DOI: 10.13009/EUCASS2019-677

Additive manufacturing of Scalmalloy® satellite parts

Sébastien BEGOC, Florence MONTREDON**, Gilles POMMATAU**, Guillaume LEGER***, Maxime GAS*** and Sébastien EYRIGNOUX****
**CNES*
18 avenue Edouard Belin, 31401 TOULOUSE Cedex 9, FRANCE
sebastien.begoc@cnes.fr
***THALES ALENIA SPACE FRANCE*
5 allée des Gabians, BP 99 – 06156 CANNES LA BOCCA Cedex, FRANCE
Florence.montredon@thalesaleniaspace.com
****LISI AEROSPACE ADDITIVE MANUFACTURING*
2 route Robert Algayon, 33640 AYGUEMORTE-LES-GRAVES, FRANCE
Guillaume.leger@lisi-aerospace.com, Maxime.gas@lisi-aerospace-am.com, Sebastien.eyrignoux@lisi-aerospace.com,

Abstract

Laser Beam Melting technology is of particular interest for satellite parts due to their small number, their complexity and to the goal of lowering their mass. Today, however, the mechanical performance to weight ratio is limited by the choice of available materials.

Focusing on the high mechanical performance offered by Scalmalloy® and the industrial scale-up required for the production of large parts, the first objective of this study was to develop the appropriate process parameters. The second step focused on thermal treatment selection and thermal deformation simulation. The final stage was dedicated to the manufacturing of full-size parts and industrialization.

1. Introduction

LISI AEROSPACE ADDITIVE MANUFACTURING is currently producing with LBM various satellite parts in aluminum alloy AlSi7Mg0,6 (i.e. AISI 357.0) for THALES ALENIA SPACE and both companies are now working on the development of new materials in order to maximize the benefit offered by the LBM technology.

A collaborative effort between the French Space Agency CNES, THALES ALENIA SPACE and LISI AEROSPACE ADDITIVE MANUFACTURING (AM) was initiated to study Scalmalloy®, a promising high strength alloy for space applications, with the following objectives:

- Develop LBM process and post-process parameters for Scalmalloy®
- Characterize the main mechanical properties obtained with this alloy
- Manufacture of the first demonstrator for space application
- Improve the productivity and economic performance for large-size parts

2. Space requirements

2.1 Laser Beam Melting in Space industry

The space sector is one of the pioneers for the industrial use of Additive Manufacturing (AM) technology [6], [7]. Among all the available AM processes, the industrial space actors primarily chose the LBM process due to its maturity and due to the applicability for complex and unique parts. Coupled with topological design optimization, the LBM process is capable of manufacturing complex structural parts with up to 50% mass savings compared to standard processes. Also, contrary to the other aerospace sectors, the space sector has low requirements in terms of fatigue resistance, which is often a limiting factor for the use of LBM structural parts.

More than 100 metallic LBM parts are currently in-orbit on THALES ALENIA SPACE telecom satellites and more than 400 other LBM parts are already printed and will be soon launched soon on new platforms such as Spacebus Neo.

Figure 1: Examples of THALES ALENIA SPACE aluminum LBM secondary structures flight models. From left to right: TTC Antenna support and Ku Horn support of Koreasat 5A and Koreasat 7 (in orbit since May 2017), Antenna support and Ku horn support of Insmarsat Hellasat 3 (in orbit since June 2017), TMTC support of Telkom 3S (in orbit since February 2017) and the Banghabandu shimplate (in orbit since 2017)

In addition to structural parts such as mechanism brackets and horn or antenna supports, new thermal and radio frequency applications are now targeted

2.2 .Materials in Aerospace Additive Manufacturing

Properties of metallic materials usually used in LBM are compared to Scalmalloy properties in the table below:

Table 1: Main material in LBM

	Density (kg/dm3)	**Typical UTS after thermal treatment (MPa)**	**Specific Resistance**	**Elongation (%)**	**Maximal T° of use (°C)**
AlSi7Mg0,6 aluminium	2,68	330	153	5	130
316L Austenitic Stainless steel	7,95	622	78,2	55	550
Ti6Al4V Titanium	4,43	1100	248	11	370
Inconel® 718 Nickel alloy	8,2	1350	165	25	700
Scalmalloy®	2,7	515	191	7	130

Most of the alloys used for metallic additive manufacturing are not selected for their technical properties but for their commercial and specification availability.
The AlSi7Mg0,6 alloy was originally designed for the casting of large industrial parts. Indeed, the high content of silicon improves the alloy liquid state fluidity and solidification. These properties enable good weldability, as well as the ability to be printed by LBM.

DOI: 10.13009/EUCASS2019-677

Other alloys used in LBM such as 316L, Ti6Al4V and Inconel 718 were developed mainly for wrought applications In this case, the relatively slow solidification of the original casting ingot induces a coarse microstructure with quite poor mechanical properties: further deformation (forging and rolling) and/or heat treatment (solutionizing + ageing) are required to reach elevated mechanical properties.

In the case of LBM, however, post-printing deformation is impossible due to the complexity of the parts and any high solutionizing heat treatment would permanently damage the microstructure as well as impair the mechanical resistance. On the contrary, the LBM hardening mechanism relies on the very fast solidification which induces an incredibly fine microstructure.

Mechanical properties of ALM metallic parts can be significantly improved by the conception and use of new alloys, such as Scalmalloy®. In addition to their printing ability, the development of LBM-dedicated alloys must take into account the additive manufacturing specific requirements such as rapid solidification, cyclic thermal history, high anisotropy and their heat treatment should rely mainly on direct ageing.

2.3 Scalmalloy®: an exciting compromise

Having a positive industrial experience on multiple LBM AlSi7Mg0,6 parts, THALES ALENIA SPACE is now considering new functions and applications that require specific material properties. New requirements include, for example, thermal or electrical properties (conductivity, thermal expansion …), specific surface conditions, or higher mechanical characteristics. At the same time, a lot of research is being done on customized materials for AM that allow targeting material for a specific application.

