Institution: University of Derby

Unit of Assessment: 12

Title of case study: Additive manufacturing process developments for the transport and regulated industries

Period when the underpinning research was undertaken: 2014–2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Professor Paul Wood	Director of IISE	2015–present
Dr Gavin Williams	Researcher	2014–present
Dr Urvashi Gunputh	Researcher	2019–present
Dr Ahmad Serjouei	Researcher	2017 to 2019

Period when the claimed impact occurred: 2017–31 December 2020

Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact (indicative maximum 100 words)

This ICS describes the underpinning research and impact of two funded projects carried out at the Institute for Innovation in Sustainable Engineering (IISE) focused on the development of metal 3D printing (3DP) solutions for industrial applications. One project describes the application of a metal 3DP workflow to re-manufacture obsolete parts for aging infrastructure assets within the UK gas transmission grid. The other on the application of metal 3DP to fabricate a complex aircraft engine component in a superalloy to improve efficiency in new engine development programmes. The research has demonstrated metal 3DP delivers a competitive advantage to these business sectors, reducing time to market, cost, waste streams and CO_2 emissions. Impacts in other sectors such as rail are evidenced together with broader impacts to new skills and job creation and to the region's SMEs.

2. Underpinning research (indicative maximum 500 words)

2.1. 3D printing obsolete parts to extend asset life within the UK gas transmission grid.
The research was carried out between May 2017 and January 2019, under a funded Innovation Project secured by SME, Premtech Ltd [G3.1], in partnership with, National Grid and IISE.

The project [G3.1] applied metal 3D printing (3DP) to re-manufacture obsolete parts for assets in the utilities sector. The research used real life cases to develop a staged workflow for 3DP to design and manufacture replacement parts for operational assets. Using the latest in digital-based manufacturing methods and practice, Wood *et. al.,* 2019 [3.1] demonstrated the workflow from the requirements capture and design specification, digital scanning and reverse engineering, substitute material selection, creation of part digital model with tolerances, design for 3DP, component durability analysis, part fabrication through to quality assurance. The latter confirms the part complies with the design specification, so it is ***Fit for Purpose*** **and** ***Right First Time*****.** Fourteen use case parts were demonstrated using Selective Laser Melting (SLM) enabling an understanding of the capabilities of metal 3DP by practical application. New stress controlled uniaxial fatigue data for 3D Printed stainless steel (316L) up to 10^7 cycles was developed in collaboration with the Polish Academy of Sciences [G3.4] and published by Wood *et. al.,* 2019 [G3.2]. The research studied the effects of as-printed, stress relief, shot peened and machined surface on fatigue properties, and highlighted the importance of SLM build orientation in enhancing fatigue strength. This new fatigue data not previously reported, was demonstrated to verify the

design of a 3DP part for the highly regulated utilities sector to ensure the part was ***Fit for Purpose*** **and** ***Right First Time***.

2.2. 3DP of a complex aircraft engine component in a superalloy to improve efficiency in new engine development programmes. The research carried out between October 2015 and March 2019, under two projects, was delivered sequentially: IUK KTP / FTT [G3.2] and ERDF Low Carbon / Addqual [G3.3].

Otubusin, A., Wood, P. et al. 2018 [3.3] demonstrated a method to fabricate an outlet guide vane (OGV) component in a nickel-based superalloy by Selective Laser Melting (SLM). An OGV is a complex stator component in the last stage of the engine compressor. In a medium sized engine, the OGV has 140 equally spaced airfoils secured to an inner and outer ring of 605mm diameter. The airfoil geometric precision in the finished OGV is high at +/- 0.06mm. The alloy is hard to machine with high rates of tool wear, low metal removal rates and instances of tool breakage. To fabricate the OGV using SLM, it was divided into smaller segments. Each segment with five airfoils was assembled into the turbine test rig. To start with, a redesign of the current outer and inner ring profiles, and a method to align/join each segment into the rig suited to SLM was established [3.3]. Among the SLM process parameters studied by experiments the laser spot size was found to exert the most influence on dimensional accuracy and precision which has not been quantitatively reported previously. The OGV segments were 3DP to near net shape to the accuracy and precision required of the part and process [3.3]. The finish machining of the 3DP alloy was studied using instrumented cutting trials under an academic partnership with University Carlos III [G3.5]. A relationship between the 3DP microstructure resulting from the SLM process parameters used and machinability was determined by *Wood et al.* [3.1], and the findings identified a finish machining allowance for the 3DP OGV segment for net shape manufacture.

