MAMC2016 – 2nd Congress on Innovations in Metal Additive Manufacturing

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Introduction:

More than 220 participants from 16 nations have participated at the second Metal Additive Manufacturing Conference MAMC at voestalpine Stahlwelt in Linz, from Nov. 24-25, 2016, which was organised by the Austrian Society for Metallurgy and Metals (ASMET). In 35 oral presentations and an exhibition newest trends and very innovative developments along the entire processing chain as well as novel applications have been presented. Some of the most interesting statements and developments will be reflected here. AM is a highly dynamic market. The worldwide market size in 2015 was around 5.000US$, showing a growth of more than 25% compared to the previous year. In every year since 2010 the AM market has shown an annual growth of at least 24%[1]. The metal market is of special interest in AM, since it has a significant strategic importance for fields like energy and aerospace industry. The growth in this field has been impressive in the last years. Machine sales in metal AM went up 45% from 2014 to 2015, and more than 800 metal AM-systems were sold in 2015. The opportunities connected with such a dynamic technology raises interest in the Austrian materials and machinery industry, as indicated by the numbers of participants and oral presentations at MAMC.

A further clear indication of the relevance of AM for Austrian industry was given in the first talk of the conference. Franz Rotter, head of the voeastalpine's Special Steel Division and head of ASMET, pointed out that he has set a clear focus on Metal Additive Manufacturing, not only by installing an AM-Center in Düsseldorf, but also by offering new metal powders especially for tooling applications.

1 Overview on AM-processing

Prof. R. Poprawe, the head of the Chair for Laser-Technology at RWTH Aachen, started with an overview on the role of Additive Manufacturing Technologies (AMT) within the envelope of "Technology 4.0". He illustrated the RWTH view on Integrative Production Technology and explained the basics of laser technology at its interaction with the different materials. He showed some examples on graded materials (e.g. with ductile core and wear resistant surface) as well as hybrid materials (e.g. Stellite on copper alloy). High speed LMD using primary energy deposition into the

[1] Wohlers report 2016, 3D-printing and additive manufacturing: State of the industry, Wohlers Associates, 2016

powder has been used for large components. Hybrid machine concepts like those of the DMG Mori Lasertec concept have also been highlighted. Regarding Selective Laser Melting (SLM), the way from prototyping to first series production in a large scale (motor block) has been shown with many interesting new applications, always indicating no waste, no tools and no joining. Typical AM-examples in the automotive industry are shown in figure 1.