In terms of mechanical characteristics, the AlSi7Mg0,6 alloy is far below the aerospace reference alloy A7075 used in structural parts. One of the major benefits of the LBM technology for the space industry is the weight savings which has a strong impact on launch costs. In order to be even more competitive in mass, THALES ALENIA SPACE is looking for new high strength LBM alloys.

Scalmalloy® has been developed and patented by APWORKS (100% subsidiary of Premium AEROTEC, part of AIRBUS GROUP) and was specifically designed for LBM manufacturing and especially for aerospace structural applications. All customers can now use this alloy through various powder manufacturers. According to the APWORKS data sheet, Scalmalloy® is a high strength aluminum alloy with improved elongation compared to AlSi7Mg0,6, good corrosion resistance and welding ability. It matches well with the ambitions of THALES ALENIA SPACE for structural parts, with the exception of the stiffness that is unfortunately not improved according to the data sheet. As it is designed especially for LBM, benefits can be expected in terms of minimal internal defects and limited residual stress that should lend itself to more industrial productions. The use of Scalmalloy® appears to be promising for space applications, possibly replacing titanium when high strength and thermal conductivity are required.

3. Development and validation of parametric set

3.1 Frame

3.1.1 Machine

The first development step was to choose the appropriate additive equipment, according to manufacturing print volume, number of lasers and parametric set customization. LISI AEROSPACE ADDITIVE MANUFACTURING has various LBM machines from different supplier such as CONCEPT LASER, SLM SOLUTIONS and EOS. Some machines have a standard manufacturing volume (250x250x300mm) with one laser, while other offers very large manufacturing volume (400x800x500mm) and use several lasers. The EOS M290 equipment has been chosen for the first Scalmalloy trials, due to the possibility of customization and limited parameters (one laser in a standard size chamber of 250x250x300mm),. Moreover, argon flow is highly controlled in this machine, which is crucial to prevent Scalmalloy® slag issues.

3.1.2 Powder

Scalmalloy® powder was carefully analyzed in terms of morphology, particle size analysis, internal microstructure and porosity upon reception and after 5 recycling cycles.

The powder morphology was analyzed with SEM and was found to be the same between new and recycled powder and to be mainly composed by spherical particles, with a dendritic surface aspect.
Few particles were found embedded into a "casing" of similar material, probably due to particle interaction during powder atomization.
The metallographic analysis showed a dendritic microstructure and very few porosities within the particles.

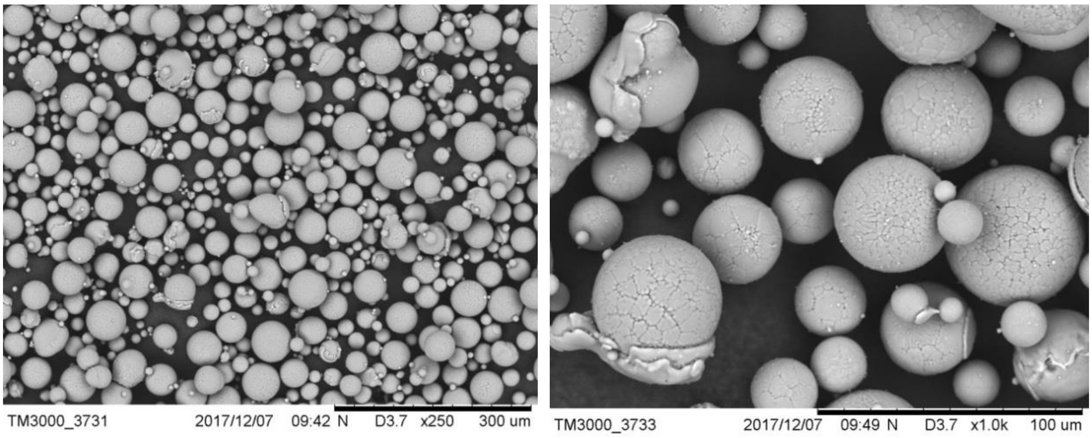


Figure 2: Scalmalloy® powder (SEM x250) and (SEM x1000)

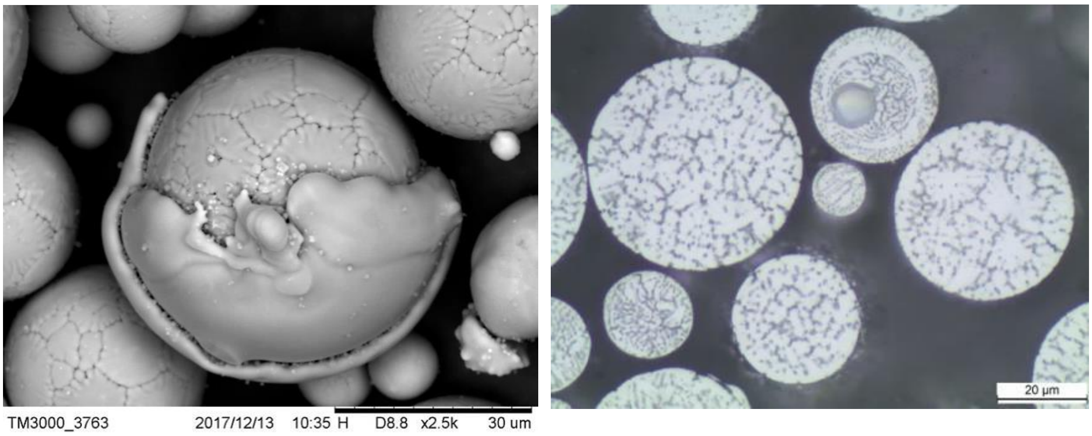


Figure 3: Scalmalloy® "casing" particle (SEM x2500) and powder metallography (SEM x2500)

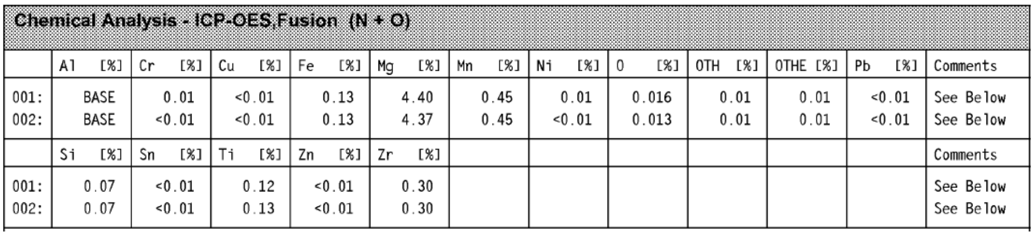
The laser diffractometry grain size analysis of new and recycled powder showed that the printing and recycling cycles tends to slightly eliminate the biggest particles.

