End report KK profile SUMAN-Next

2020-10-28

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1. The benefit of the profile to the university

Introduction

University West, established in 1990, is one of the country's younger universities and has grown rapidly to over 12,000 students and over 600 employees. The range of education is broad and to a large extent focused on professional areas. During the university's first 15 years focus has been on building up a significant breadth within the education. Research has intensified over the past 10 years and production technology is today the largest research area and the base in the research environment Primus. A special focus in the development work is currently the construction of complete academic environments, i.e. environments where education at undergraduate, advanced, and doctoral level are performed and where research is conducted with the highest international standard. Production technology and WIL have a special priority in this context because the university has a permit to examine doctors in these two areas. The research profile SUMAN and the follow-up profile SUMAN-Next have been valuable in this work as they have contributed to developing the research connection in undergraduate education, contributed to the development of educations at advanced level (Robotics, Automation and Materials and Manufacturing technology and Additive Manufacturing) and also significantly contributes to our research production (Fig. 1 and Fig. 2).

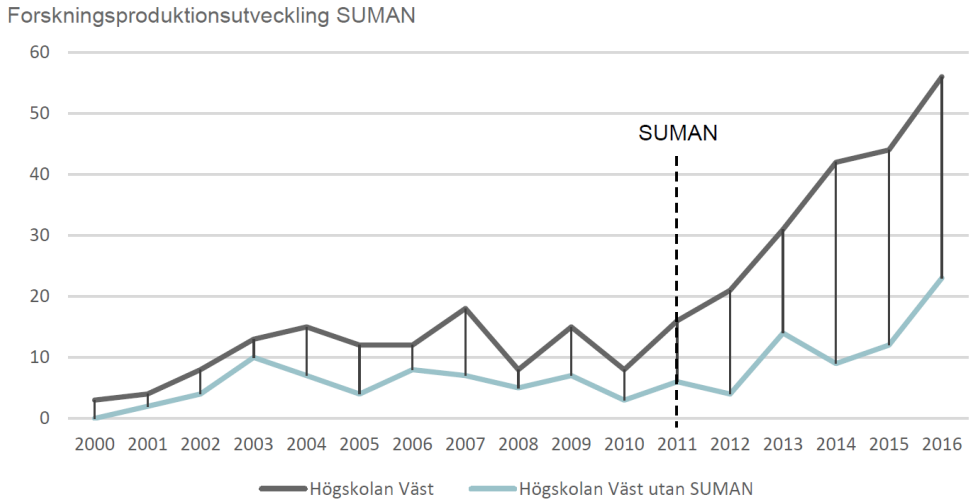

Figure 1. Development of research production at University West. Source: DAMVAD 2016, based on data from Scopus.

Many degree projects (11 theses works) have been carried out under the supervision of SUMA-Next´s researchers, which also has been valuable for strengthening the link between education and research. The research group has also been involved in life-long learning activities i.e. besides seminars and workshops developed and conducted several courses for professionals.

Growth into an internationally competitive research environment

The profile SUMAN covered three different manufacturing technologies (welding, thermal spray and additive manufacturing i.e. metal deposition and powder bed fusion). Additive manufacturing was focused on in SUMAN-Next since it was an area in which the research group saw both a national industrial research need and an area where the research group had the potential to position itself internationally. In this context it is interesting to note that the powder bed fusion had only been initiated at the start of SUMAN-Next but is today the area that expands the most! In SUMAN, research was also conducted in several different material areas unlike SUMAN-Next which focused on the superalloy IN718. This process and material focus in SUMAN-Next made it possible for the research environment to position itself internationally, see Figure 2.

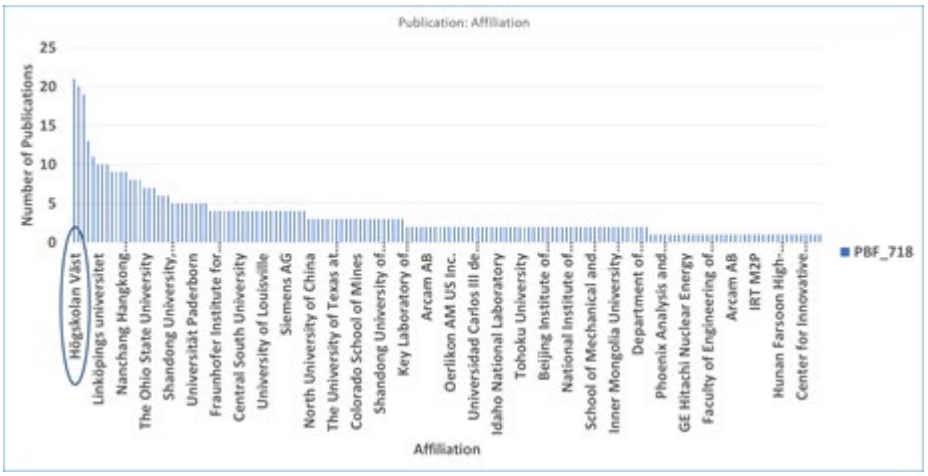

Figure 2. No of publications within powder bed fusion (PBF) and IN718, 2019

Besides the impressive array of publications in highly reputed journals and conference proceedings (22 journal articles and 10 conference articles) a wide network of academic collaborations was established in SUMAN-Next that have resulted in invitations to participate in global network projects, keynote/invited talks at major conferences and also attracted foreign experts to on guest/visiting assignments at our university. SUMAN-Next has also contributed to our licentiate and doctor degree production (two PhDs and four licentiates that will have their dissertation in 2020). The profile has also enabled strategic recruitment. From a handsome number at start to: 7 Full-time Senior Researchers, 9 Part-time Senior Researchers, 4 Post-Docs, 10 PhD students and 7 Research Engineers/Lab Assistants.

Establishment of networks for co-production

SUMAN-Next has also strengthened our collaboration with the project partners: GKN, Siemens, Sandvik, Arcam, Quintus and Element and has also played a major role in the department of Engineering Science co-production development. Not least in the powder bed area, in which the network has expanded and today spans over the entire value chain from material manufacturers, equipment manufacturers, service providers to final manufacturers. It is also very gratifying to see that the new collaborations initiated within the framework of SUMAN-Next have been developed and that the companies are participating in more and more collaboration projects. The profile has formed a platform within the framework of which a number of new interesting research questions have been crystallized, that has led to a significantly increased project portfolio (Fig. 3) and additive manufacturing is today by far the largest research area in the KK environment Primus.

