mechanical properties.

Door Stop Fitting

Within WP3 IFUM developed a forging process for an aeronautical application. The whole process chain from material characterization to the production of the part was performed successfully. The forging of the door stop fitting shows the feasibility of a forging process of a complex shaped geometry.

## WP4

Service Door Inner Panel

Both AZ31 and ZK10 sheet achieved perfectly the final geometries.

AZ31B alloy showed better superplastic behaviour versus both 6061 and 5052 Aluminium alloys.

Table 11 summarizes the comparison of several parameters between Magnesium and Aluminium alloys.

| Material | UTS | Yp | Elon. % | Feedstock cost (US$) | Process duration (min.) | Energy (% from total) | Finishing cost (US$) for 2000 SSH |
|---|---|---|---|---|---|---|---|
| **AL 5083-O** | 280 | 145 | 20 | 42 | 120 | 90 | 75-90 |
| **AL 6061-T451** | 241 | 145 | 22 | 30 | 140 | 100 | 75-90 |
| **Mg AZ31B-O** | 260 | 175 | 25 | 80 | 90 | 60 | 75-90 |

Table 11: Comparison of Magnesium vs. Aluminium

Compressor Scroll

Basically, one can define that during the SPF process the reduction in strength properties is acceptable.

Microstructure examination showed us that in spite of the significant grain growth (up to 50µm) there are some evidences for a dislocation sliding which explains the improvement in strength.

In general, the microstructure is quite typical for warm plastic deformation which proves that no exceeding in forming schedule has been allowed.

The SPF process, which was suggested for the production of compressor scroll, is feasible with Magnesium Alloy AZ31B.

Furthermore:

- The alternative forming process (which available nowadays) is done through two drawing steps and requires two separate sets of tooling and dies. Thus, the suggested SPF procedure seems to be more effective.
- The alternative forming process is done in stainless steel with the same sheet dimensions. Therefore, the weight reduction, by using Magnesium material system, is quite significant.
- Same SPF procedure can be also applied by using Aluminium alloy but without any advantage (versus Magnesium use).

The influence of the SPF process, which its basic parameters were mentioned above, on fine microstructure as well as on the properties of the final product, is acceptable.

Still should be investigated within the frame of this topic:

- The option to operate the same process with Magnesium alloy WE43 (better creep properties)
- Fine and effective joining technique.

## WP5

G-150 Leading edge Rib

A review of the pad-forming process according to IAI's route-card revealed several changes between Magnesium and Aluminium.

The ecological aspects of all process stages gathered in Table 12. Ecological calculation was expressed in energy terms of MJ (Mega Joule). The calculations based on the power requirements of each stage.

There are three major differences between the materials:

1. Magnesium requires prior heating but it includes the power of the pressing machine.
2. The energy of the coating is higher due to the specific technology used.
3. Magnesium does not require heat treatment which lowers the number of stages, the duration of the product preparation time and the energy.

The bottom line is that Magnesium requires fewer stages for manufacture and less energy.

| Aluminium | | | Magnesium | | |
|---|---|---|---|---|---|
| Stage | | Energy [MJ] | Stage | | Energy [MJ] |
| 1 | Milling and Drilling | 2.25 | 1 | Milling and Drilling | 2.25 |
| 2 | Removing Leftovers | 0 | 2 | Removing Leftovers | 0 |
| 3 | RT Pressing | 432 | 3 | Hot Pressing | 432 |
| 4 | Cleaning before H.T | 0 | 4 | Flattening | 0 |
| 5 | Solution H.T. to "W" | 26 | 5 | Coating | 28 |
| 6 | Flattening | 0 | 6 | Painting | 0 |
| 7 | H.T. to T42 | 0 | --- | | |
| 8 | H.T. review | 0 | | | |
| 9 | Coating | 8 | | | |
| 10 | Painting | 0 | | | |
| Total stages: 10 | | ~470 | Total stages: 6 | | ~460 |

Table 12: Energy comparison between Magnesium and Aluminium

One of the paramount considerations in any project is the cost issue. A simple cost evaluation is summarized in Table 13. The economic aspect should not be compared only by the price per pound, or by the price per volume. There is a density difference of 36% between Aluminium and Magnesium which when viewed per volume needed per part, reduces the price difference of Aluminium to Magnesium, from between 55% - 60% to 30% - 35%.