Table 2: Grain size analysis before and after recycling

	New powder	**Recycled powder**
Dv(10) (µm)	29,9	31,3
Dv(50) (µm)	47,3	45,0
Dv(90) (µm)	72,4	64,3

DOI: 10.13009/EUCASS2019-677

Chemical composition analysis showed no significant difference between the new (line 001) and recycled (line 002) powder. However, we were not able to assess the scandium content due to the lack of calibration samples.



Chemical Analysis - ICP-OES,Fusion (N + O)

	Al [%]	Cr [%]	Cu [%]	Fe [%]	Mg [%]	Mn [%]	Ni [%]	O [%]	OTH [%]	OTHE [%]	Pb [%]	Comments
001:	BASE	0.01	<0.01	0.13	4.40	0.45	0.01	0.016	0.01	0.01	<0.01	See Below
002:	BASE	<0.01	<0.01	0.13	4.37	0.45	<0.01	0.013	0.01	0.01	<0.01	See Below

	Si [%]	Sn [%]	Ti [%]	Zn [%]	Zr [%]							Comments
001:	0.07	<0.01	0.12	<0.01	0.30							See Below
002:	0.07	<0.01	0.13	<0.01	0.30							See Below

Figure 4: Chemical composition analysis before and after recycling

3.2 Parametric set development

3.2.1 Fusion

The volume specific energy density EV is defined depending on laser power P, scan velocity v, layer thickness l and hatch distance d.

$$E_v = \frac{P}{v.l.d}$$

A previous study [1] demonstrates, for a CONCEPT LASER M2 machine equipped with a 200 W laser and with a 30µm layer thickness, that material density is higher than 99% in a range of E_V between 135 J/mm3 and 240 J/mm3 and d between 135 µm and 150 µm.

The parametric set has been adapted to be used in EOS M290 machine, and 9 cubes have been manufactured with this adapted parametric set. The results are excellent compared to AS7 aluminum and the same production rate than TA6V Titanium can be achieved without quality defects.

Table 3: Porosity on Scalmalloy® samples

	Porosity rate (%)	**Size of biggest porosity (µm)**
Average	0,08	74,6
Standard deviation	0.01	17,8

CT Scanning has been done on samples, with a 70µm resolution, and confirms the excellent material quality. Very few porosities have been found, around 75µm size.

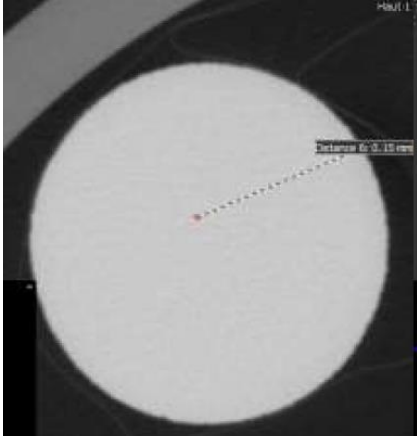


Figure 5: CT Scanning of a Scalmalloy® sample

Metallographic analysis have been carried out on Scalmalloy samples and showed an homogeneous and porosity-free microstructure, with extra-fine grains and precipitates at the melt pool boundaries.

