Final report for the project SAMw

Purpose of the project SAMw*

The purpose of this project was to develop the Laser Metal Deposition (LMD) process to enable successful manufacturing of a DSS2205 demonstrator with similar geometry as the real application. In parallel, a simulation model for the same process manufacturing, but also for Ti-6Al4V, will be developed and validated with regard to predicting formation of pores in the melt pool related to applied process parameters. The project also involves two PhD students, one focused on modelling of the melt pool of Ti-6Al-4V and one focused on the metallurgical characterization and understanding of LMDw of DSS, both will nearly finish within the time frame of the project.

**SAMw stands for Synergi for AM using laser beam source and Wire*

Project goals

The project is divided into three work packages, which are Thermal history & Geometry (**T-SAMw**), Process Monitoring (**P-SAMw**) and Materials (**M-SAMw**).

T-SAMw - focuses on simulation and modelling of the built material, including predicting thermal history. Within T-SAMw the goal is to develop simulation models, provide knowledge and understanding of the physics taking place while the energy source (LB), the additive material (Ti-6Al-4V and DSS 2205) and the base/built material interact during the layer-by-layer LBAMw deposition process. This also includes the thermal history during single and multi-layer deposition, the geometry, and concerning defects the possible formation of pores, as well as evaluating risk of lack of fusion. This requires model development and model application.

P-SAMw - focuses on on-line monitoring (temperature, geometry, currents/resistance) and the development of a regulation system for process control. Within P-SAMw the goal is to determine what sensors to use for in-process monitoring, and what control functions need to be developed. Monitoring and sensor-based control tools will be developed based on the process knowledge gained in T-SAMw to maintain the material properties of the manufacturing product within the defined window. Iterative interactions with M-SAMw and T-SAMw will take place in order to validate the solutions and refine them as needed. The development of thermography as a technology for possible early detection of surface defects of multi-layer deposits with limited access will also be conducted.

M-SAMw - focuses on the metallurgical aspects of built material, including microstructure and defect characterization and their relationship with mechanical properties. The alloys Duplex Stainless Steel 2205 (DSS2205) and Ti-6Al-4V (Ti-64) are explored. The goal within M-SAMw is to characterize the microstructures and metallurgical aspects in both these alloys, and support T-SAMw to develop process parameters which enable successful additive manufacturing of DSS2205 with appropriate fractions austenite/ferrite in order to keep good enough corrosion resistance in as deposited DSS2205.

Project plan

One of the main targets of the project was to develop the LMDw process for a completely new alloy in this process, namely DSS2205, and to demonstrate the technology by manufacturing a component like geometry and if possible test this component in a relevant environment (i.e. researching ~TRL6). The project managed, with important support from Procada (consultant), to manufacture this demonstrator, which Alfa Laval heat treated and machined into final component geometry, and finally also mounted in their test separator and ran it with success.

For the LMDw process to become fully mature, more research and development work is needed though, not least on the advanced process monitoring and control system fields. The demonstrator was successfully manufactured thanks to very skilled technicians and research engineers, but to fully automate this LMDw process and to include a corrective adaptive control system for assuring the high material quality needed, more work is needed.

Since defects plays a crucial role for dynamic properties, such as fatigue strength, and since the two large end users in this project targets high-end applications (i.e. fatigue strength is important, which is limited by defects), it was the projects intention already from start to try and model how possible defects forms during the LMDw process. The modelling work was deliberately focusing the alloy Ti-6Al-4V, led in its own work package. This work is highly complex, and the models developed advanced. Even so, with support from GKN that did selected experimental trials dedicated for validation of the model, this work rendered in a validated and accurate simulation model for the LMDw process of Ti-6Al-4V where pore formation related with process parameters is captured in the model.

To achieve a continuous involvement of all partners the project had scheduled 4 project meetings every year, from which two where in real life while two meetings were held as on-line meetings (Zoom or Teams). When the pandemic hit the world, all meetings were held as on-line meetings. In the end of the project however, the pandemic restrictions were released enough to enable a physical meeting that was done here at Production Technology Centre in Trollhättan, with all project partners attending. This was fortunate since it enabled the project to fulfill the second out of two important milestones (the first milestone was to manufacture the demonstrator), i.e. a workshop with all partners about the results and outcomes from the project including a demonstration in the LMDw cell, as well as discussing future needs and plans for continued work post SAMw.

The staff and needed competences followed the original plan to a large extent. The same goes for the budget. Regarding the time plan, the project needed to be extended with 2 months because of a delay in getting the new laser system implemented at PTC and up running (the delay was mainly because of the pandemic situation - one sub-supplier with parts for the new laser optics did not deliver the parts in time). Thanks to the approved project extension, and hard work from the research engineers and partners during the summer in 2021, the project managed to achieve all planned goals and deliverables in line with the initial project plan.