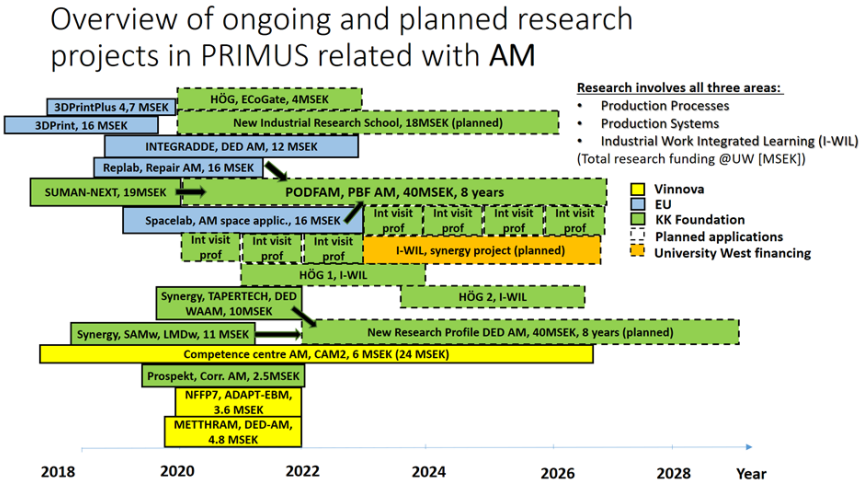

Figure 3. Research project portfolio within additive manufacturing.

Effect on external funding

The external funding has also increased during the implementation of the research profile. It has had a steadily increasing trend during the profile's years and constitute in productions technology today of more than SEK 64 million. SUMAN- Next's area as stated above dominates the university's externally funded research. SUMAN-Next has significantly contributed to this development through its strategic focus, it´s long-term perspective and planning horizon which included the newly started follow-up profile PODFAM that will ensure a further growth.

Establishment of national and international collaborations

The university's collaboration with other universities and institutes, both nationally and internationally, has also been strengthened during the research profile. An example in this context is the national arena in 3D printing, which was created together with Chalmers and Swerea. The vision for this arena is to create a world-leading position for Swedish industry in 3D metal printing that drives innovative product development and manufacturing and that supports Swedish reindustrialization. The three research performers today have a well-functioning collaboration. Another example is CAM2, the Vinnova Excellence Centre within additive manufacturing, which is coordinated by Chalmers and with University West and Linköping University as academic partners, a partnership that has been significantly strengthened through the profile. Examples of international links that have been established are Oak Ridge National Laboratory, University of Manitoba, University of Waterloo, North Carolina State University, Indian Institute of Technology-Bombay, NTNU-Singapore, University of Sheffield, Monash University, University of Idaho and McMaster University.

Contribution to Lifelong learning and new educations

Lifelong learning and skills development of professionals is an important part of companies' strategy to retain and develop professional skills and competence. University West has a strong ambition to develop needs-adapted education activities based on modern information technology that can be implemented in flexible forms. SUMAN-Next has also contributed to this area through the researcher's engagement in the KK-funded project Prodex developing additive manufacturing courses that meet the needs of the manufacturing industry. Through the close collaboration with the companies, the expert competence of participating companies could be utilized in this development (the research group currently regularly offers four different courses in additive manufacturing for professionals). In 2020 the department also decided to offer an international master's program in additive manufacturing, to be started autumn of 2021. The education program is now under development and several courses will be given in flexible form and offered as independent courses. International industrial internships are also planned in this program which also will strengthen our national and international partnerships. The company contacts established within the framework of SUMAN-Next has been valuable in the construction of this international network.

In summary, it can be said that the research profile has been very valuable for the strategic development of the university where production technology runs as a common red thread from undergraduate education via magister / master's, doctoral education to research. The profile has given international competitiveness, has significantly contributed to developing the link between education and research, and developed the university's collaboration with industry and at the same time strengthened its industrial partners competitiveness. The profile has also been very valuable in developing our internationalization and our collaboration with internationally leading academic environments.

2. Development of the Research Environment

The project SUMAN-Next was conceptualized by considering the varied ambitions of all the stakeholders involved. The primary motivation was provided by the emergent worldwide trends in the domain of production technology to exploit additive manufacturing (AM) routes and the need for the Swedish manufacturing industry to keep pace with the developments to remain globally competitive. However, the project aims were also formulated combining (a) the aspirations of the research environment at University West (HV); (b) the need to address diverse scientific challenges at various levels to develop an in-depth understanding of the field for laying a sound foundation within the consortium for creating niche expertise; (c) the overall long-term goal of the partner companies to subsequently spur industry-relevant AM technology development based on the above. It is clear, as described below, that all the above goals have been successfully achieved during implementing project SUMAN-Next.

Development of the Research Environment

When the SUMAN-Next application was submitted, it was envisioned that it would lead to benefits at multiple levels. At the University level, it was imagined that it would lead to development of a hub for its continued strategic development particularly by attracting further grants, enabling strategic recruitment, augment collaboration and benefit education. This has clearly been the case as evident from the following.

Expanding project portfolio

Apart from being an important cog in the University's strategy and constituting a prominent part of its AM project map at the time the project was granted, the significant accomplishments and visibility made possible by SUMAN-Next have provided an ideal springboard for the environment to remarkably expand its AM activities. This is amply evident from HV's existing AM project portfolio illustrated in Fig. 4 below:

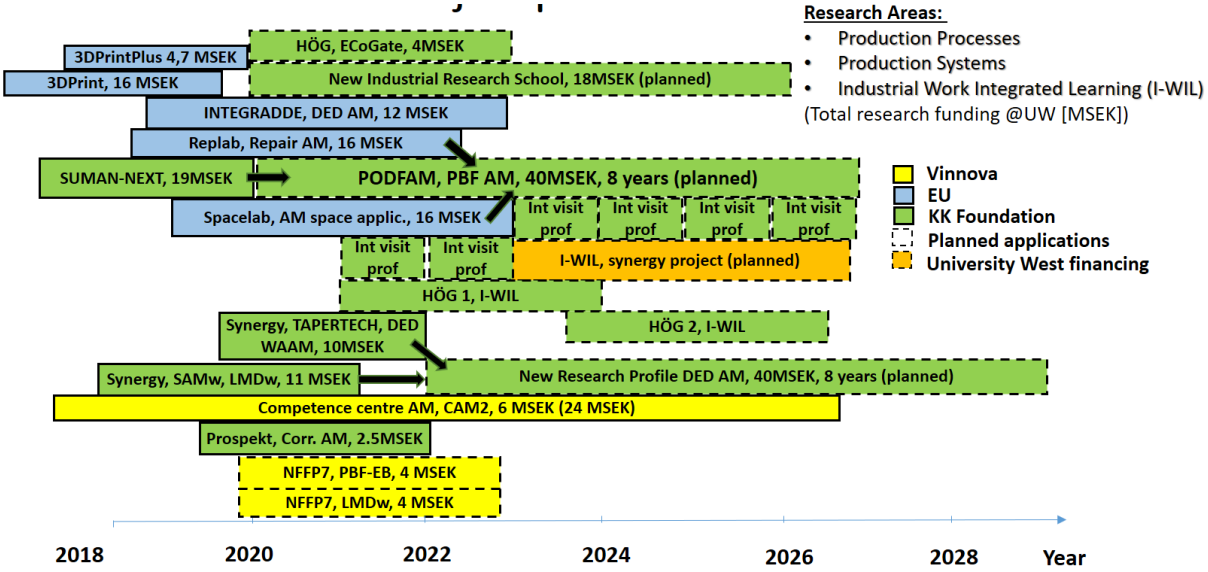

Figure 4. Enhanced project portfolio at University West

Enabling strategic recruitment

Apart from catalyzing a significant upsurge in AM related activities at HV, SUMAN-Next has also been singularly responsible for all round growth in the environment as related to AM. The activities within the project have been valuable for HV's recruitment of national and international researchers, which has not only significantly strengthened and diversified HV's research capabilities but has also allowed induction of scientifically competent staff for teaching activities teaching. The greater visibility of the environment within the AM domain because of SUMAN-Next has contributed to the advertised positions receiving many interesting applicants and this has also been confirmed during conversations with those recruited to the positions. The overall growth because of the new recruitments is apparent from the handsome increase in the number of personnel at HV who now participate in AM-related research. The AM Team and HV currently comprises 7 Full-time Senior Researchers, 9 Part-time Senior Researchers, 4 Post-Docs, 10 PhD students and 7 Research Engineers/Lab Assistants.

Infrastructure build-up

The sharp increase in AM-related projects at HV since SUMAN-Next has also supported augmentation of facilities to keep pace with increase in manpower. Most prominent has been the acquisition of the powder bed fusion by electron beam (PBF-EB) equipment (ARCAM A2X), which had been established in anticipation of SUMAN-Next. During the tenure of SUMAN-Next, HV also acquired a time share in a powder bed fusion by laser beam (PBF-LB) facility at RISE. Both have made HV uniquely qualified among all the academic institutions in Sweden to logically initiate a dedicated effort on PBF-AM of Ni-based superalloys and Ti6Al4V to further build upon the outcomes of SUMAN-Next. The above availability of PBF-EB and PBF-LB facilities, and the cultivated expertise in these areas, has been augmented by a Gleeble thermal mechanical simulation system and field emission gun scanning electron microscope (FEG-SEM) installed during recent years. This has made HV ideally suited to spearhead major initiatives in the AM domain.

Education and human resource development

Another significant outcome of SUMAN-Next has been the opportunity that it has provided for meriting researchers and educating employable manpower in the emergent technological field of AM. At educational level, the project has allowed bachelor, masters, and doctoral students to be engaged in the emergent AM technologies through course modules, project- and thesis works. A total of 9 PhD students were associated either fully or partially with SUMAN-Next; among them, 2 completed their PhDs during the tenure of the project while 5 others completed their Licentiates. 10 Master's thesis projects and 4 Bachelor/internship projects were also anchored to project SUMAN-Next. As far as basic education is concerned, research results have been continuously integrated into teaching through active participation of senior researchers involved in SUMAN-Next in teaching, and also through the participation of doctoral students. All master level thesis projects have also been carried out under the supervision of researchers involved in the project. New basic and advanced education courses related to AM have also now been initiated at HV. These include a 7.5 credit Master course Additive manufacturing (ADT600) as well as a 7.5 credit course "P20 – Additive Manufacturing Technologies for Metals" that is being offered along with Örebro University and Mid University, as part of Graduate School Produktion2030. Four Prodex courses on AM targeting industry professionals have also been organized and have been an important part of dissemination. Additionally, a new two-year Master Program in Manufacturing Engineering with specialization in Metal Additive Manufacturing has also now been conceptualized at HV and will be offered from Fall 2021.

Establishment of networks for co-production

At co-production level, SUMAN-Next has significantly strengthened HV's collaboration with all project partners, namely GKN, Siemens, Sandvik, Arcam, Quintus and Element. It may be noted that the above industrial partners who were involved in SUMAN-Next represent globally competitive Swedish industries who aspire to stay ahead in their respective fields. The collective experience from the consortium played a major role in accomplishing the project goals and ensuring efficient industrialization of research results. Thus, SUMAN-Next successfully achieved one of the main overarching goals of building a strongly profiled knowledge, while simultaneously strengthening national competitiveness through co-production with collaborating industries. Such networking has enabled us to derive synergy from the respective complementary knowledge and experience that existed within the consortium. The willing participation of all these companies (except Element) in a dedicated powder-bed fusion specific research profile (PODFAM) following the conclusion of SUMAN-Next is an affirmation of the benefits that they have derived through co-production with HV. The expansion of the project portfolio has served to expand this network further considerably, for the benefit of both HV and the partners. The students, senior researchers and industry representatives associated with SUMAN-Next were all actively involved in bi-annual technical seminars that were held all through the project period. This proved to be a good platform to assure the quality of the projects as well as maintain the desired balance between relevant scientific quality and industrial relevance of technical activities undertaken. Augmenting the twice-a-year technical seminars with more frequent separate meetings among active partners associated with each sub-area also proved to be a good model to increase collaboration between HV and the partner companies.

Thus, in summary, it is amply evident that project SUMAN-Next has fulfilled the originally stated desire of HV to provide a platform that will serve as a model for joint inter-disciplinary research and create a globally recognized vibrant research profile in AM that will serve the Swedish industry well for future innovations and technology developments in the field. It has also been demonstrated that this has already led to development of a hub for continued strategic development of HV, enabling strategic recruitment of promising and established researchers, empowering it to attract grants from other funding sources and thereby create a sound base for developing activities within the KK-environment Primus. It has supported the ambition of the University to merit its researchers, publish high-quality scientific papers and educate employable manpower in the emergent technological field of AM.