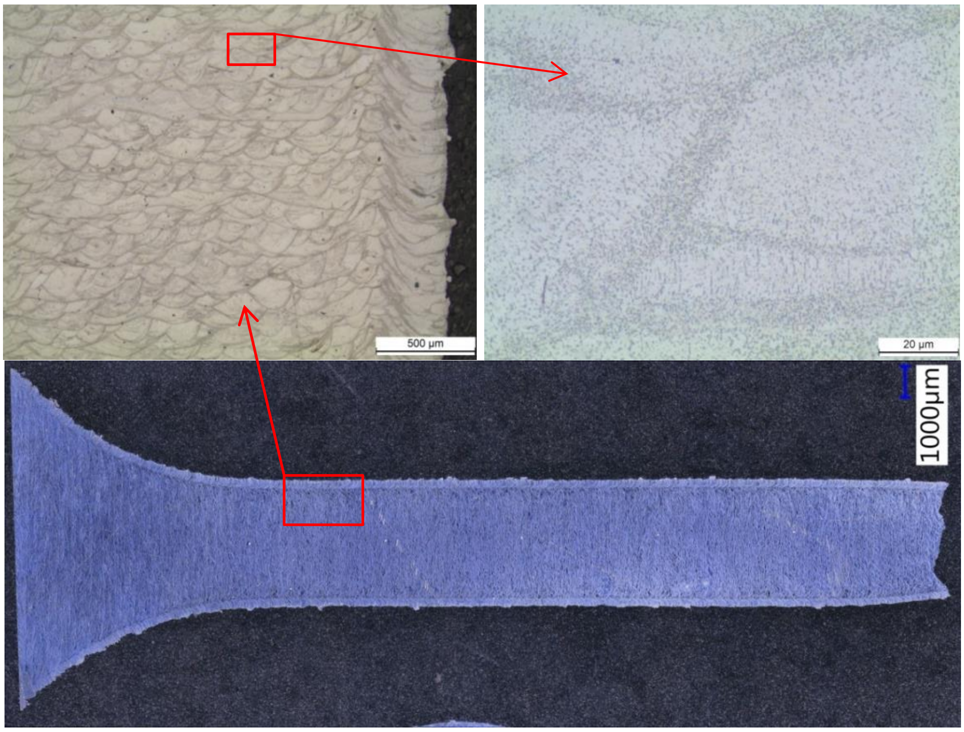


Figure 6: Metallographic analysis of a Scalmalloy® sample

3.2.2 Heat treatment

The hardening mechanism of Scalmalloy® relies both on very fine grain size during solidification and on precipitation hardening via Al3(Sc_1; Zr_{1-x}) which enables a unique combination of fracture toughness and high yield strength [3]. A previous study [2] demonstrated that a post-process heat treatment for fused Scalmalloy® should be between 325 °C and not exceed 350 °C, with an aging duration between around 4 h to a maximum of 10 h to achieve maximum material strength with UTS>520 MPa and YS>480 MPa. Due to its very high aging response (0.1 wt% Sc can generate 50 MPa strength increase) [4], it was found interesting to perform mechanical testing after different thermal treatments. The effect of surface preparation (as printed for internal channel or sand blasted for external surface) was also investigated and the best combination of thermal treatment and surface preparation was selected for the production of the parts.

3.2.3 Technical results

3.2.3.1 Tensile tests results

We manufactured 49 samples in one manufacturing batch to control the homogeneity of mechanical properties after the selected thermal treatment (see 3.2.2).

We also controlled the repeatability of several manufacturing batches, with 7 samples for each batch.
Mechanical properties were found to be above specification with a very low deviation within the manufacturing batch and between the different manufacturing batches.

DOI: 10.13009/EUCASS2019-677

Table 4: Mechanical results after heat treatment (flat samples, after sandblasting)

	Average XY direction	**Standard deviation XY direction**	**Average Z direction**	**Standard deviation Z direction**
UTS (MPa)	513,6	5,8	515,1	2,5
Yield strength (MPa)	507,9	3,3	495,6	2,4
Elongation (%)	4,9	1,1	5,6	1,5

3.2.3.2 Roughness

Inspections have been performed on samples without surface treatment to check the roughness. The 4 measurable faces of flat samples have been controlled in 2 directions

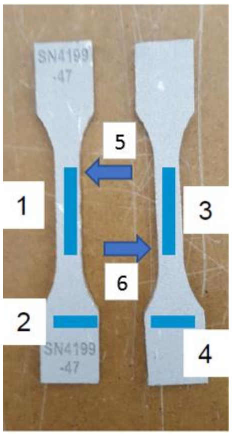


Figure 6: Roughness orientation

Table 5: Roughness results (average values)

	Face 1	**Face 2**	**Face 3**	**Face 4**	**Face 5**	**Face 6**
Roughness (µm)	13,8	12,7	12,0	12,5	15,6	13,8

We observed that roughness is the same in Z or XY orientation. The “face 5” roughness is slightly above the other results, because of the orientation of samples in the manufacturing batch (opposed to the argon flow).
The roughness achieved in the as-built condition is remarkable since the values are close to the values found in AlSi7Mg0,6 samples after sand-blasting.

3.2.3.3 Fatigue results

Fatigue performance of Scalmalloy® is obtained via samples tested in alternated traction compression (R=-1) at 10Hz. Samples are flat dog bone samples manufactured with a worst case 55°orientation, heat treated and in as-built surface conditions.
Comparison of S-N curves for sand-blasted AlSi7Mg0,6 samples and as-built Scalmalloy® samples presented in figure 1.

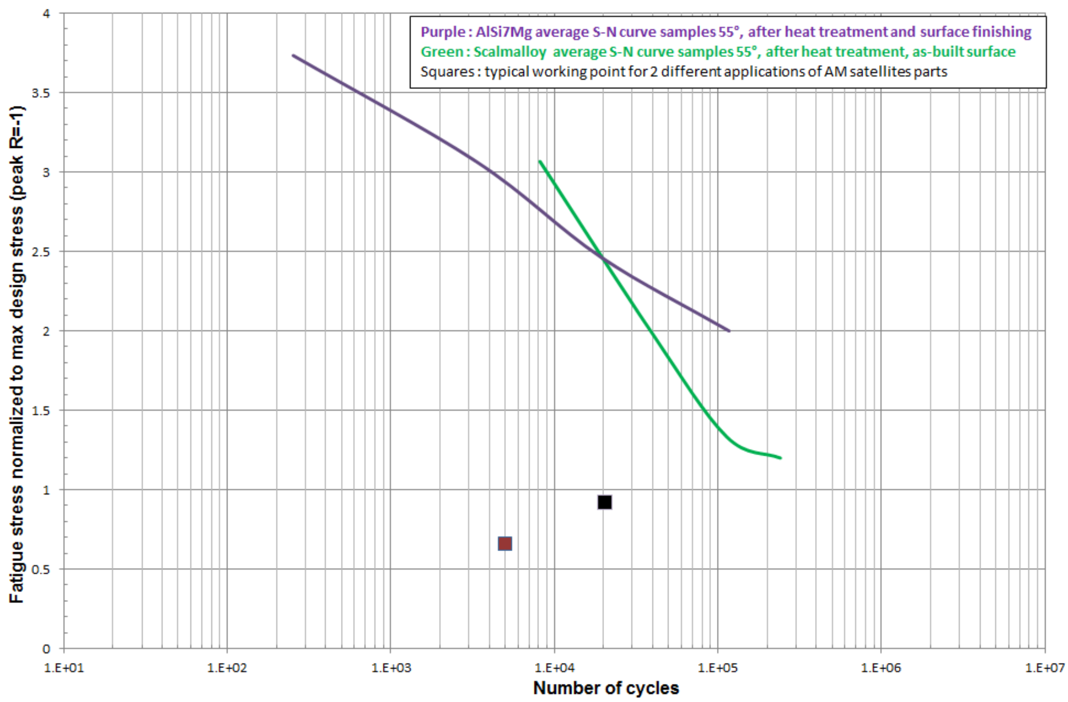


Figure 7: Comparison of AlSi7Mg0,6 and Scalmalloy® ® S-N curves (R=-1, 10 Hz) with satellites parts fatigue working points

It shows that

- up to a number of cycles of 1E4, Scalmalloy® <u>without surface finishing</u> exhibits better fatigue performance than AlSi7Mg0,6 <u>with surface finishing</u>
- up to a number of cycles typical of applications presently addressed by Additive Manufacturing technology (ie up to 1E5 cycles), Scalmalloy® can be used without surface finishing, even if performance decreases more rapidly than AlSi7Mg0,6 with surface finishing, probably due to the influence of surface finishing.
- In addition, S-N curve seems to inflect and stabilize at 1E5 cycles, which makes this material promising for part where fatigue number of cycles is more critical.