| | Aluminium | Magnesium | | Aluminium to Magnesium ratio | |
|---|---|---|---|---|---|
| | 2024 | AZ31B-H24 | ZE10A-F | $^{Al}/_{AZ31B\text{-}H24}$ | $^{Al}/_{ZE10A\text{-}F}$ |
| ρ [$^{gr}/_{cm}$3] | 2.74 | 1.78 | 1.78 | 1.54 | 1.54 |
| Price [$^{\$}/_{lb}$] | 6 | 13.26 | 14.69 | 0.45 | 0.40 |
| Price [$^{cent}/_{cm}$3] | 3.6 | 5.1 | 5.7 | 0.70 | 0.63 |

Table 13: Economic comparison between Magnesium and Aluminium

A more in depth approach to the calculations needs to be done for each part, if the material is switched all else equal, because we can see that 30% cost saving for raw material will result in an increase of 36% in weight. This leads to higher energy costs, from the basic process to the fuel consumption, aircraft performance and aircraft weight. In most civilian aircraft the cost of a kg saved is reckoned at about $1000.

The mechanical properties of IAI's chosen part (Aluminium 2024-T42) and in parallel the mechanical properties of the suggested Magnesium alloys (AZ31B-H24 and ZE10A-F) are compared in Table 14. The heating conditions of the pad-forming process for Magnesium alloys showed no significant change in the ultimate strength, a decrease of 27.6-34.4 MPa units for both Magnesium alloys, but the yield was more affected by the process dropping of 48.3-69 MPa units for both alloys this is to be expected when the yield strength is based on cold work. The elongation showed different behaviour for each alloy to the process, AZ31B-H24 became more ductile due to the heating exposure (to be expected as the cold work is relaxed); on the other hand, ZE10A-F lost some ductility.

There is a difference of 35% in the ultimate and yield strength for AZ31B-H24 and the Aluminium 2024 T42 alloy, and 50% in the ultimate and the yield strength for ZE10A-F and Aluminium 2024-T42 alloy. The difference in the properties is misleading as one should look at the specific strength and design accordingly based on part requirements. In such a case, if we are not limited by size, we see the AZ31 is equivalent to the Aluminium 2024. While this does not show an advantage for the Magnesium, other design requirements will give distinct advantages to one or the other.

| Property/Alloy | Aluminium6061-T62 | Aluminium 2024 – T42 | Magnesium AZ31B-H24 | | Magnesium ZE10A-F | |
|---|---|---|---|---|---|---|
| | | | Before heating | After heating | Before heating | After heating |
| UTS [MPa] | 289.5 | 393 | 289.5 | 255.1 | 234.4 | 206.8 |
| UTS/ ρ[gm/cc] | 15.6 | 20.8 | | 20.8 | | 16.9 |
| YS [MPa] | 241.3 | 234.4 | 220.6 | 151.6 | 165.5 | 117.2 |
| YS/ ρ[gm/cc] | 13.0 | 12.4 | | 12.4 | | 9.6 |
| Elongation [%] | 10 | 15 | 14 | 18 | 21 | 18 |

Table 14: Comparison of mechanical properties between Aluminium and Magnesium alloys

IAI achieved the goal of pad forming a representative Magnesium alloy part as an alternative to an existing Aluminium part, with radii and joggles. The Magnesium required fewer stages for manufacture and consumed less energy.

The only obstacle was the bending properties of Magnesium at room temperature, to reach similar geometry to the Aluminium part R=2 we had to pad-form at high temperature. At temperature that is above 225℃, the grains become finer and the structure becomes more ductile which enable the Magnesium to be bent to smaller radii. The lubricants did not help in this case.

Placing a formed Aluminium sheet part on the tool effectively enlarged the bend radius enabling to achieve better forming results, closer to room temperature. This means that we cannot exchange the alloys one for one if we work at room temperature. If we are required to work at room temperature larger bend radii must be used for Magnesium during the design stage or current drawings modified.

We succeeded forming the part with ZE10A-F. On the other hand the AZ31B-H24 requires more work to optimize forming parameters. We succeeded in the simplified sample, see Figure 38, but could not reproduce this success on the actual part with the joggles and double curvature. High temperature was not enough.

Airbus Pad Forming Reference Part

Comparison of pad-forming process on Magnesium in regard to Aluminium:

The comparison was done with the manufacturing pad-forming process used for thin Aluminium sheet (1 – 2 mm), i.e. using the wooden tools of the Airbus Reference part and applying the existing process parameters to Magnesium sheet alloys AZ31 and ZE10.