Growth into an internationally competitive research environment

Prior to embarking on Project SUMAN-Next, HV was already a core member in the Swedish arena for Metal Additive Manufacturing. The team at HV also had vast experience in metal wire additive manufacturing, powder deposition by laser and thermal spraying, as well as laser processing in general. HV was also considered to be among the top groups globally in robotized laser wire AM. However, SUMAN-Next has played a huge game-changing role in realizing the aspirations of HV to further bolster its global reputation in the field of AM. This has been made possible by the impressive array of publications (see Annexure) in highly reputed journals that have emerged out of the work carried out within SUMAN-Next and the concomitant visibility that the group has received. Another significant reason has also been the very wide network of collaborations that HV has succeeded in establishing during SUMAN-Next. The enhanced stature of the group has translated into invitations to participate in global network projects, deliver keynote/invited talks at major conferences, and in attracting foreign experts to HV on guest/visiting assignments.

Accomplishment of scientific goals

The scientific objectives that were sought to be realized through SUMAN-Next were manifold and were anchored to the various precisely stated research questions that had been a priori formulated. Addressing these questions comprehensively through co-production has led to the main objective of developing a fundamental understanding of the process-microstructure-property relationships being fulfilled. It is expected that this will eventually form the basis for enabling reliable fabrication of AM parts of desired quality. Specifically, meeting the stated goals has led to the following:

development of better insight into process parameter impact on microstructure, defects, homogeneity etc. during AM processing by various routes, including PBF-EB, PBF-LB and laser metal deposition with powder (LMD-p);

- understanding influence of post-treatment on microstructure and properties;
- development of a simulation-based predictive capability to forecast AM-built microstructures;
- identifying suitable sensors and methodologies to eventually permit reliable and adaptive process control during LMD;
- preliminary assessment of potential non-destructive approaches to characterize AM builds; and
- explore sustainability issues associated with AM processing

Accomplishment of parallel industrial objectives

Apart from addressing the specific stated scientific objectives, a significant aspiration of project SUMAN-Next proposal was to strengthen and contribute to competitiveness of partner user industries through development of robust procedures for processing of high quality AM structures. Consistent with the above, specific priority challenges for AM processing of the Nickel-based superalloy Alloy 718 by three AM routes, namely PBF-EB, PBF-LB and LMD-p, were comprehensively investigated. Although the near-term objective was to address only the above specific alloy within SUMAN-Next, it has also fulfilled the goal of setting the stage for more widespread investigation and adoption of AM technologies to meet the increasingly aggressive conditions that high temperature components are exposed to in gas turbines. This is reflected in the ambition of the entire consortium to further continue the joint development efforts in the form of a dedicated separate profile on powder bed fusion (PODFAM) that will include both a Ni-based superalloys' track and a Ti-alloys track. Thus, SUMAN-Next has also successfully met the long-term goal of laying the foundation for continued development of AM technologies for industrial benefit.

Establishment of links with other research groups

As already pointed out, the extremely close co-production relationship established with all the industrial project partners has now extended beyond SUMAN-Next via the eager participation of the companies in PODFAM, and HV's industrial linkages have further substantially grown by virtue of the growth in its project portfolio enabled by SUMAN-Next. In addition, yet another significant outcome of SUMAN-Next has been the creation of mutually rewarding links with several other national and international research groups with complementary expertise in AM and allied fields. Among such groups within Sweden, HV has now developed particularly close alliance with Chalmers, Linköping University and Luleå University, which is reflected in the joint publications that have emerged during the implementation of SUMAN-Next, as well as with SWERIM and RISE. Among the other extremely useful international linkages that have been established include Oak Ridge National Laboratory, University of Manitoba, University of

Waterloo, North Carolina State University, Indian Institute of Technology-Bombay, NTNU-Singapore, University of Sheffield, Monash University, University of Idaho and McMaster University. Some of these groups have also hosted PhD students associated with SUMAN-Next on long-term internships. Such national and international cooperation within SUMAN-Next has also played a key role in ensuring that the quality of the research remained at a high level.

3. Development potential and international positioning

Until SUMAN-Next was granted, there was no collaborative network in place that was devoted to AM of technologically important Ni-based superalloys. This research profile as well as other past research efforts admirably supported by the KK Foundation have enabled HV to carve out a niche for itself in the above domain. This is reflected aptly in the leadership position that HV occupies globally at the time of submitting this report, as far as publications related to PBF of Alloy 718 are concerned. Apart from the impressive publication numbers (Fig. 5) , the improved understanding on varied facets of AM of Alloy 718 spanning processing by both PBF and LMD routes, post-treatment, modeling & simulation, mechanical properties etc. that has resulted in a sound foundation that bears immense potential for further development of the research environment.

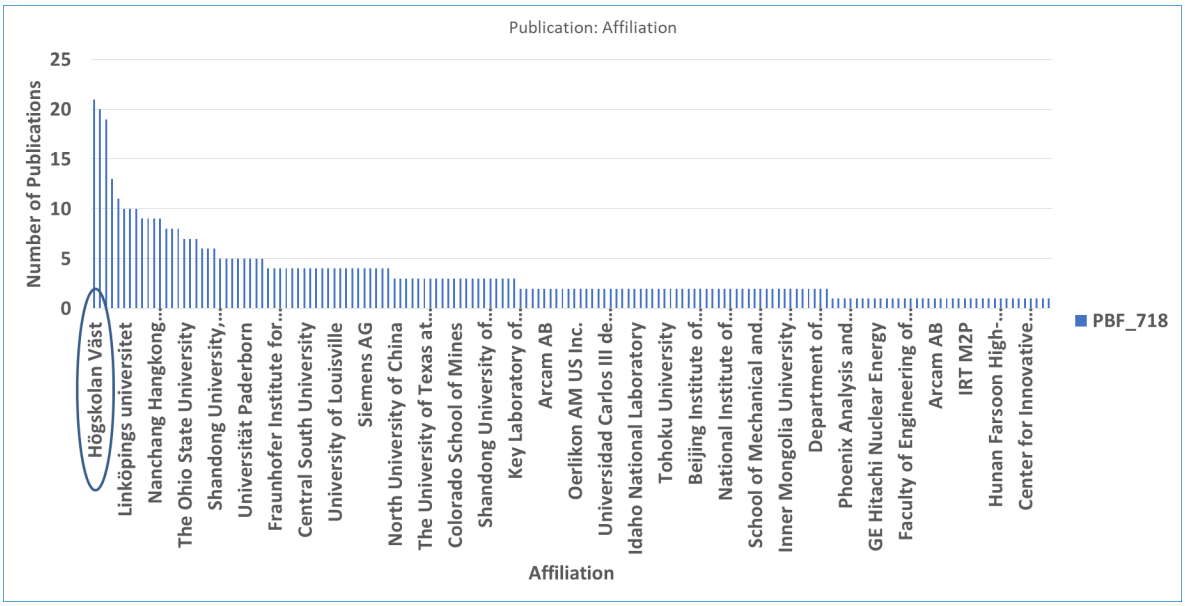

Figure 5. No of publications within powder bed fusion (PBF) and IN718, 2019

The next logical step in continued development of the overall research environment, based on the considerable learning from SUMAN-Next and improved appreciation of AM requirements of the Swedish industry, is to further strengthen the existing knowledge platform at HV by separately creating two independent verticals of focus, namely on powder bed fusion (PBF) and direct metal deposition. Each of the above verticals will involve a multi-disciplinary work approach, not only utilizing the considerable expertise that already exists in the two domains but also augmenting it through specific need-based recruitment. All these activities will also be synchronized with the development strategy envisioned in the KK environment Primus. Long term planning of high-quality research under clear control from the university management is a characteristic of the plan.