This better general performance could be explained by:

- A low manufacturing layer thickness (30µm) for Scalmalloy® compared to AlSi7Mg0,6 (50µm)
- Roughly the same average roughness for Scalmalloy® in as-built condition asAlSi7Mg0,6 in finished condition: 12-15µm
- Excellent material health demonstrated for the Scalmalloy® samples that were CT scanned by CNES: very few defects were found, all < 200µm, better than usual AlSi7Mg0,6

3.2.3.4 Internal stresses

Cantilevers samples have been used to calibrate the simulation software. These samples were analysed before heat treatment, to measure internal stresses during manufacturing. Thanks to an EDM cutting, deformation was measured and used as an input to the simulation software.

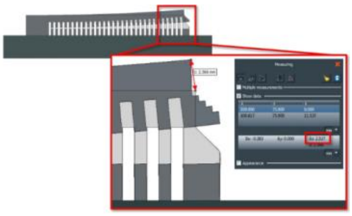


Figure 8: cantilever deformation

DOI: 10.13009/EUCASS2019-677

Table 6: Scalmalloy® Cantilever deformations

	Scalmalloy® vs TA6V Titanium	**Scalmalloy® vs AlSi7Mg0,6 Aluminium**
% Displacement between before and after cutting	-50,2	29,1

Scalmalloy® internal stresses were found to be 29% higher than AlSi7Mg0,6 Aluminium internal stresses, but half as TA6V Titanium internal stresses. Supporting strategy was developed accordingly and operated properly during manufacturing.

3.2.3.5 Porosity analysis

Porosity analysis was performed on cubic samples all along the manufacturing height in terms of porosity rate and size of porosities.

Figure 9: Porosity analysis on Scalmalloy® sample

Table 7: Porosity analysis after heat treatment

	Scalmalloy®	**AlSi7Mg0,6 Aluminium**
Porosity rate (%)	0,1	0,7
Largest porosity (µm)	110	173

3.2.3.6 Thermal properties

CNES performed some Coefficient of Thermal Expansion (CTE) measurements on samples. Indeed, it is important to check that the CTE still matches that of the satellite structure mainly made with standard aluminum and also that there is no significant anisotropy due to the layer process.
The measurements were done on small cylindrical samples according to ASTM E831 “Standard Test Method for Linear Thermal Expansion of Solid Materials by Thermo-mechanical Analysis”.

The mean value in the range [-130°C; 145°C] is 22,2 ppm/°C in both x and z directions show no major difference with other aluminum alloys used for space applications and no anisotropy.

The diffusivity was measured by Influtherm with a Flash method on 2 cylinders, one built in x and the other in z direction. No anisotropy was revealed in either. The thermal conductivity was then calculated by TAS to be about 30% less than AlSi7Mg0,6 alloy reference.

DOI: 10.13009/EUCASS2019-677

4. Parametric set development synthesis and industrialization

4.1 Proof of concept part

Space applications constrains

The selected demonstrator is a THALES ALENIA SPACE mechanism bracket that represents a series production already being manufactured by LISI AEROSPACE AM for SpacebusNeo platforms.

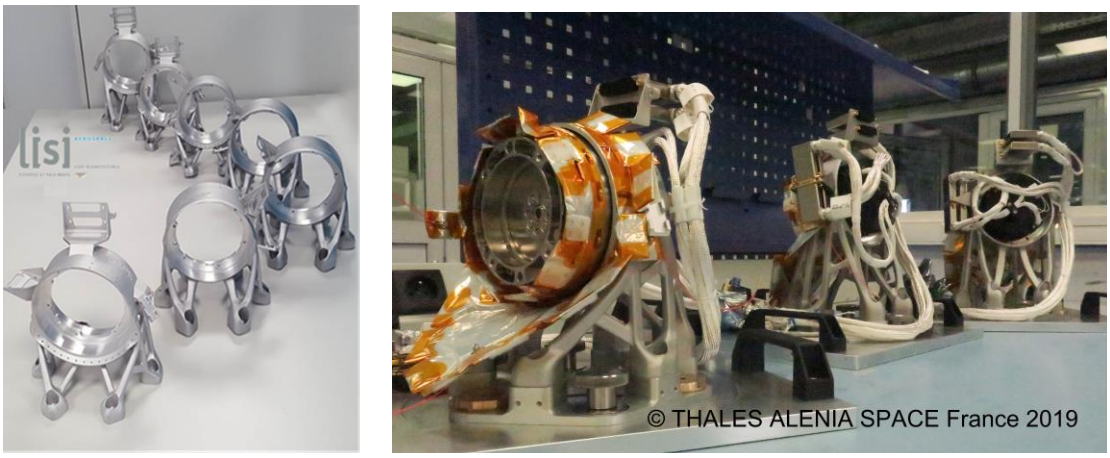


Figure 10: Small series production of AlSi7Mg0,6 mechanisms brackets by LISI AEROSPACE AM for THALES ALENIA SPACE SpacebusNeo platform

This bracket has been selected as a first Scalmalloy® demonstrator for the following reasons::

- Its size fits in the EOS M290 machine
- LISI AEROSPACE AM has the experience of the geometry and can compare the manufacturing feasibility to AlSi7Mg0,6 alloy (LBM and post-machining)
- THALES ALENIA SPACE models are already developed to simulate the bracket behavior and can easily compare its performance with similar AlSi7Mg0,6 brackets

The bracket includes 6 screwed interface points to the satellite structure and one large cylindrical interface with mechanism deployment arm. All these interfaces have to be post-machined in order to match with tight dimensional requirements.

