MAGNESIUM FOR AEROSPACE APPLICATIONS

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OVERVIEW

The density of Magnesium is only 65% of the density of commonly used aluminium alloys in the aerospace industry and therefore can be a break through technology if used for low weight airframe structures. However to use this low weight material several mechanical properties have to be increased and the technological behaviour improved. The technical focus of this project is the modification of existing and the development of new Magnesium wrought products (sheets and extrusions), that provide significantly improved static and fatigue strength properties for lightweight fuselage applications. The specific strength properties of these innovative materials are required to be higher than AA2024 for structural applications (secondary structure) and higher than AA5083 for non-structural applications.

At the beginning of the project new alloys will be developed and experimental alloys will be tested. Appropriate manufacturing (rolling, extrusion), forming and joining technologies require development, simulation and validation for the innovative material and application. Corrosion is a problem to be solved with newly adapted surface protection systems according to aerospace requirements and advanced design concepts. (The special problem of grounding has to be solved.) Flammability will be addressed with addition of chemical elements, special surface treatments and comparative investigations to aluminium alloys. A further essential task is the development of material models and failure criteria for the prediction of forming processes, plastic deformation and failure behaviour of components. Finally material adapted design and the evaluation of structural behaviour will be investigated to close the process and development chain for aeronautic components.

The technological objective is a weight reduction of the fuselage structure, system and interior components up to 30 %. The strategic objectives are an increase in the operational capacity of 10 %, a reduction in the direct operating cost of 10 % and finally a reduction in the fuel consumption of 10 % and therefore a reduced environmental impact with regard to emissions and noise.

1. DESCRIPTION OF PROJECT OBJECTIVES

The aluminium alloys used today for aerospace applications are already optimized concerning aeronautic requirements such as strength, fatigue and damage tolerance properties. Therefore weight reduction is more and more difficult to be reached with only small progress in aluminium material development.

Due to the fact that weight reduction is a very important objective for strengthening the competitiveness of the whole European aeronautic industry, several alternatives to obtain weight reduction have to be investigated. One alternative can be the use of new design principles like welded or bonded airframes or the use of laminates such as Glare® or Metal Laminates. Another alternative could be the application of low density structural plastics or fibre reinforced composites. But the application of non-metallic materials is in some areas not possible due to limited properties under low or elevated temperatures, missing electric conductivity or low damage tolerance. Fibre reinforced plastics are a rather costly material only used for primary structure applications with highest requirements.

The family of magnesium alloys and especially magnesium wrought materials can be an excellent alternative because of their low density, good mechanical properties, moderate cost and metallic character (in respect of manufacturing, repair, maintenance compared to composites). In the past decade a lot of research activities and development projects have been carried out working on magnesium cast materials mainly for automotive applications. There were only very few activities on magnesium wrought products like sheets, extrusions or forged parts. The alloy spectrum of magnesium wrought alloys is still very limited. Aeronautic requirements and applications of wrought products have been evaluated only in some subtasks of a few projects.

Increasing the research on magnesium wrought alloys will promote a new class of metallic materials for aeronautical applications to win the competition against plastics and fibre reinforced plastics. Therefore, the spectrum of available metallic materials will be enlarged, not only for aircrafts, but also for space, military and satellites applications. Thus, as a consequence, it will also stimulate the research in the field of other engineering materials.

Within this project the overall objective is to demonstrate that Magnesium is a suitable engineering material which can be applied for weight savings up to 35 % compared to aluminium. To reach this goal magnesium has to deliver significantly higher weight specific mechanical properties compared to Aluminium. The targets for replacement of aluminium can be divided into two different steps in respect of time scale and risk:

- replacement of medium strength 5xxx aluminium alloys for cockpit and cabin applications
- replacement of medium to high strength 2xxx aluminium alloys for secondary structure or non-pressurized fuselage applications

Therefore new alloys will be developed and existing alloys will be tested. Appropriate manufacturing processes (rolling, extrusion) will be adjusted between material suppliers and universities. Forming and joining technologies require development, simulation and validation for the innovative material and technologies commonly used within aeronautic industry.