Parameters:

| | |
|---|---|
| Device: | ASEA Press |
| Pressure: | 700 bar |
| Temperature: | ambient temperature (25℃ +/- 5℃) |
| Forming: | rubber pad-forming, medium velocity, |
| Radii: | see Airbus Reference part (1.6 mm thick) for process verification |

| Material (thickness):<br>Features: | Al blank (1-2mm) | AZ31 (2 mm) | ZE10 (2 mm) | ZE10 (1.4 mm) |
|---|---|---|---|---|
| rectangular flange | OK | Failed | Failed | OK |
| curved flange | OK | Failed | Cracked | OK |
| curved flange & joggl | OK | Failed | Cracked | small crack |
| crimped rim | OK | Failed | OK | OK |
| longitudinal joggle | OK | Failed | OK | OK |

Table 15: Pad forming results

Cost Assessment

Consequently the reference pad-forming process established for Aluminium sheet parts is applicable for thin ZE10 material as well. Hence, forming of a real part from Magnesium alloy ZE10 seems feasible without cost penalties, provided the Magnesium properties met the requirements of the part in question.

For the material cost assessment the prices of Aluminium and Magnesium sheets in 2 mm thickness were taken from Airbus procurement (Aluminium) and MEL (Magnesium), status May 2009:

| Material (thickness):<br>Properties: | UNIT | Al2024 sheet ( 2 mm ) | AZ31 sheet ( 2 mm ) | ZE10 sheet ( 2 mm ) |
|---|---|---|---|---|
| UTS | [Mpa] | 450 | 270 | 250 |
| TYS | [Mpa] | 350 | 200 | 170 |
| Elongation | [%] | 16 | 7 | 14 |
| Density | [g/cm3] | 2.75 | 1.8 | 1.8 |
| Price per kg sheet [USD] | 1 ton /year<br>10 ton/year | 8 | 29.2<br>25.8 | 32.2<br>28.43 |
| Price per squaremeter sheet 2 mm [USD] * | 1 ton /year<br>10 ton/year | 43 | 105<br>93 | 116<br>102 |
| * 1 sqm of 2 mm sheet = 2000 cm3 | | 5.4 kg | 3.6 kg | 3.6 kg |

Table 16: Material properties and cost assessment

Depending on the amount procured per year especially the prices for the Magnesium alloys differ in certain ranges, see above. Hence, one square-meter of Magnesium sheet is between 2.2 (AZ31) to 2.7 (ZE10) times more expensive than Standard Al 2024 sheet.

Pad forming of the Airbus reference part at ambient temperature with the pad-forming process established for Aluminium sheet is feasible for thin Magnesium sheet material as well. This was shown with ZE10 (1.4 mm sheet), whereas thicker sheet of ZE10 and AZ31 material displayed a lot of failures. Further optimization/adaptation of tools concerning radii should be provided to account for the slightly different behaviour (spring back) and lower ductility of Magnesium. Hence, forming of a real part from Magnesium alloy ZE10 seems feasible without process cost penalties, provided the Magnesium properties met the requirements of the part in question.

Concerning material cost Magnesium sheet will be about 2.5 times more expensive per square-meter than standard Al 2024 sheet, but of course this is depending on the purchased amount of material, respectively the amount of sheet material produced in a certain quality.

Roll bending part

Palbam-AMTS contributed its bending facilities (Figure 31) to IAI for their bending tests prior to the pad forming process. The conclusion from those tests was that technologically it is possible to bend Magnesium sheets at room temperature to radii of 10T, i.e. if the sheet thickness is 2mm, the possible bending radius is 20mm.

## WP6

Antenna Support

In general, Mg AZ31B sheet responds excellent to deep drawing and SPF apart, as well as to the combination of the two processes. Furthermore:

- The structure is stabilized during the SPF. No significant grain growth after deep drawing. No significant difference in microstructure between several locations along the formed parts.
- The preheating schedule has its dramatic influence on the process stages properties.
- The gas forming process is probably going forward through grain growth and following grain refinement under relatively high deformation stresses. The deformation mechanism must be grain boundary sliding (which causes the structure refinement) but not just it. There is clear evidence for conventional dislocation sliding which can be observed through the twins' bands. Based on the above, it is quite clear that the optimization could be achieved by an effective and precise combination between heating schedule and internal pressure operated.
- There is no significant advantage in properties within 90min SPF versus 30min process. This fact shows that the combination of two-stage process definitely reduce the production schedule.