This kind of part is designed taking into account:

- Specific stiffness as most important sizing parameter
- Quasi-static load at room temperature and number of mechanical cycles as a robustness driver
- Thermal excursion and thermal conductivity as performance driver
- Coefficient of Thermal Expansion compatible with surrounding parts (mainly aluminum)

The load history before launch for this kind of part (ie for a ProtoFlight Model) includes:

- A static test on the part with about 10 loadings on ground
- Sine vibration test on the part along the 3 axis, and at 3 different steps: on-ground integrated in its sub-system / on-ground mounted on satellite / in-flight during launch)
- Random vibration on the part along the 3 axis at 1 step: on-ground mounted on satellite
- Acoustic vibration test on the satellite part included in its sub-system at 2 steps: on-ground mounted on satellite and in-flight during launch
- Thermal cycling during flight

All this load history contributes to accumulate number of mechanical cycles at different levels. A calculation provides an equivalent worst-case working point, as presented in Figure 7 for relatively small amount of number of cycles (<1E5). When the equivalent working point reaches a higher number of cycles, a count of damage referring to S-N curve is performed in order to calculate margins to fatigue.

4.1.1 Proof of concept manufacturing

4.1.1.1 Simulation

Thanks to the previous cantilever analysis, we carried out simulations on a manufacturing batch in order to:

- Localize the deformation areas and develop the supporting strategy accordingly
- Make sure the manufacturing will not be interrupted by excessive deformation
- Anticipate these deformations for the subsequent machining operations
- Optimize the supporting strategy (with same orientation) according to the predicted thermal stress localization

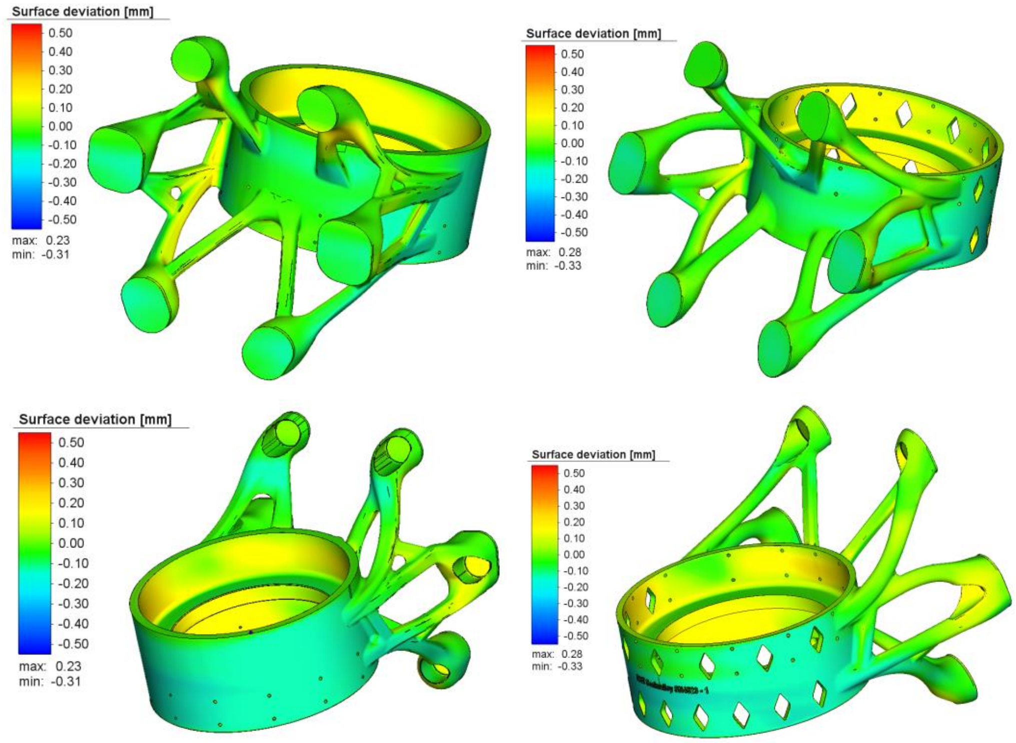


Figure 11: Simulation results between AlSi7M0,6 part (left) and Scalmalloy® part (right)

- After a proper and minimalistic supporting strategy, those simulations revealed that the Scalmalloy® parts deformations are in the same order of magnitude as AlSi7Mg parts and localized in the same area.

This successful analysis allowed us to launch the manufacturing of the demonstrator.

4.1.1.2 Manufacturing

As for AlSi7Mg0,6 part, the orientation was chosen to minimize the deformation in the cylinder area. 7 tensile samples and 2 porosity samples were manufactured with the part, and will undergo the same heat treatment and surface finishing than the part prior to testing.