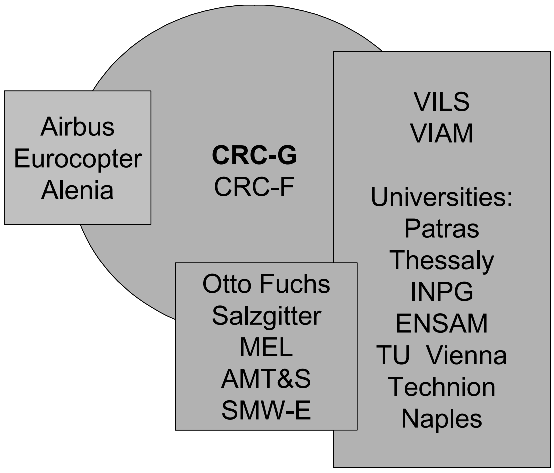
Corrosion is one of the most important problems to be solved with newly adapted and environmentally friendly surface protection systems according to aerospace requirements. Advanced design concepts are requested to prevent any galvanic corrosion within joinings of components made from dissimilar materials. Additional topics in that area are the needs for grounding and local surface protection technologies for damages which have to be realized for nearly all aeronautic components.

Flammability will be evaluated and addressed with addition of chemical elements, special surface treatments and comparative investigations to reference aluminium alloys. The fire worthiness requirements (FAR/JAR) for the different areas of aircraft will be the base for the assessment of efficiency of the selected protection systems.

A further essential task is the development of material models and failure criteria for the prediction of forming processes, plastic deformation and failure behaviour of components. Finally material adapted design and the evaluation of structural behaviour will be investigated to close the process and development chain for aeronautic components. A cost reduction within the development stage is therefore assumed.

Summary of the scientific and technical objectives:

- Static and fatigue strength properties comparable to properties of 5xxx and later 2xxx aluminium alloys
- Damage tolerance behaviour comparable to aluminium alloys
- Weight reduction of single components up to 35 % compared to aluminium
- Cost efficient processes for manufacturing of magnesium semi-finished products (sheets, extrusions)
- Flammability behaviour of magnesium wrought components approved concerning fire worthiness requirements (FAR/JAR)
- Corrosion behaviour of environmentally friendly surface protected components comparable to aluminium
- Investigation of process technologies (forming, welding, bonding, fastening) commonly used in aeronautic industry especially to magnesium
- Development of material models for plastic deformation and failure criteria
- Basic preparation of the qualification of magnesium products for aerospace applications
- Material adapted design and design rules for structural elements made from magnesium



2. WORK PERFORMED

The technical focus of the university driven proposal, AEROMAG which has been prepared in close collaboration to the Network of Universities "EASN" is the development of new Magnesium wrought products (sheets and extrusions), that provide significantly improved static and fatigue strength properties. The strength properties of these innovative materials are required to be as high as

AA5083 for non-structural applications and as high as AA2024 aluminium alloys for secondary structure applications.

At first new alloys will be developed and existing alloys will be tested. Appropriate manufacturing (rolling, extrusion), forming and joining technologies require development, simulation and validation for the innovative material and application. Corrosion is a problem to be solved with newly adapted and environmentally friendly surface protection systems and advanced design concepts. Flammability will be addressed with addition of chemical elements and special surface treatments. A further essential task is the development of material models and failure criteria for the prediction of forming processes, plastic deformation and failure behaviour of components. Finally material adapted design and the evaluation of structural behaviour will be investigated to close the process and development chain for aeronautic components.