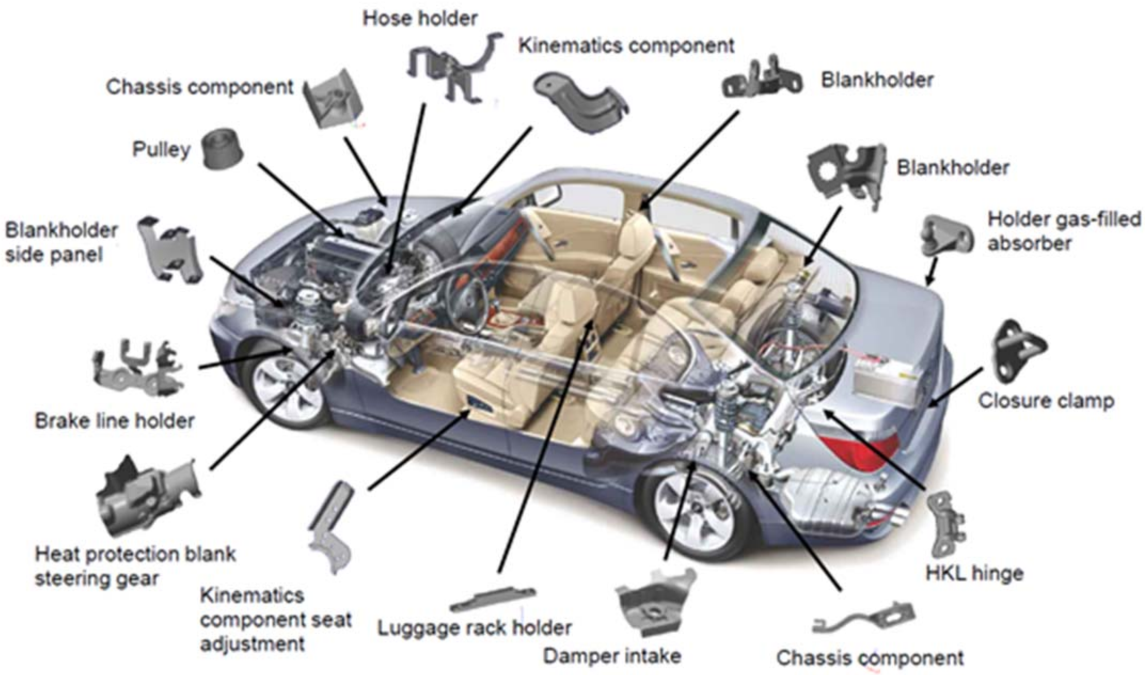

Figure 1: Laser Additive Manufacturing – Automotive Examples, Source: N.Skrynecki, Kundenorientierte Optimierung des generativen Strahlschmelzprozesses, 2010

Bionic inspired designs will tell the production system what it wants to be in terms of functionality and the production system designs the product as well as material and prints it. The integrative research needs knowledge on material, processes, machines product design and business models. The functionality needs to be translated into a design, addressing the geometry and the material properties. AM offers a significantly enhanced design freedom, compared to state of the art manufacturing technologies. As shown in Figure 2, this design freedom can be used to create (bio-inspired) lightweight-structures. The component design with lattice structure can be load or functional adopted. An increased productivity via multiple laser sources, increase of laser power, application of a skin-core principle and new exposure concepts are proper ways to reach this goal.

Figure 2: Digital photonic production allows the fabrication offers tremendously increased design freedom compared to traditional manufacturing, leading to highly optimized metallic structures.

2 Market situation

Mr. Blitz from SMR gave an interesting overview about the overall market situation for metal powders. Figure 3 shows the share of different applications for metal powders. Despite the impressive growth numbers of AM in general, and metal AM in special, the absolute numbers are still small compared to other PM-technologies like Press/&Sinter, HIP and MIM. The analysis showed that, the AM powder market, exhibiting sales of $88 Mio. US$ in 2015[1], is only about 1% (in weight) of the overall worldwide powder market, but with increasing value. Concerning the time line, it has been shown that AM growth is much faster compared to HIP and MIM (especially in the last two years). Blitz also showed the price range of different metal powders and concluded, that the powder price could be 50% in the next 10 years.