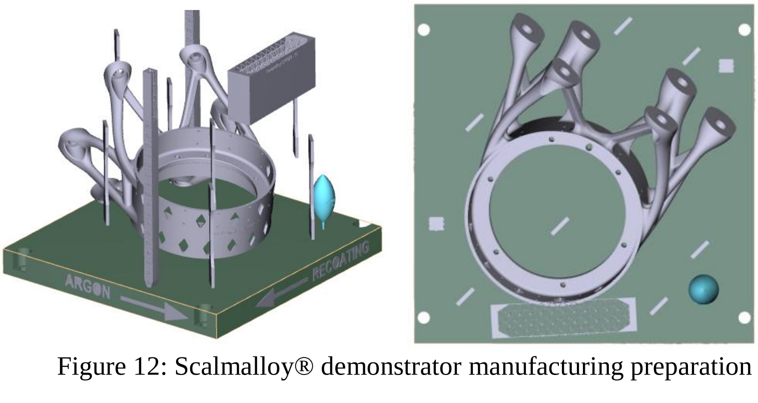


Figure 12: Scalmalloy® demonstrator manufacturing preparation

DOI: 10.13009/EUCASS2019-677

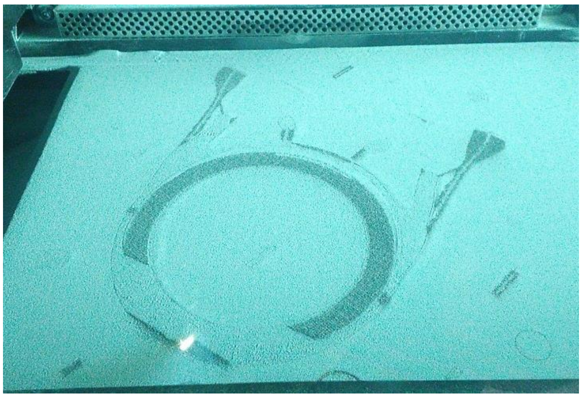


Figure 13: Scalmalloy® demonstrator in-process manufacturing

Figure 14: Scalmalloy® demonstrator after manufacturing

4.1.1.3 Post-treatment and controls

After heat treatment , parts and samples were separated from the plate with the specific AM sawing machine. Finishing operations such as support removal, and sandblasting / microblasting were finally achieved. Tomography inspection revealed no porosities or other internal defects

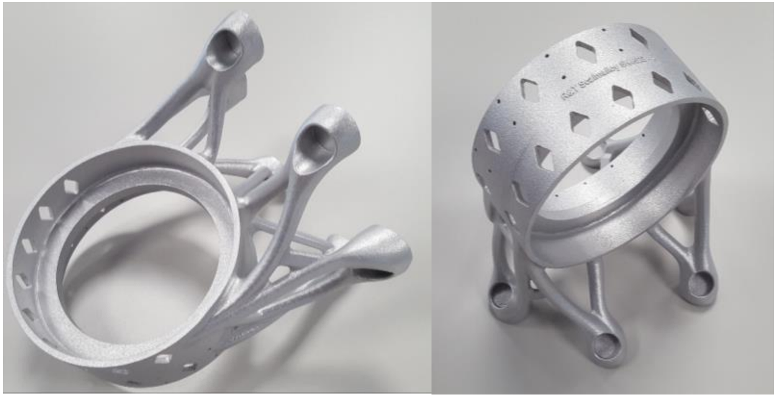


Figure 15: Scalmalloy® demonstrator after finishing operations

DOI: 10.13009/EUCASS2019-677

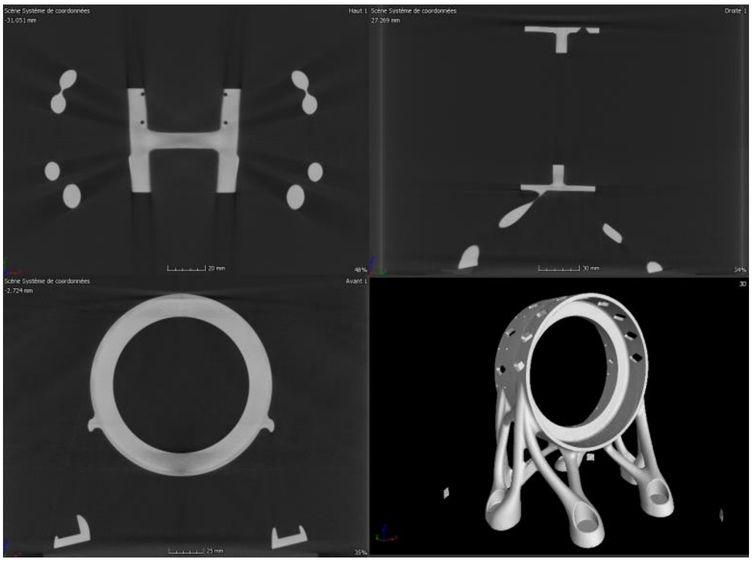


Figure 16: Scalmalloy® demonstrator tomography

As a conclusion, the production of this demonstrator was a success in terms of manufacturing process, appearance and integrity of the part and also in terms of mechanical properties of the production samples.
It and enabled us to validate our technical choices such as part orientation, supporting strategy, processing parameters, thermal treatment and finishing processes.

4.1.2 Production cost analysis

Following the success of this first demonstrator production, a technico-analysis was carried out, comparing the production cost between the Scalmalloy® part (produced in 1laser machine) and similar AlSi7Mg0,6 part (produced in 2 lasers machine), for two different powder deposition layer thickness (30 and 60 µm).

Table 8: Cost variation: Scalmalloy (1 laser) vs AlSi7Mg0,6 (2 lasers)

	% cost variation Scalmalloy (30µm) vs AlSi7Mg0,6 (50µm)	**% cost variation Scalmalloy (60µm) vs AlSi7Mg0,6 (50µm)**
Manufacturing	81%	27%
CT Scan	0%	0%
Machining	0%	0%
Finishing operations	0%	0%
Methods / Quality / Simulation	0%	0%
Heat Treatment	111%	111%
Powder	280%	280%
Total	**22%**	**9%**
NRC cost	0%	0%

This analysis showed that the initial extra cost of 22% induced by the use of Scalmalloy® can be drastically reduced to an extra cost of 9% by simply increasing the powder deposition layer thickness.
This improvement could be established during our last Scalmalloy® production: by using 60µm powder layer thickness we achieved more than 30% production time reduction compared to standard 30µm thickness layer while keeping the same level of quality.