Deliverables to be generated by the programme

- Improved magnesium alloys with significantly improved mechanical and technological properties (comparable to 5xxx and 2xxx aluminium)
- Cost efficient production routes for semi-finished products (sheets, extrusions) optimized for magnesium wrought alloys
- Comprehensive material data base on mechanical and technological properties of different magnesium alloys
- Evaluation of improved flammability behaviour of magnesium with and without surface protection according to FAR/JAR standards
- Verified simulation tools and key parameters of forming processes for magnesium components
- Key parameters and properties of different joining processes adapted to magnesium
- Environmentally friendly surface protection systems for magnesium
- Definition of design rules especially for magnesium components and their assembly to dissimilar materials
- Knowledge about structural behaviour of magnesium components
- Weight specific cost analysis of typical components

3. FIRST RESULTS

3.1. Material development and characterization

The end-users Alenia, Eurocopter and Airbus defined together with the EADS Research Centers the requirements for new magnesium alloys to be applied within interior and systems or secondary structural aeronautic applications (table 1).

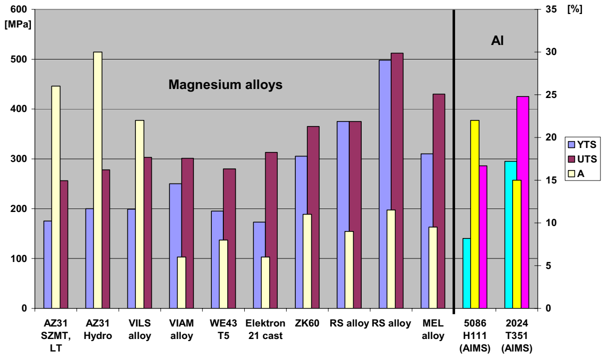
Property	**Temperature**	**Requirements Mg alloys**	
		systems application	**structural application**
UTS	RT	275-350 MPa	450 MPa
YTS	RT	200-300 MPa	350 MPa
Elongation	RT	12-16 %	16-18 %
YTS	150°C	-10% of YTS	-10% of YTS
Compressive YS	RT	±10% of YTS	± 10% of YTS
Failure under compression	RT	comparable Al 5083	comparable Al 2024 T3
Density	RT	1,7-1,8	1,7-1,8
Residual Strength	RT	n.a.	comparable to 2024 T3
FCG	RT	n.a.	comparable to 2024 T3
Fatigue limit K_t=1.0, R=0.1	RT	160 MPa	140 MPa

Table 1: Requirements for magnesium alloys for aeronautic applications.

The Russian Institutes VILS and VIAM proposed some new alloys and made a comprehensive review about available magnesium alloys and magnesium applications in aerospace in past and present products. The Technion also contributed with a new rapid solidified, interesting alloy. Magnesium Elektron joined the consortium to support the material processing step by feedstock supply and knowledge transfer of rolling specialty alloys.

The most promising alloy systems (fig. 1) which were selected due to corrosion behaviour, environmental friendliness and mechanical performance for further investigation as wrought products in the project, were Mg-Al-Zn, Mg-Zn-Zr-Re and Mg-Y-Re. Especially the compression curves of several alloys does not show the weakness under compression loads any more, which is typical for most magnesium alloys. For some systems the behaviour under tension and compression is the same, similar to aluminium alloys.

Fatigue limits were measured in the range between 150 and 200 MPa for constant amplitude fatigue under tension loading and with smooth specimens.



a)

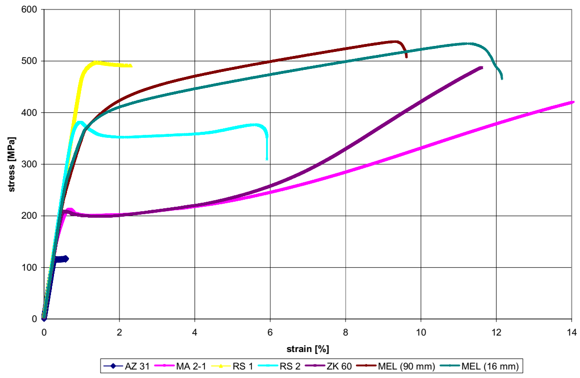


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Fig. 1: Static properties of commercially available and new alloys, a) tensile properties, b) stress-strain curves under compression.