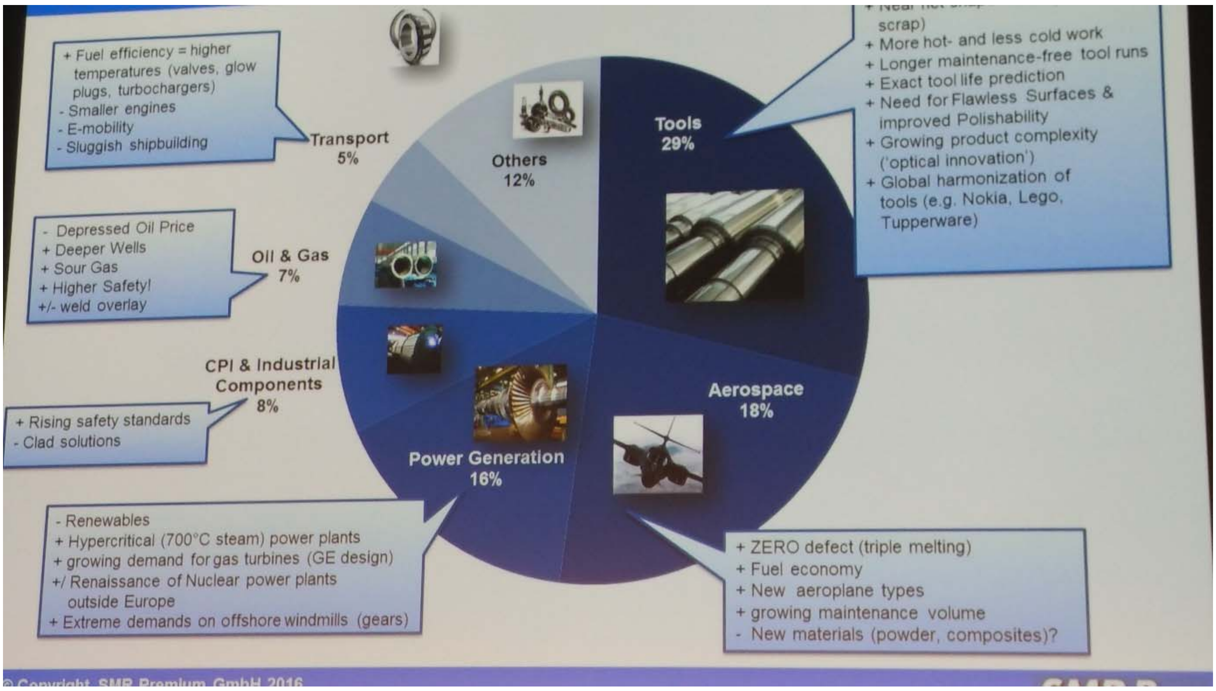

Figure 3: Share of world market of metal powders in different application fields.

3 Metallurgical aspects of SLM

3.1 Characterization of processing and service properties of different materials

Speakers from Uddeholm, FH-Wels and Montanuniversitaet Leoben showed some typical features during SLM-processing. Tool steels and the necessity for preheating to temperatures above 300°C, the influence of C-content on the likelihood for cracking. Prof.Dr. Thomas Niendorf from Kassel University showed very detailed investigations using TEM, EBSD and IPE. For steel grade AISI-316L, he also explained the quantitative difference on service properties, like fatigue limit, based on the processing conditions, i.e. the fatigue limit increased in the sequence as-built/SLM surface, as-built/turned surface, 650°C/turned surface and HIPed/turned surface. Using X-Ray diffraction, residual stresses were measured in all three directions. The highest internal stresses were found for y-direction (=building direction). As-built and heat treated samples showed elongated grains in building direction with a strong texture. This microstructure changed significantly after a HIP-treatment, which led to almost equiaxed, coarse without any texture. Prof. Niendorf also showed interesting creep curve results for SLM-nickel-base-alloy IN718 with superior creep strength. The effect of remelting to smooth the component surface and laser polishing using a defocused beam were demonstrated by CRM Group. Mr. Wu from voestalpine Additive Manufacturing Center in Düsseldorf presented a literature survey review on testing procedures and the multiple influence of process parameters at different length scales. Wallis gave an overview on the influence of process parameters on the hybrid joint between steel and copper. The fracture location was not found within the HAZ but in the copper base material. P.K.Gokuldoss from ESI Leoben has demonstrated how nano-structured alloys can be processed by SLM to tailor the mechanical properties by in-situ treatments. Pavel Krakhmalev from Karlstad University showed the solidification microstructure and texture of a austenitic stainless steel 316L, which can be controlled by a the crystallographic orientation of a colony and the laser movement direction.

3.2 Topology optimization and lattice structures

The basics and the strength of different approaches for topology optimization were comprehensively explained by A. Walzl, Leoben. He pointed out, that the different optimization methods need specific parameters to be successful, as shown in table 1. The final optimised, complex geometries are however not always producible in a conventional way, that is way AM has a superior position.