4.2 Industrialization constrains

4.2.1 Developing a large part and productive Scalmalloy® solution

The techno-economic analysis carried out by THALES ALENIA SPACE showed that the use of a productive parametric set and a large manufacturing size machine is required for most of its mechanical parts applications. The productivity of a LBM machine depends on the laser speed and powder deposition speed. Starting from the parametric set developed in this paper, the next step will be to double the powder layer thickness. The following step will be to manufacture parts on larger equipment, going from an EOS M290 (250x250x300mm) to an EOS M400 machine (400x400x400mm), and possibly to a CONCEPT LASER X-LINE 2000R machine (400x800x500mm).

4.2.2 Scandium: a rare supply

Supply concerns often emerge from the future use of Scalmalloy® due to its scandium content (around 0,7%).

Scandium is a silvery-white metallic chemical element with symbol Sc and atomic number 21, that was discovered in 1879 by spectral analysis minerals from Scandinavia (hence its name). The main applications of Scandium by weight are in Aluminium-Scandium alloys, solid oxide fuel cells and high-intensity discharge lamps.

Despite the fact that Scandium is not particularly rare in the earth's crust (estimates vary from 18 to 25 ppm, which is comparable to the abundance of cobalt (20–30 ppm), worldwide production of scandium is limited to 10 to 15 tons per year in the form of Scandium oxide. This low production can be explained by the fact that Scandium is rarely concentrated in nature as it lacks affinity to combine with the common ore-forming anions.

Historic Scandium supply was limited to:

- Russian stockpiles generated during the Cold War (Uranium byproduct)
- Zhovti Vody mine in Ukraine (Uranium and iron byproduct)
- Kola peninsula, Russia (Apatite byproduct)
- Rare earth mines in Bayan Obo, China

However new projects are emerging with various Scandium production potential such as:

- Nebraska (US) mine by NioCorp Development Ltd and Traxys: **60T/y** (Niobium byproduct)
- Philippines mine by Nickel Asia Corp. and Sumitomo Metal Mining: **8T/y** (Nickel byproduct)
- New South Wales mine (Australia) by Scandium International Mining Corp: **5T/y**
- European SCALE Project to recover Scandium from aluminium bauxite

Those upcoming projects could rapidly double the worldwide Scandium production and enable to establish an industrial Scandium supply.
The current elevated price of Scandium (3000 -5000 $/kg for Scandium oxide) may also be maintained artificially high by financial speculation on those projects.

In conclusion, Scandium current low production is not due to the lack of demand but rather to the lack of supply. The future supply chain structure should enable a greater access to the use of this remarkable element in the near future, especially in the form of Aluminium-Scandium alloys.

DOI: 10.13009/EUCASS2019-677

4.2.3 Next steps

The mechanism bracket demonstrator performances will now be assessed (comparatively to the same AlSi7Mg0,6 bracket type) in terms of:

- Dimensional accuracy (inspection of the post-machined interfaces by contact probe + shape comparison to the 3D file by CT scan)
- Roughness
- Material integrity evaluation (defects detection by Computed Tomography Scan with a resolution of 150µm)
- Weight
- Mechanical behavior analysis

CNES will support another step of the study to be started before the end of the year 2019 to increase again the maturity level of this material handled by LISI AEROSPACE AM for space applications and with the lessons learnt from the current results.

It is foreseen to address several topics, such as:

- Use of a larger machine and a more productive set of parameters for producing a larger demonstrator
- Continue the mechanical characterization (both static en dynamic) possibly with some different finishing states and / or temperatures
- Establish mechanical allowables values for sizing, based on several jobs results
- Check the density of the material
- Check the molecular and particular cleanliness after standard cleaning process
- Address corrosion and stress corrosion resistance
- Assess the weld ability
- Establish torque / tension relation for screwed assemblies

5. Conclusion

These first results on Scalmalloy® demonstrate that it is a very promising material for the space market. The main applications for THALES ALENIA SPACE with this new alloy material are structural parts (even parts subject to fatigue or to high static load), especially when aluminum alloys are required for thermal reasons. The outstanding properties found during this study also allowed us to foresee other types of applications such as thermal application or radio frequency components.

New developments will now be carried out to reach the industrial maturity level required for production.

References

[1] Spierings, Adriaan & Dawson, Karl & Voegtlin, Mark & Palm, Frank & Uggowitzer, Peter. 2016. Microstructure and mechanical properties of as-processed scandium-modified aluminium using selective laser melting. CIRP Annals - Manufacturing Technology. 10.1016/j.cirp.2016.04.057.

[2] Spierings, Adriaan & Dawson, Karl & Kern, K & Palm, Frank & Wegener, Konrad. 2017. SLM-processed Sc- and Zr- modified Al-Mg alloy: Mechanical properties and microstructural effects of heat treatment. Materials Science and Engineering: A. 701. 10.1016/j.msea.2017.06.089.

[3] Spierings, Adriaan & Dawson, Karl & Uggowitzer, Peter & Wegener, Konrad. 2017. Influence of SLM scan-speed on microstructure, precipitation of Al 3 Sc particles and mechanical properties in Sc- and Zr-modified Al-Mg alloys. Materials & Design. 140. 10.1016/j.matdes.2017.11.053.

[4] Palm, Franck & Leuschner, Ronny & Schubert, Thomas & Kieback, Bernd. 2010. Scalmalloy® = A Unique High Strength AlMgSc Type Material Concept Processed by Innovative Technologies for Aerospace Applications. PM2010 World Congress – PM Aluminiumn and Magnesium 2

[5] Awd , Mustafa & Tenkamp , Jochen & Hirtler , Markus & Siddique , Shafaqat & Bambach, Markus & Walther, Frank. Comparison of Microstructure and Mechanical Properties of Scalmalloy® Produced by Selective Laser Melting and Laser Metal Deposition. Materials 2018, 11, 17.

[6] Thomas, Marc & Davoine, Cécile & Drawint, Stefan. Techniques de l’ingénieur - Fabrication additive en aéronautique et en spatial 2019,05,10

[7] J.N. Pelton et al. (eds.), Handbook of Satellite Applications, # Springer Science+Business Media New York, 2016