3.2. Manufacturing of semi-finished products

Salzgitter Magnesium Technologie is responsible for the work package and is mainly concentrating on the development of the rolling process of sheets. Sheets can be produced up to a width of 2000 mm and a thickness down to 1.0 mm using an industrial rolling mill at their facility. Magnesium Elektron is supporting these activities by delivering feedstock material from their alloys and know how of thermo-mechanical processes for high strength alloys. MENA (Magnesium Elektron North America), also supplied sheet in AZ31 & AZ61 to the programme

Otto Fuchs is casting feedstock material of AZ alloys and is responsible for commercial extrusion of magnesium profiles. Magnesium extrusions are fabricated by Otto Fuchs using industrial equipment, facilities and representative tool geometries. Up to now commercial profiles of AZ31, AZ61 and AZ80 have been delivered to the project consortium. Extrusion of new alloys is planned.

The Russian Institutes VILS and VIAM are not only responsible for the development of new magnesium alloys but also for the production of sheets and profiles. Some advanced materials (sheets and profiles) were delivered by them in limited amount.

3.3. Investigation of forming processes

INPG has done the full characterization of deformation behaviour at room and elevated temperatures by microstructural analysis and mechanical testing. The objective is to define the forming windows for different alloys and processes. University of Savoie in Annecy performed some forming tests at room temperature with specific devices to study strain localisation effect by image correlation techniques.

To determine the forming windows, besides the microstructural characterisation the investigation of the mechanical behaviour of the reference material AZ31B 2.0 mm sheet material at room and elevated temperatures was performed. In the two last months, efforts were devoted to interpret the data obtained by the image correlation techniques in order to have a criterion for strain localisation and the possibility to measure locally Lankford coefficients (figure 2). For elevated temperatures microstructure stability, strain rate jump tests and tests at constant strain rate (see figure 3) were performed.

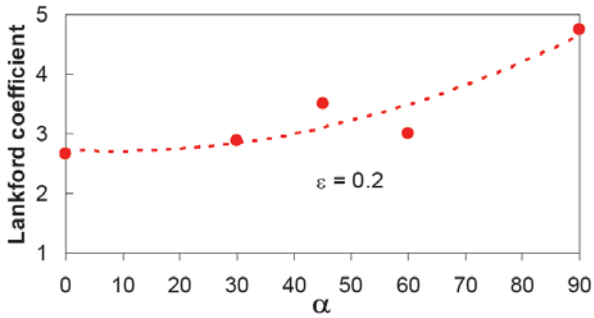


Figure 2: Lankford coefficient versus angle to rolling direction

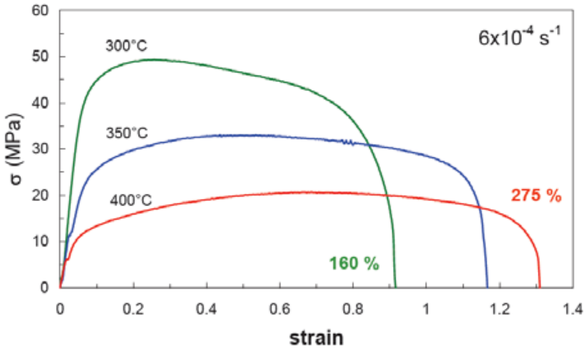


Figure 3: Tests at constant strain rate

3.4. Surface protection

Existing and commercially available, environmentally friendly surface treatment technologies are investigated and tested in accordance with aircraft and aerospace standards. The specifications have been defined by the end-users.
The main focus of work comprises the definition of

pre-cleaning technology, the development of sol-gel technology (TU Vienna), comparison of commercial surface treatment technologies, testing of bare corrosion protection and testing of multilayer coating. Conversion coatings, anodizing treatments and hard and wear resistant coatings suitable for Mg substrates will be tested, evaluated and rated. AMT&S Alonim, Eurocopter and external companies are providing the surface protection systems.