Academic outreach and significance: Establishment of new international collaborations and PhD programmes since July 2018 [G3.4, G3.5, G3.6] with focus on underpinning research into 3DP nickel-based alloys. These include co-supervision of a PhD student funded by the French Ministry of education; Polish Academy of Sciences under the National Academic Exchange Agency (NAWA) with the Universities of Lorraine and Louisiana State (LSU) from July 2018; University Carlos III Madrid (UC3M) from April 2019; Military University of Technology Warsaw from April 2020. National collaboration with MTC includes joint sponsorship of a PhD. By 2020, 5 NAWA workshops were delivered in UK, EU and USA, 3 journal publications [3.4, 3.5, 3.6]. The impact of these partnerships has accelerated the embedding of new skill and capability in metal 3DP within the team at IISE and strengthened concurrent knowledge transfer.

3. References to the research (indicative maximum of six references)

University of Derby researchers are indicated by black, underlined text:

[3.1] Wood, P., Williams, G., Gunputh, U. and Serjouei, A. (2019) 'Selective Laser Melting of Stainless Steel 316L Pressure Fittings', DynaMAT 2019, 17-19 April 2019, Nicosia, Cyprus (Conference Workshop Presentation): http://hdl.handle.net/10545/625322

[3.2] Wood, P., Libura, T., Kowalewski, Z.L., Williams, G. and Serjouei, A. (2019) 'Influences of Horizontal and Vertical Build Orientations and Post-Fabrication Processes on the Fatigue Behaviour of Stainless Steel 316L Produced by Selective Laser Melting', *Materials*, MDPI. https://doi.org/10.3390/ma12244203 (Peer Reviewed Open Access Journal): http://hdl.handle.net/10545/624589

[3.3] Otubusin, A., Wood, P., Appleby, J. and Adamczuk, R. (2018), 'Analysis of Parameters Influencing Build Accuracy of a SLM Printed Compressor Outlet Guide Vane', *ASME Proceedings Manufacturing Materials and Metallurgy*, *Turbomachinery Technical Conference and Exposition*, Paper No. GT2018-75548, pp. 10 pages, doi: https://doi.org/10.1115/GT2018-75548 (Proceedings Paper): http://hdl.handle.net/10545/625321

[3.4] Wood, P., Díaz-Álvarez, A., Díaz-Álvarez, J., Miguélez, M.H., Rusinek, A., Gunputh, U., Williams, G., Bahi, S., Sienkiewicz, J. and Płatek, P. (2020) 'Machinability of INCONEL718 Alloy with a Porous Microstructure Produced by Laser Melting Powder Bed Fusion at Higher Energy Densities', *Materials*, 13, 5730. https://doi.org/10.3390/ma13245730 (Peer Reviewed Open Access Journal): http://hdl.handle.net/10545/625514

[3.5] Voyiadjis, G.Z., Znemah, R.A., Wood, P., Gunputh, U. and Zhang, C. (2020) 'Effect of element wall thickness on the homogeneity and isotropy of hardness in SLM IN718 using nanoindentation', *Mechanics Research Communications*, Elsevier. https://doi.org/10.1016/j.mechrescom.2020.103568 (Peer Reviewed Journal) http://hdl.handle.net/10545/625089

[3.6] Delcuse L., Gunputh, U., Bahi, S., Wood, P., Rusinek, A. and Miguelez, M.H. (2020), 'Effect of powder bed fusion laser melting process parameters, build orientation and strut thickness on porosity, accuracy and tensile properties of an auxetic structure in IN718 alloy', *Journal of Additive Manufacturing*, Elsevier. https://doi.org/10.1016/j.addma.2020.101339 (Peer Reviewed Journal): http://hdl.handle.net/10545/625093

Evidence of Research Funding and Collaborations:

[G3.1] Premtech Ltd, Advanced Manufacturing (3D Printing) of Obsolete Parts, for National Grid Network Innovation Allowance (NIA), 2017-2019 GBP156,063.

[G3.2] Florida Turbine Technology Ltd, Knowledge Transfer Partnership (KTP No. 010027) (2015-2017) GBP147,074. KTP Associate: Adetayo Otubusin.

[G3.3] Enabling Innovation Time 2 Innovate, European Regional Development Fund, GBP3,070,000 [IISE: GBP1,300,000 (Capital: GBP619,000; Project Cost: GBP681,000)], 2016-2019.

[G3.4] Letter of intent regarding Partnership for joint implementation of the Programme entitled "International collaboration on complex systems and modern technologies" under the International Academic Partnership Programme announced by the National Agency for Academic Exchange, 12 July 2018.

[G3.5] Letter of intent for a research collaboration between the University of Derby's IISE and UC3M, 13 May 2019, Universidad Carlos III de Madrid.

[G3.6] Letter of intent for a research collaboration between the University of Derby's IISE and WAT, 15th April 2020, Maj. PhD Eng Pawel Platek, Military University of Technology, Poland.