By virtue of Primus, HV already has a set organizational and management structure to strategically lead the research environment and profile the university.

Consistent with the strategy to continue to develop today's cutting edge research to support or realize industry-relevant applications and exploit the development potential for the research environment enabled by SUMAN-Next, a research profile PODFAM exclusively dedicated to PBF has already been conceptualized and subsequently approved by the KK Foundation. PODFAM seeks to undertake a comprehensive effort to establish HV as an internationally well recognized research organization in PBF AM of advanced metallic materials while also providing significant tangible benefits to the Swedish manufacturing industry. As articulated in the PODFAM application made to the KK Foundation, the overarching aim of PODFAM is to create a hub for continued strategic development of a strong and sustainable PBF research and education environment at HV and considers all of the following:

- aspirations of HV to sustain and further bolster its national and international reputation in AM;
- immediate requirements of HV's long-standing industrial partners for remaining globally competitive in high technology areas;
- desire as well as capability of HV's existing faculty to pursue cutting-edge research in the rapidly burgeoning domain of PBF-AM;
- expectations of PRIMUS, including co-production of research and education;
- harnessing Swedish and European finance agencies to continually develop AM at HV;
- identifying knowledge chains and technology development projects (road maps) from basic research to new products and production processes on the market;
- establishment of an innovative culture for developing new design and production solutions and a test strategy for prototypes, risks and verification data by using NASA TRL methods;
- fulfillment of HV's vision for digitalization and internationalization;
- knowledge-driven development of new AM-relevant courses;
- current worldwide trends in production technology to exploit PBF AM, which Swedish industry must keep pace with;
- requirements of Industry 4.0 with regard to automation, process control etc;
- enhancement of technology and delivery capability within PBF AM, enabling the region's small and medium-sized companies to supply to international aerospace industry;
- establish plans for future career planning and recruitment both at HV and industry partners;
- develop future plans for research and product development after the project has been completed.

The willing participation in PODFAM of all the companies (except Element) who were partners in SUMAN-Next is not only an affirmation of the benefits that they have derived through co-production with HV but also of their concurring viewpoint regarding the prudence of consolidating the wide-ranging expertise developed by prioritizing the field of PBF (specifically addressing other Ni-based superalloys beyond Alloy 718, as well as Ti- alloys). HV is also already working on conceptualizing a parallel profile devoted to DMD as the next logical step. Both these profiles will comprise parts that aim at deeper physical understanding of AM build processes and post-

treatments associated with production, as well as creation of new knowledge linked to effective monitoring, simulation and control of production systems and processes.

The above ambitious, yet realistic, development plan will also demand strategic recruitment to implement all aspects of these large projects and to enhance HV's international position in the coming years. Table 1 beneath illustrates not only the growth in personnel that has taken place since SUMAN-Next was granted but also how it has increased the ambition at HV for the future.

Table 1. Increase in number of researchers within AM and goal for future.

Year	2018		2028	
	AM	**PRIMUS**	AM	**PRIMUS**
Total number of researchers	26	83	65	150
Full time equivalents (FTE)		45,1		
PhD students	12	33	18	50
FTE		25,2		
Post-docs	0	3	11	15
FTE		0,9		
Doctors	4	19	12	30
FTE		8,6		
Associate Professors	3	10	8	20
FTE		3,8		
Professors	4	10	8	20
FTE		4,8		
Visiting Professors	3	7/3	5	10
HE		1,6		
Adjunct professors		0	3	5
FTE		0		

Appendix 1. Dissemination – PhD and Licentiate theses

- Andreas Segerstark - (WP4) LMD Alloy 718 (PhD completed!)
- Suhas Sreekanth - (WP4) LMD Alloy 718 & Local Heat Treatment
- Tahira Raza - (WP2 related) SLM Alloy 718 (PhD completed!)
- Paria Karimi Neghlani - (WP2) EBM Alloy 718
- Olutayo Adegoke - (WP2) SLM / EBM
- Sneha Goel - (WP3) Post-treatment of AM 718
- Arun R B - (WP8) Mechanical properties of AM Superalloys
- Chamara Kumara - (WP6) Modeling: Mechanical Properties & Microstructure
- Agnieszka Kisielewicz - (WP5) Processing Monitoring & Control

PhDs completed:

Andreas Segerstark**, 2017-12-20**
Laser Metal deposition using Alloy 718 – Influence of process parameters on material characteristics
Opponent: Docent Boian Alexandrov, The Ohio State University, USA

Tahira Raza**, 2020-04-02**
Process Understanding and Weldability of Laser-Powder Bed Fusion Manufactured Alloy 718
Opponent: Docent Boian Alexandrov, The Ohio State University, USA

Licentiates completed:

Paria Karimi, 2018-11-21
Electron beam melting of Alloy 718 - Influence of process parameters on the microstructure
Opponent: Associate Professor Amir Rashid, Institutionen för industriell produktion, KTH Universitet

Arun Balachandramurthi Ramanathan, 2018-12-05
Fatigue Properties of Additively Manufactured Alloy 718
Opponent: Professor Eduard Hryha, vid avd. för Material och tillverkning, Industri- och Materialvetenskap, Chalmers Tekniska Högskola

Chamara Kumara, 2018-12-14
"Microstructure modelling of additive manufacturing of Alloy 718
Opponent: Associate Professor Martin Fisk, Institutionen för materialvetenskap och tillämpad matematik, Malmö Universitet

Sneha Goel, 2019-02-18
Post-treatment of electron beam melted Alloy 718
Opponent: Docent Magnus Hörnqvist Colliander, Institutionen för fysik, Chalmers Tekniska Högskola