Comparison of Magnesium vs. Aluminium is presented in Table 17.

| **Material** | **Post process tensile properties** | | | **Feedstock cost (US$ per Kg)** | **Process duration (Min)** | **Energy (% from total)** | **Finishing cost (US$) for 2000 SSH** |
|---|---|---|---|---|---|---|---|
| | **UTS** | **YS** | **Elon. %** | | | | |
| **AL 5086-H112** | 269 | 131 | 14 | 12 | 210 | 10 | 50-60 |
| **Mg AZ31B-O** | 260 | 175 | 25 | 25 | 45 | 100 | 50-60 |

Table 17: Comparison of Magnesium vs. Aluminium

## WP7

Integral welded fuselage panel with stiffeners

The creep forming of stiffened panels could be realized with AZ (AZ31 sheet and AZ31 profile), see Figure 85 and ZK (ZK10 sheet and ZK30 profile) alloys, just by the use of vacuum and elevated temperatures between 200℃ and 250℃. Depending on the used alloys any heat treatments might be combined with or integrated in the creep forming process. For the used alloys this was not applicable.

The stringer profiles were laser beam welded (LBW) on the flat sheet and formed together with the sheet. Longitudinal joints realized by friction stir welding (FSW), did not influence the forming behaviour of the sheet.

The creep forming process time which was quite long in the research project might be significantly reduced in production conditions using a heat/cool able die and/or a separable die.

Since the idea was to weld (LBW, FSW) flat panels and then do hot forming and heat treatment of the welded component in one step, this process would be especially suitable for alloys which need a heat treatment to acquire better properties.

Cost can be reduced when decreasing the necessary process steps by integrating several processes. This might help to realize applications with still higher cost Magnesium sheet, replacing cheaper standard Aluminium sheet.

# Impact of the Project on the Industry or Research Sector

MagForming project which aimed at manufacturing current Aluminium made aeronautic parts out of Magnesium alloys achieved its main goals. Structural parts which were initially selected as the demonstrators of the principal study were successfully manufactured through acceptable parameters and at reasonable costs. Mechanical and metallurgical properties of the produced parts were investigated and evaluated compared to end-users specification requirements.

These solid results might minimise hesitations of the aeronautic structural designers and engineers when considering the use of Magnesium wrought alloys as well as their related production techniques. Yet Magnesium is suitable for secondary structural and non structural parts.

Another conclusion which emerged from the project is the advantage of using specific Magnesium alloys, such as WE43, as a suitable feedstock while forming processes are considered. This high strength Magnesium alloy can be equal to certain Aluminium alloys in respect of mechanical properties and working environment requirements. This alloy which is available in cast and wrought conditions can facilitate the use of Magnesium alloys in aircraft parts.

Another conclusion which producers of aircraft parts can earn from MagForming project is the option of modifying manufacturing methods and processes which can drastically reduce process.

# Dissemination and Use

The outcome of WP9 was the following Table which concentrate the dissemination activities which were executed and those which are planned to be executed in the near future.

| **Planned / actual Dates** | **Type** | **Type of audience** | **Countries addressed** | **Size of audience** | **Partner responsible /involved** |
|---|---|---|---|---|---|
| 22nd of March 2007 | EADS internal workshop on Magnesium | EADS Bus | Germany, France, Spain, UK | 30 | EADS CRC |
| August 19th - 22nd 2007 | International Conference “NEW CHALLENGES IN AERONAUTICS” ASTEC’07, Moscow, I. Ostrovsky, Y. Henn: “Present State and Future of Magnesium Application in Aerospace Industry”, Presentation | Research, Industry | International | | PALBAM-AMTS |
| October 17th 2007 | Conference Materialica – Innovativer Leichtbau in Metall, Munich, Germany, E. Hombergsmeier: “Magnesium for Aeronautic Applications”, Presentation | Research | Germany | 50 | EADS CRC |
| January 24th 2008 | Conference L*A*T*E*S*T Magnesium Alloys: Future Technologies, Applications and Opportunities, Manchester, UK E. Hombergsmeier: „Magnesium Research for Aeronautic Applications“, Presentation | Research, local Industry | UK, European | 100 | EADS CRC |
| June 23rd to 26th 2008 | AeroMat2008 conference in Austin, TX, USA, Gady I. Rosen: „MagForming Project“, Presentation | Aeronautic Industry | International | | Alubin |
| November 27th 2008 | AEROMAG Workshop, EADS Munich, Gady I. Rosen, Yonatan Henn: „Development of new Magnesium Forming Technologies for the Aeronautics Industry”, Presentation | Consortium of AEROMAG project, EADS group | International | 30 | PALBAM-AMTS |
| May 31st - June 2nd 2009 | 66th Annual World Magnesium Conference, IMA, San Francisco, CA, USA, Bruce Davis et al: “MagForming - Development of New Magnesium Forming Technologies for the Aeronautics Industry”, Presentation | Magnesium community | International | 100 | Magnesium Elektron et al |
| October 26th-29th 2009 | 8th International Conference on Magnesium Alloys and their Applications, DGM, | Magnesium community | International | 150-200 | EADS CRC |