The magnesium sheet shall be pre-cleaned for maximum corrosion protection. Investigating the corrosion resistance of anodizing treatments, the corrosion resistance was quantitatively estimated thanks to pitting depth measurements on metallographic sections. For each specimen, the pitting depth has been measured on 3 different metallographic sections. All the specimens corroded only by pitting, no intergranular corrosion, no filiform corrosion appeared under the protective layers. No particular influence of the scratch (depth/corrosion morphology) has been evidenced on the micrographs. The metallographic sections confirm the visual observations. Currently only HAE with varnish and unsealed Tagnite coated specimens fulfilled the requirements in terms of corrosion resistance.

The compatibility of the different pre-treatments to the sol gel process was investigated. The corrosion rate of the untreated substrate decreases by a factor of five after sol gel coating. Acid pickled samples have a corrosion rate that is five to ten times lower than that of the untreated substrate. When acid pickling and sol gel treatment are combined, the factors of the two procedures roughly multiply, and the corrosion resistance is enhanced by a factor of up to 60. Because of the good performance and the lower weight-loss during pickling hydrofluoric acid treatment is the recommended method for sol gel coatings (see figure 4) [1].

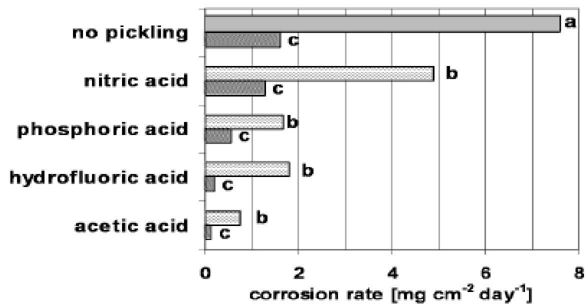


Figure 4: Anticorrosive performance of samples with different treatments: a)untreated sample, b) after acid pickling and c) after acid pickling and sol gel coating

The additional influence of potential corrosion inhibitors was also investigated. The amount of the additives was calculated to be 5 % of the total mass of the nonvolatile compounds in the sol. The films were deposited on samples pretreated with hydrofluoric acid. The results of the corrosion test are summarized in Fig 5. The anticorrosive effect of manganese and cerium is outweighted by the negative influence on the barrier properties of the sol gel coating in this system. Zinc acetate showed only a minor effect. Triethylphosphate and 1,2,4-triazole proved to be efficient inhibitors, decreasing the corrosion rate by a factor of 1.7 and 3.3 respectively [1].

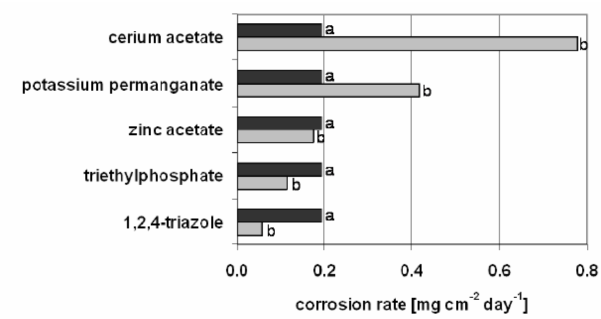


Fig. 5: Corrosion of HF-pretreated Mg AZ31 samples after sol gel coating. A) without, b) with corrosion inhibitor