Appendix 2. Dissemination – Master and BSc Theses

Master Theses

1. Bengt Gustavsson, "*Influence of scan length on microstructural characteristic of Alloy 718 manufactured by electron beam melting process*", Master Thesis (HV), 2017; Supervisors: P Karimi & J Andersson.
2. Sebastian Brandtberg, "*Microstructural inhomogeneity and anisotropic properties in IN-718 structures fabricated by Electron Beam Melting*", Master Thesis (Linköping University), 2017; Supervisors: J Moverare, C Söderström, O Johansson Berg.
3. Linus Haglund and Simon Folgerö, "*Additive manufacturing of nickel based superalloys: Evaluation of crack formation in laser metal deposited Alloy 718*", MSc thesis (Chalmers), 2017; Supervisors: J Andersson and P Jonson.
4. Enrico Zaninelli, "*Influence of post treatment schedules on microstructural changes in EBM-built Alloy 718*", Master Thesis and Internship (HV), 2018; Supervisors: S Goel and S Joshi.
5. Nikhil Dixit, "*Fatigue life studies of IN-718 manufactured by SLM process*", Master Thesis (HV), 2018; Supervisor: Arun Ramanathan Balachandramurthi.
6. Henrik Nöbauer, "*Residual stresses and distortions in austenitic stainless steel 316L speci-mens manufactured by Selective Laser Melting*", Master Thesis (HV), 2018; Supervisors: T Raza & J Andersson.
7. Tejas Gundgire, "*Role of Different Post-Treatments on Characteristics of EBM-Built Alloy 718*", Master thesis (HV), 2019; Supervisors: S Goel and S Joshi.
8. Christopher Schnur, "*Influence of contour parameters on the surface roughness and microstructural characteristic of Alloy 718 manufactured by electron beam melting process*", Master Thesis (HV), 2019; Supervisor: P Karimi.

BSc Theses

1. Daniel Johansson and Erik Nilsson, "Testing and evaluation of component made using electron beam melting and Alloy 718 powder", BSc thesis (Mälardalens University), 2017. Supervisors: J Andersson and P Jonson.
2. Kévin Bourreau, "Post treatment of EBM-built Alloy 718", Internship (HV), 2018; Supervisors: S Goel and S Joshi.
3. Lakshmi Srujana Sarvepalli , "Modelling heat transfer in EBM process", Internship (HV), 2018; Supervisors: Chamara Kumara and Per Nylén.

Appendix 3. Dissemination - Journal Publications

1. P. Karimi, T. Raza, J. Andersson, L-E Svensson, "*Influence of laser exposure time and point distance on 75-µm-thick layer of selective laser melted Alloy 718*", Int J Adv Manuf Technol., vol. 94, pp. 2199-2207, 2017. DOI 10.1007/s00170-017-1019-1.
2. Andreas Segerstark, Joel Andersson, Lars-Erik Svensson and Olanrewaju Ojo "*Microstructural Characterization of Laser Metal Powder Deposited Alloy 718*", Materials Characterization, 142, pp. 550-559, 2018.
3. Chamara Kumara, Dunyong Deng, Johan Moverare, Per Nylèn, '*Modelling of anisotropic elastic properties in alloy 718 built by electron beam melting*', Materials Sci. Technology, vol. 34, pp.529-537, 2017.
4. P. Karimi, D. Deng, H. Gruber, J. Andersson, and P. Nylén "*Influence of build layout and orientation on microstructural characteristics of electron beam melted Alloy 718*", Int J Adv Manuf Technol., vol. 99, pp. 2903-2913, 2018. https://doi.org/10.1007/s00170-018-2621-6, published (2018).
5. Tahira Raza, Joel Andersson & Lars-Erik Svensson (2018): *Varestraint weldability testing of additive manufactured alloy 718*, Science and Technology of Welding and Joining, vol. 23, pp.606-611, 2017. DOI: 10.1080/13621718.2018.1437338.
6. Claes Fredriksson, "*Sustainability of metal powder additive manufacturing"*, Proc. 6th Global Conference on Sustainable Manufacturing, Lexington, Kentucky, USA, 2-4 October, 2018; Procedia Manufacturing, vol. 33, pp 139-144, 2019.
7. B. Arun Ramanathan *et al.*, "*Influence of defects and as-built surface roughness on fatigue properties of additively manufactured Alloy 718*," Mater. Sci. Eng. A, vol. 735, pp. 463–474, Sep. 2018. https://doi.org/10.1016/j.msea.2018.08.072.
8. Paria Karimi, Esmaeil Sadeghi, Pia Åkerfeldt, Joakim Ålgårdh, Joel Andersson, "*Influence of Successive Thermal Cycling on Microstructure Evolution of EBM-Manufactured Alloy 718 in Track-by-Track and Layer-by-Layer Design*", Journal of Materials & Design, vol. 160, pp. 427–441, 2018. DOI: 10.1016/j.matdes.2018.09.038.
9. Sneha Goel, Magnus Ahlfors, Fouzi Bahbou, Shrikant Joshi, "*Effect of different post-treatments on the microstructure of EBM-built Alloy 718*", Journal of Materials Engineering and Performance, vol. 28, pp. 673-680 (2019).
10. Chamara Kumara, Andreas Segerstark, Fabian Hanning, Nikhil Dixit, Shrikant Joshi, Johan Moverare, Per Nylén, *"Microstructure modelling of laser metal powder directed energy deposition of Alloy 718",* Additive Manufacturing, Vol. 25, pp.357-364 (2019).
11. Paria Karimi, Esmaeil Sadeghi, Joakim Ålgårdh, Joel Andersson, "*EBM-Manufactured Single Tracks of Alloy 718: Influence of Energy Input and Focus Offset on Geometrical and Microstructural characteristics*, Journal of Materials Characterization 148 (2019) 88–99, https://doi.org/10.1016/j.matchar.2018.11.033.
12. Sneha Goel, Anumat Sittiho, Indrajit Charit, Uta Klement, Shrikant Joshi, "*Effect of post-treatments under hot isostatic pressure on microstructural characteristics of EBM-built Alloy 718*, Additive Manufacturing, vol. 28, pp. 727-737 (2019).
13. B. Arun Ramanathan *et al.*, "*Microstructural influence on fatigue crack propagation during high cycle fatigue testing of additively manufactured Alloy 718*," Mater. Charact., vol. 149, pp. 82–94, Mar. 2019 https://doi.org/10.1016/j.matchar.2019.01.018.
14. B. Arun Ramanathan *et al.*, "*Additive Manufacturing of Alloy 718 via Electron Beam Melting: Effect of Post-Treatment on the Microstructure and the Mechanical Properties,*" Materials, 12, 68, 2019. https://doi.org/10.3390/ma12010068.
15. Chamara Kumara, Dunyong Deng, Fabian Hanning, Morten Raanes, Johan Moverare, Per Nylén, "*Prediction of the microstructure evolution in electron beam melting of Alloy 718 with phase-field modelling"*, Accepted to Metallurgical and Materials Transactions A, vol. 50, pp. 2527-2537, 2019.