| Planned / actual Dates | Type | Type of audience | Countries addressed | Size of audien ce | Partner responsible /involved |
|---|---|---|---|---|---|
| | Weimar, Germany, Elke Hombergsmeier: "MagForming – Development of New Magnesium Forming Technologies for the Aeronautic Industry", Presentation | | | | |
| October 26th-29th 2009 | 8th International Conference on Magnesium Alloys and their Applications, DGM, Weimar, Germany, J. Knigge et al: EU Project MagForming: "Development of a Magnesium Forging Process for Aeronautical Applications", Poster | Magnesium community | International | 300 | University of Hannover |
| 8th/9th of October, 2009 Paris | MAGFORGE Workshop, Ilya Ostrovsky: "Surface treatments for Magnesium (incl. lubrication for forging)", Presentation | Consortium plus guests | European | 50 | Chemetall |
| December 30th 2009 | Magnesium seminar at AMTS-PALBAM, Yonatan Henn: "Production of Mg aeronautical parts by SPF process" and Amir Fein: "MagForming – Development of New Magnesium Forming Technologies for the Aeronautic Industry", Presentation | Engineers, Managers | Israel | 50 | PALBAM-AMTS |
| February 14th-18th 2010 | TMS 2010, 139th Annual Meeting & Exhibition, Seattle WA, Bruce Davis et al: "MagForming - Development of New Magnesium Forming Technologies for the Aeronautics Industry", Presentation | Material science community | International | | Magnesium Elektron et al |
| | | | | | |
| September 2007 | Publication at Zeitschrift Metall B.A. Behrens, J. Knigge, T. Huinink, I. Pfeiffer: „Forming of Magnesium Alloys for Aeronautical Application“ | Research, Industry | Germany | | University of Hannover |
| 2009 | Publicationn at Kovove Materialy – Metallic Materials R. Kral, P. Lukac, P. Minarik, B. Smola, S. Danis and F. Chmelik: "Optimization of solution | Research, Industry | Czech Republic | | Charles University, Prague |

| Planned / actual Dates | Type | Type of audience | Countries addressed | Size of audien ce | Partner responsible /involved |
|---|---|---|---|---|---|
| | treatment of ZK60 Magnesium alloy using differential scanning calorimetry and electron microscopy" | | | | |
| July 2009 | Publication at Projects Magazine<br>Amir Fein: "New materials for efficient aircraft design" | Research, Industry, Politics | Europe | | PALBAM-AMTS |
| | | | | | |
| June 26th to $27^{th}$ 2007 | Exhibition at AEROMAT 2007, Baltimore, Maryland, USA | Aeronautic Industry | International | | PALBAM-AMTS |
| June 23rd to $26^{th}$ 2008 | Exhibition at AEROMAT 2008, Austin, Texas, USA | Aeronautic Industry | International | | PALBAM-AMTS |
| | | | | | |
| Beginning of 2008 | Project web-site was established at www.palbam.co.il/magforming/index.htm | www | World wide | | PALBAM-AMTS |

Table 17: Final plan for dissemination of MagForming knowledge

Table 18 below depicts the publishable exploitation plan.

| Exploitable knowledge (description) | Exploitable product(s) or measure(s) | Sector(s) of application | Timetable for commercial use |
|---|---|---|---|
| Behaviour of magnesium alloys | Material data, general knowledge, forming behaviour, optimum heat treatment | 1. Aeronautics<br>2. Transportation applications in general<br>3. Lightweight engineering in a broader sense | Ready for qualification 2010 |
| Formability of magnesium, Applicability of different forming processes | Increased variety of available forming processes for magnesium products, range of applicability | 1. Aeronautics<br>2. Transportation applications in general<br>3. Lightweight engineering in a broader sense | Ready for qualification 2010 |
| Behaviour after forming | Material data, material behaviour after forming | 1. Aeronautics<br>2. Transportation applications in general<br>3. Lightweight engineering in a broader sense | Ready for qualification 2010 |
| Process parameters and lubrication suitable for magnesium | Deep knowledge about forming processes, parameters, applicability and lubrication | 1. Aeronautics<br>2. Transportation applications in general<br>3. Lightweight engineering in a broader sense | Ready for qualification 2010 |

Table 18: Publishable plan for exploitation of MagForming knowledge