3.5. Flammability

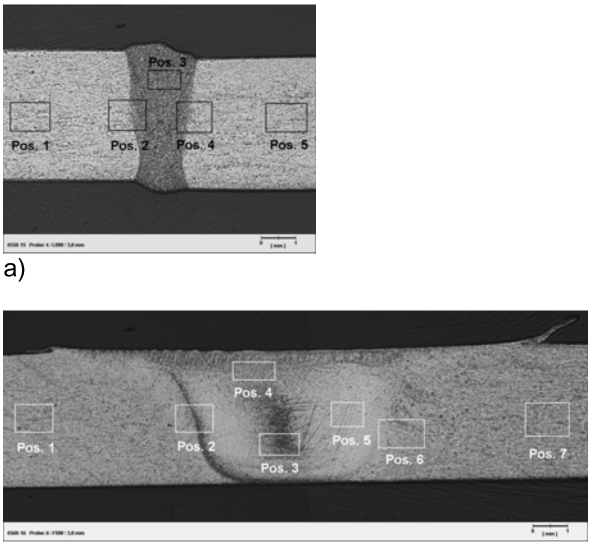
Some tests to determine the auto-ignition temperature of magnesium alloys have been carried out by the Technion. First the mechanism of auto-ignition was studied to understand the problem of flammability and to conclude on the influence of different alloy compositions [2].

- Eutectic phases ignite first (low melting temperature)
- Homogeneity of bulk increases auto-ignition temperature (no low-temperature melting phases)
- Highly dependent on geometry (powder, bulk)
- No standard for solid materials available (the closest standard is ASTM standard E659-78)
- Dependent on atmosphere and reactions

Airbus and Technion have carried out some first measurements to compare the general flammability behaviour of aluminium and magnesium sheets and real magnesium components. First it has to be stated that all tests which were carried out passed without any problem the JAR/FAR, Part 25, § 25.853(a) requirements. The reason for that is that the specification was made for non-metallic materials which are often used in the cabin of an aircraft. Airbus found that the time to melting for AZ31B, 2 mm sheet was about half as for comparable AA2024. Without external heat the Mg sheet did not continue burning. But to learn more about the flammability of magnesium, the Technion performed additional tests close to a catastrophic scenario. Different magnesium components were directly placed within a burning jet fuel with a temperature of 600 to 800°C. It needed 240 seconds until the components were melted and other 10-20 seconds until they ignited. Coated components could increase the time to only partial ignition up to 10 min. After 1 min when the fuel was fading out, the coated components self extinguished. In comparison to that the Al case melted 350 seconds after the full ignition of the fuel. No ignition of the Al case was observed in this test. But for all cases there was no ignition observed till melting of the magnesium material.

3.6. Joining technologies

Different joining techniques were applied to magnesium wrought semi-finished products, in order to promote their introduction on aeronautical structures. Airbus has performed some first tests to join magnesium sheets by friction stir welding. ENSAM has performed some initial tests to define the parameter window for friction stir welding of magnesium. PALBAM has been working on TIG welding. They performed several welding trials and did some microstructural (fig. 6) and mechanical characterization (fig. 7).



a)

b)

Fig. 6: Welded AZ31B joints a) laser beam welded, b) friction stir welded

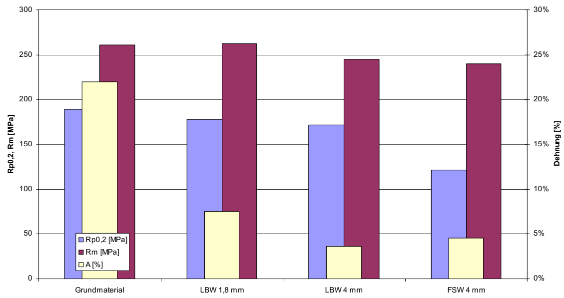


Fig. 7: Static strength of welded AZ31B joints, AZ61 filler material for LBW

In general magnesium AZ31B is quite easily weldable by different processes. Using laser beam welding an AZ61 filler wire is advantageous for the mechanical properties (see fig. 7) to weld AZ31B. Rather high strength values can be obtained, besides increased elongation.

4. CONCLUSIONS

- Several product forms and alloys are available
- Interesting alloys with good mechanical properties exist
- More than 33 % increase in specific strength, some alloys with symmetry under tension and compression
- Fatigue strength (Kt=1.0, R=0.1), 150 - 200 MPa
- Corrosion behaviour has improved
- New surface protection systems are evaluated
- Forming possible under elevated temperatures
- Welding, riveting, bonding easily possible
- Flammability issue has to be further discussed with FAA

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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