16. B. Arun Ramanathan *et al.*, *"Microstructure tailoring in Electron Beam Powder Bed Fusion additive manufacturing and its potential consequences",* Results in Materials, vol. 1, Article ID 100017, 2019. https://doi.org/10.1016/j.rinma.2019.100017.
17. P. Karimi, E. Sadeghi, J. Ålgårdh, P. Harlin, and J. Andersson, "*Effect of build location on microstructural characteristics and corrosion behavior of EB-PBF built Alloy 718*", Int J Adv Manuf Technol., vol. 106, pp. 3597-3607, 2020.
18. Paria Karimi, Christopher Schnur, Esmaeil Sadeghi, and Joel Andersson, "*Contour design to improve topographical and microstructural characteristics of Alloy 718 manufactured using* electron beam-powder bed fusion", Journal of Additive Manufacturing, Published, vol. 32, Article ID 101014, 2020, doi.org/10.1016/j.addma.2019.101014.
19. Agnieszka Kisielewicz et al. *"In-process spectroscopic detection of chromium loss during Directed Energy Deposition of alloy 718."* Materials & Design, vol. 186, Article ID 108317, 2020.
20. Sreekanth, S., Ghassemali, E., Hurtig, K., Joshi, S., Andersson, J., 2020. "*Effect of Direct Energy Deposition Process Parameters on Single-Track Deposits of Alloy 718"*. Metals 10, 96, 2020. https://doi.org/10.3390/met10010096.
21. S. Goel, K. Bourreau , J. Olsson , U. Klement, and S. Joshi, "*Can appropriate thermal post-treatment make defect content in as-built electron beam additively manufactured Alloy 718 irrelevant?*," *Materials,* vol. 13, pp. 536, 2020.
22. B. Arun Ramanathan *et al.*, *"Anisotropic fatigue properties of Alloy 718 manufactured by Electron Beam Powder Bed Fusion", International Journal of Fatigue*, Article ID 105898, 2020. https://doi.org/10.1016/j.ijfatigue.2020.105898
23. C. Kumara, A. R. Balachandramurthi, S. Goel, F. Hanning, and J. Moverare, "*Toward a better understanding of phase transformations in additive manufacturing of Alloy 718*," Materialia, vol. 13, no. June, Article ID 100862, Sep. 2020. https://doi.org/10.1016/j.mtla.2020.100862
24. T. Gundgire, S. Goel, U. Klement, S. Joshi, "*Response of different electron beam melting produced Alloy 718 microstructures to thermal post-treatments*", Mat. Charac., vol. 167, p. 110498, 2020.
25. S. Goel, H. Mehtani, S.-W. Yao, I. Samajdar, U. Klement, S. Joshi, "*As-Built and Post-Treated Microstructures of an Electron Beam Melting (EBM) produced Nickel Based Superalloy*," Metal. & Mat. Trans. A, vol. 51, pp. 6546-6559, 2020.
26. S. Goel, E. Zaninelli, J. Gårdstam, U. Klement, S. Joshi, "*Microstructure evolution based design of thermal post-treatments for EBM-built Alloy 718*," Journal of Materials Science, vol. 56, pp. 5250-5268, 2020.

Appendix 4. Dissemination – Conference Proceedings

1. Sneha Goel, Jonas Olsson, Magnus Ahlfors, Uta Klement, Shrikant Joshi, " *The effect of location and post-treatment on the microstructure of EBM-built Alloy 718*", Superalloy 718 and derivatives conference, Manuscript accepted, Pittsburgh, Pennsylvania, USA (2018).
2. Tahira Raza, Joel Andersson, Lars-Erik Svensson. *Microstructure of Selective Laser Melted Alloy 718* in As-Manufactured and Post Heat Treated Condition. 8th Swedish Production Symposium, SPS 2018, 16-18 May 2018, Stockholm, Sweden.
3. Agnieszka Kisielewicz, Fredrik Sikström, Anna-Karin Christiansson, Antonio Ancona, *'Spectroscopic monitoring of laser blown powder directed energy deposition of Alloy 718*', 8th Swedish Production Symposium, SPS 2018, 16-18 May 2018, Stockholm, Sweden.
4. Tofeldt O, Pierce SG, Smillie G, et al. *Investigation of fundamental ultrasonic propagation characteristics in NDT of Electron Beam Melted additive manufactured samples – Inconel 718*. In: 12th European Conference on Non-Destructive Testing (ECNDT 2018). Göteborg; 2018:1-4. http://www.ndt.net/?id=22728.
5. Chamara Kumara, Dunyong Deng, Fabian Hanning, Morten Raanes, Johan Moverare, Per Nylén, *Prediction of the microstructure evolution in EBM Alloy 718 through phase-field modelling*, MMM2018, Osaka, Japan
6. Paria Karimi, Dunyong Deng, Joakim Ålgårdh, Joel Andersson, "*Microstructure Development in Single Bead Electron Beam-Melted Alloy 718*", Superalloy 718, June 3 -6, 2018, Pittsburgh, Pennsylvania, USA.
7. Esmaeil Sadeghimeresht, Paria Karimi, Joel Andersson, Shrikant Joshi "*Cyclic oxidation behaviour of EBM-additive manufactured Alloy718*", Superalloy 718 and derivatives, June 3-6, 2018, Pittsburgh, Pennsylvania, USA.
8. Paria Karimi, Esmaeil Sadeghi, Joakim Ålgårdh, and Joel Andersson, "*Location and Thickness Dependency of EB-PBF Manufactured Alloy 718 on the Microstructural Characteristics*", International conference on welding, additive manufacturing and associated non-destructive testing, June 5-7, 2019, Metz, France.
9. Sneha Goel, Tejas Gundgire, Johny Varghese, Koteswararao V. Rajulapati, Uta Klement, Shrikant Joshi, "*Role of HIPing and heat treatment on properties of Alloy 718 fabricated by electron beam melting*", EuroPM, Manuscript published, Maastricht, Netherlands (2019).
10. O. Adegoke, Andersson J, O. Ojo, H. Brodin, and R. Pederson, "*Laser beam powder bed fusion and post processing of Alloy 247LC*," Material Science and Technology (MST), Portland, USA, 2019, pp. 27–34.