Tab. 1: Method dependent optimisation parameters

No.	OPTIMISATION METHOD	SCOPE OF APPLICATION	OPTIMISATION PARAMETERS
1	topology	• bulky solids and sheet metals • structure roughness depends on the used mesh (hex/quad vs. tet/tria) • subsequent machining necessary • gives possible proposals of the design	• fraction of volume/weight/mass • compliance / stiffness • displacement • stress, strain • fatigue • …
2	topography	• sheet metals only • increase of the moment of inertia • only for out-of-sight surfaces (because of beads) • increase of the stiffness without material addition	• localised or global stress/strain • adjustment boundaries (upper and lower limit) • symmetry (1-plane, 2-plane, cyclic, …) • depth and width of beads
3	shape	• bulky solids (surface) • adjustment of the surface depending on the load onset • reduction of critical areas primary • useful for abrupt geometry change	• localised stress or strain • notch stress • adjustment boundaries (upper and lower limit)
4	size	• sheet metals and composites • optimisation of the sheet thickness • stress dependent	• stress/strain • sheet thickness • composite thickness • frequency
5	lattice	• bulky solids • development of lattices depending on the existing mesh • further lightweight possibility • arbitrary cell structures possible • open/closed cells • structured → lattice • non-structured → foam	• stress dependency • thickness of struts • mesh size (cell size = element size) • mesh type (hex/quad vs. tet/tria) • relative density (upper and lower limit) • increments between density limits (P-value → high, med, low) • sensitivity of normalised stress (k-value)

Additional cases with high commercial potential were shown by Mr.Schäfer from FIT Production GmbH. Mr. Schäfer also mentioned the balance between cost and benefits especially when they are compared with conventional manufacturing processes. Design aspects are not enough, there is also a need for support minimization and reduction of machine cost, which contribute to about 80% to the overall costs. The scrap proportion has to be kept below 30%. Quality assurance measures and data analysis as well as testing (CT scan) are part of the game. Karl Neulinger from AIM Sweden showed EBM applications and explained the pros of the ELISE concept, a tool for topology optimization. Similar examples were shown by Ziegler from ILT/RWTH Aachen, where lattice structures as well as hollow sphere structures were made out of steel. The values for stiffness and specific energy absorption were evaluated for different wall thicknesses and cell sizes to determine scaling laws for practical applications. Kellermeyer from CADFEM showed the complete processing from design and engineering by topology optimization to production and testing of an additive manufactured jump robotic leg.

3.3 Process Simulation

Zielinski and coworkers from Aachen investigated numerically the spatial distribution of individual particles and used two different methods, a) a discrete element method and b) a volume-to-fluid method (melting of the powder particles and solidification to a solid). The results provided insights on how the powder bed packing density affects the AM process and the final product quality. The melted area along a single track is shown in Figure 4.