Scientific achievements

Conference presentations:

• IIW- Intermediate meeting IX-H-919-2021 (online): Wire Laser Metal Deposition of Duplex Stainless Steel Components. Amir Baghdadchi, Vahid A Hosseini1, Maria Asuncion Valiente Bermejo, Björn Axelsson, Ebrahim Harati, Mats Högström, Leif Karlsson.

• IIW- Annual Assembly IX-2732-2021 (online): Wire Laser Metal Deposition of Duplex Stainless Steel Components. Amir Baghdadchi, Vahid A Hosseini, Maria Asuncion Valiente Bermejo, Björn Axelsson, Ebrahim Harati, Mats Högström, Leif Karlsson.

• Swedish academic conference for metal additive manufacturing hosted by the Swedish arena for metal AM. The conference will be held online January 11-12th 2021. “Additive Manufacturing of Duplex Stainless Steel by Laser Metal Deposition with Wire”. Amir Baghdadchi, Vahid A Hosseini, Maria Asuncion Valiente Bermejo, Björn Axelsson, Ebrahim Harati, Mats Högström, Leif Karlsson

• EUROMAT 2021 (European Congress and Exhibition on Advanced Materials and Processes) to be held in September 12-16, 2021. “Additive Manufacturing of Full-Size Duplex Stainless Steel Components by Laser Metal Deposition with Wire”. Amir Baghdadchi, Vahid A Hosseini, Maria Asuncion Valiente Bermejo, Björn Axelsson, Ebrahim Harati, Mats Högström, Leif Karlsson. Poster on-line.

• Influence of Laser Beam Shaping on Melt Pool Thermocapillary Flow, presented and published in HTFF20- August 2020.

• CFD-simulation assisted feasibility study of laser metal wire additive manufacturing for on-orbit applications, On-orbit Manufacturing and Assembly Technologies for Future Space Activities, 2022. – Abstract accepted in Nov. 2021.

Journal publications:

• M.A. Valiente Bermejo, K. Thalavai Pandian, B. Axelsson, E. Harati, A. Kisielewicz, L. Karlsson. Microstructure of laser metal deposited duplex stainless steel: influence of the shielding gas and heat treatment. Welding in the World 65, 525-541 (2021). https://doi.org/10.1007/s40194-020-01036-5

• A. Kisielewicz, K. Thalavai Pandian, D. Sthen, P. Hagqvist, M.A. Valiente Bermejo, F. Sikström, A. Ancona. Hot-wire Laser Directed Energy Deposition: process characteristics and benefits of resistive pre-heating of the feedstock wire. Metals 2021, 11, 634. https://doi.org/10.3390/met11040634

• Noori Rahim Abadi, Seyyed Mohammad Ali, Mi, Yongcui, Sikström, Fredrik, Ancona, Antonio, Effect of shaped laser beam profiles on melt flow dynamics in conduction mode welding, published in the international journal of thermal sciences, 2021, ISSN 1290-0729, E-ISSN 1778-4166, Vol. 166, p. 1-15, article id 106957

• Noori Rahim Abadi, Seyyed Mohammad Ali, Mi, Yongcui, Sikström, Fredrik, Choquet, Isabelle, Modelling of beam energy absorbed locally in conduction mode laser metal fusion, published in Journal of physics. D, 2021, Applied physics, ISSN 0022-3727, Vol. 55, no 2, article id 025301

• Amir Baghdadchi, Vahid A Hosseini; Maria Asuncion Valiente Bermejo; Björn Axelsson; Ebrahim Harati; Mats Högström; Leif Karlsson. Laser Metal Deposition of Duplex Stainless Steel− As-Deposited and Heat-Treated Microstructure and Mechanical Properties. Submitted to the Journal of Materials Science for the special issue on “Microstructure design in metal additive manufacturing – physical metallurgy revisited”. Submitted 2021-08-11.

• Amir Baghdadchi, Vahid A Hosseini; Maria Asuncion Valiente Bermejo; Björn Axelsson; Ebrahim Harati; Mats Högström; Leif Karlsson. Wire Laser Metal Deposition Additive Manufacturing of Duplex Stainless Steel Components− Development of a Systematic Methodology, published 2021 in Materials, E-ISSN 1996-1944, Vol. 14, no 23, article id 7170

Co-production achievements

The research work in SAMw has been very applied, i.e. in close collaboration with industry. For example, the LMDw manufacturing of test samples of DSS2205, and eventually a complete component, was conducted at University West, while heat treatments and mechanical/corrosion testing was performed by Alfa Laval, and finally the results gathered by University West, which rendered in several publications with authors from both University West and Alfa Laval.

Another example is within the sub project T-SAMw, which involved modelling of the LMDw process for Ti-64. The process model developed within T-SAMw needed validation experiments, which were performed by GKN Aerospace at Production Technology Centre.