Appendix 5. Dissemination – Conferences/Seminars/Workshops

1. Sneha Goel, Magnus Ahlfors, Per Nylén, Shrikant Joshi, '*Effect of Different Post-Treatments on Properties of EBM-built Alloy 718 Processed Under Varying Conditions*', Materials Science & Technology 2017, October 8-12, 2017, Pittsburgh, USA.
2. Sneha Goel, Shu-Wei Yao, Chang-Jiu Li, Fouzi Bahbou, Magnus Ahlfors, Shrikant Joshi, '*Effect of build height and post treatment on behaviour of EBM Alloy 718*', APICAM 2017, December 4-6, 2017, Melbourne, Australia.
3. Sneha Goel, Magnus Ahlfors, Shrikant Joshi, '*Effect of post treatment on behaviour of EBM built Alloy 718*', Superalloy 718 and derivatives, June 3-6, 2018, Pittsburgh, Pennsylvania, USA.
4. Paria Karimi, Joakim Ålgårdh, Joel Andersson, "*Influences of thermal cycles on microstructure evolution by building single walls in EBM-manufactured Alloy 718*", EBAM, April 11 -13, 2018, Germany.
5. O Tofeldt, SG Pierce, G Smillie, W Kerr, GMH Flockhart, CN Macleod, R Blue, A Gachagan, T Stratoudaki, J Olsson, D McMahon: "*Investigation of fundamental ultrasonic propagation characteristics in NDT of Electron Beam Melted additive manufactured sample*", 12th European Conference on Non-Destructive Testing, June 11-15, 2018, Göteborg.
6. Paria Karimi, Joakim Ålgårdh, Joel Andersson, "*Influence of process parameters on morphology and microstructure of electron beam melted single-track Alloy 718*", IIW, March 5-7, 2018, Italy.
7. Tahira Raza, Joel Andersson, Lars-Erik Svensson. *Microstructure of Selective Laser Melted Alloy 718* in As-Manufactured and Post Heat Treated Condition. 8th Swedish Production Symposium, SPS 2018, 16-18 May 2018, Stockholm, Sweden.
8. Agnieszka Kisielewicz, Fredrik Sikström, Anna-Karin Christiansson, Antonio Ancona, *'Spectroscopic monitoring of laser blown powder directed energy deposition of Alloy 718*', 8th Swedish Production Symposium, SPS 2018, 16-18 May 2018, Stockholm, Sweden.

9. Chamara Kumara, Dunyong Deng, Fabian Hanning, Morten Raanes, Johan Moverare, Per Nylén, "*Prediction of the microstructure evolution in electron beam melting of Alloy 718 with phase-field modelling",* 9th Multiscale Materials Modeling (MMM) conference at Osaka International Convention Center, Osaka, Japan, on Oct. 28 - Nov. 2, 2018.
10. Arun Ramanathan Balachandramurthi, Johan Moverare and Robert Pederson, "*Fatigue properties of EBM built Alloy 718 – Effect of As-built surface and HIP*", EBAM, April 11 -13, 2018, Germany.
11. Sneha Goel and Shrikant Joshi, "*How does HIPing influence properties of EBM-built Alloy 718*?", EPMA HIP Seminar, 11-12 Feb 2019, Sint Niklaas, Belgium.
12. Sneha Goel, Tejas Gundgire, Johny Varghese, Koteswararao V. Rajulapati, Uta Klement, Shrikant Joshi, '*Role of HIPing and heat treatment on properties of Alloy 718 fabricated by electron beam melting*', EuroPM, Maastricht, Netherlands (2019).
13. Arun Ramanathan Balachandramurthi, Johan Moverare and Robert Pederson, "*Fatigue properties of Additively Manufactured Alloy 718*", 2nd Conference of Additive Intelligence 4.0, April 8-9, 2019, Gothenburg, Sweden.
14. Arun Ramanathan Balachandramurthi, Jonas Olsson, Joakim Ålgårdh, Anders Snis, Johan Moverare and Robert Pederson, '*Microstructure tailoring in electron beam powder bed fusion processing of alloy 718 and associated mechanical properties*', APICAM 2019, July 1-3, 2019, Melbourne, Australia.
15. Chamara Kumara, Andreas Segerstark, Fabian Hanning, Nikhil Dixit, Shrikant Joshi, Johan Moverarea, Per Nylén, Laser metal powder directed energy deposition of Alloy 718 - Modelling microstructure evolution during the process and subsequent heat treatments, APICAM 2019, July 1-3, 2019, Melbourne, Australia.

16. Sneha Goel, Johannes Gårdstam, Jonas Olsson, Uta Klement, Shrikant Joshi, '*How do EBM Alloy 718 builds with different microstructures respond to post-treatment?*', Materials Science & Technology, Portland, USA (2019).
17. Olutayo Adegoke, Joel Andersson, Olanrewaju Ojo, Håkan Brådin, Robert Pederson, "*Laser beam powder bed fusion and post processing of alloy 247LC",* Materials Science & Technology, Portland, USA (2019).
18. Paria Karimi, Esmaeil Sadeghi, Joakim Ålgårdh, Jonas Olsson, and Joel Andersson, "*Transition from columnar to equiaxed morphology using a novel linear melting strategy in EB-PBF of Alloy 718*", EBAM, 25-27 March 2020, Erlangen, Germany.
19. Arun Ramanathan Balachandramurthi, Johan Moverare, Robert Pederson, Per Nylén, Thomas Hansson, Jonas Olsson, Mats Högstrom and Nikhil Dixit, "Fatigue properties of Additively Manufactured Alloy 718", UTMIS års- och nätverksmöte 2020, April 8-9, 2020, Örebro, Sweden
20. Sneha Goel, Johannes Gårdstam, Jonas Olsson, Uta Klement, Shrikant Joshi, Influence of prior EBM Alloy 718 microstructure on build properties after varied thermal post-treatments, TMS 2020, Feb 23-27, 2020, San Diego, USA.
21. Sneha Goel, Esmaeil Sadeghimeresht, James Shipley, Shrikant Joshi, Thermal Post-treatment of EBM Alloy 718, Hot isostatic pressing seminar, March 10-11, 2020, Oslo, Norway.

Appendix 6. Dissemination – Summary

- 9 PhD theses related to the project
  - 2 PhD Theses completed
  - 4 Licentitate completed
- 8 Master thesis
- 22 Journal publications (many more expected as PhD students begin to wrap up)
- 10 Conference proceedings
- 21 Conference presentations