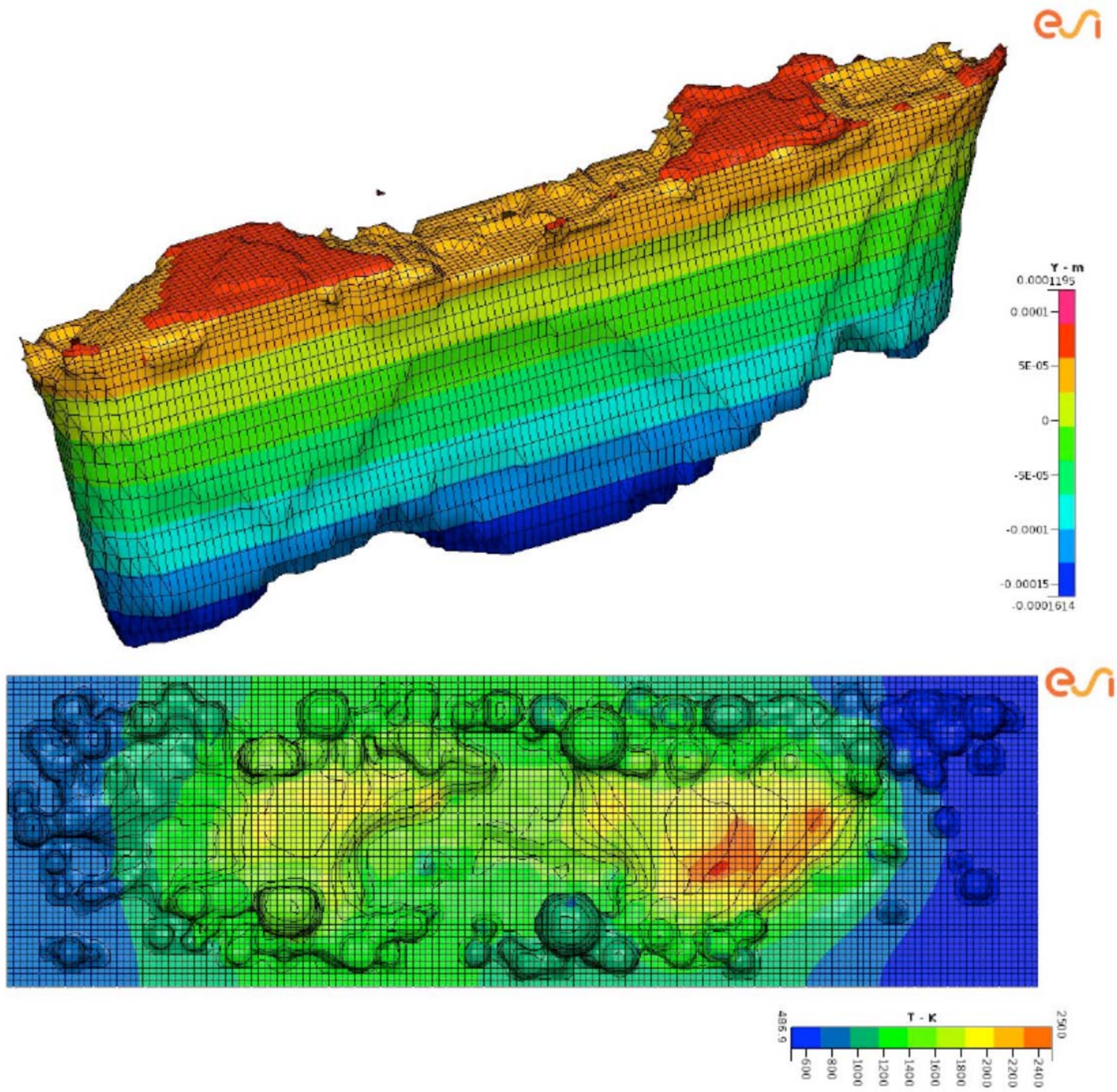

Figure 4: top: melted volume along a single track; bottom: top view of the same track

4 Further Applications

Mr. Hatos from Györ explained his work on conformal cooling and copper-based inserts to achieve a good thermal management. Huskic refered on selective laser cladding of hot stamping tools, which are made of steels with high thermal conductivity and wear resistance. The state of the art of detection of SLM defects either by in-situ monitoring or by NDT methods was presented by Prof. R.Pichler from TU Graz.

Finally, the keynote lecture by Dr.Pirklbauer from AIRBUS introduced the auditorium into the world of novel light weight designs in the aerospace industry. He explained in detail how to build a bionic (water lily) inspired cabin wall component out of an AlMgSc-alloy. He also mentioned the industrial need for increase in geometric volume, speed and laser power at high building rate.

5 Conclusion

Compared to the last MAMC-Conference in 2014, a significant progress regarding material aspects, understanding of the SLM process and exploitation of new applications can be confirmed. For lightweight use, like for aerospace and space application, a clear decision for Metal Additive Manufacturing could be realised. SLM is used more and more for very special niches, where there is also a high demand for excellent metal powders and special alloys as well as graded structures and hybrid joints. Topology optimization in combination with lattice structures are outstanding solutions for light weight constructions, in which special software tools are necessary. The final decision between conventional manufacturing processes and SLM-production is still a matter of economics, which depend on productive production machines for AM. However, the recent presentation show a significant increase of effort in all fields to promote SLM for many interesting applications, and it can be stated that metal AM has fully arrived in the daily work of industry.

REMARKS: Details of the presentations can found in the conference proceedings, which can be ordered from ASTM secretariat (Yvonne.Dworak@asmet.at).

The third MAM-Conference will be from 20th to 22nd November 2018 in Wr. Neustadt, Austria.

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