4. Details of the impact (indicative maximum 750 words)

National Grid supply chain engagement

Under the funded innovation project [G3.1] the workflow to re-manufacture obsolete parts by metal 3DP demonstrated to the client in December 2017 was a **first of a kind** in this sector. Fourteen 3DP use case parts were demonstrated for grid infrastructure, e.g. large pressure pipe fittings used in a compressor station that failed in service. They were showcased at 8 National Grid innovation events [5.1] involving internal and external stakeholders and represented by IISE staff. In December 2018, the 3DP staged workflow, with an instructive dashboard-based decision tool, was embedded in Premtech and National Grid business-as-usual practice. Twelve high quality industrial reports [5.1] were completed describing each workflow stage, citing relevant standards with active links to the dashboard tool.

Obsolescence in infrastructure is recognised internationally. The Norwegian accreditation service DNV GL, recently established a new centre for 3DP in Singapore as an incubator and test bed to build trust in 3DP, citing added value benefit to the Oil and Gas sector of USD30

billion. 3DP is a policy ambition of National Grid listed as a key topic for their Innovation Funding post-2020 (Refer to 5.1).

Financial benefits
National Grid maintains 12,000km of gas pipeline infrastructure across the UK to supply natural gas to domestic users and industry. It is a highly regulated industry sector. Gas utility infrastructure within the UK is aged and unique. Unexpected asset failure can result in an outage so parts must be replaced periodically when the need arises. Some spare parts are held at large depots to repair assets which carries a huge inventory cost. Traditional fabrication methods are still used to manufacture spare parts because digital part models are not held. 3DP is an on-demand solution and SmarTech Publishing forecast that 3DP will become a USD450 million market in the oil and gas sector by 2021, rising to USD1.4 billion by 2025. The World Economic Forum Transformation Initiative (2017) estimated 3DP could save cost and time worth USD30 billion of additional value to oil and gas companies.

Aerospace supply chain engagement
The cost and time to manufacture one off engine test rigs to clients such as Rolls-Royce limits opportunity to appraise new engine designs typically to one or two models. Suppliers of prototype engine test rigs to clients include FTT (Derby) and ITP Aero. Prototyping engine components use traditional fabrication methods such as precision CNC machining from solid stock. Machining a prototype outlet guide vane (OGV) with 140 airfoils in a superalloy to the precision required incurs a typical cost of **GBP25,000-GBP40,000** [5.2, 5.3] and requires at least **5-10 weeks** machine time. In 2018, Dr Wood developed and demonstrated a method to 3DP a complex OGV component in a superalloy by selective laser melting. The benefit with this approach is a significant cost saving of upwards of ***50%,*** manufacturing time also reduced by ***50%,*** together with reduced risk in programme delays.

Rail supply chain engagement
The German working group, Mobility Goes Additive (MGA) initiated in 2019 by Siemens Rail to leverage 3DP for aging rolling stock (see 5.4) has grown quickly into a large European wide forum with 132 business members, broadening its reach into healthcare and other sectors. IISE is the sole UK participant at this working group joining it in 2019. The UK Rail Sector is seeing impact from 3DP for example Angel Trains deployed its first 3D printed non-structural part on British passenger trains in 2019 and Deutsche Bahn Environmental Social Governance (DB ESG) invited Dr Wood to contribute to a metal 3DP Innovate UK SBRI project proposal (March 2020).

Additional regional SME engagement
Over 50 SMEs, including Addqual and FTT, have benefitted from workshops and services many of which included 3D printing delivered under the European funded programme called Enabling Innovation Time 2 Innovate [G3.3]. The independent report “A Final Evaluation of Enabling Innovation” assessed the programme’s effectiveness overall and included survey input. The Executive Summary concluded: “*just over half of respondents to our survey had improved business efficiency, productivity and business competitiveness. Around half had progressed a new technology/product/service towards market, again helping to reduce risk/uncertainty associated with R&D*.” (See 5.5, Executive Summary).

New skills acquired, job creation and business growth
Two engineers who had just graduated were recruited by Premtech [G3.1] to support delivery of the project [5.1]; they acquired new skills by learning on the job over the period the project was active. Knowledge exchange across the project team at Premtech included a project manager and company director. Within National Grid a gas pipeline maintenance engineer was assigned to lead the project along with a project manager. Two new skilled jobs were created at Addqual following project [5.2] [G3.3], by recruitment of two engineers who acquired their experience by working directly on these projects at the IISE. The impact for Addqual enabled the business to grow from no sales or customers to a current turnover of over GBP500,000 in just 3 years. One of these engineers who was recruited by Addqual has provided a testimonial [5.5]. To date, 18

students have developed 3DP skills through the Additive Manufacturing Masters course by University of Derby [5.7].

Environment benefits through reduced GHG emissions
The reduced carbon footprint of 3DP a complex engine component makes a compelling case [5.2]. Manufacturing Life Cycle Analysis has shown ***80%*** of high value material is machined away to reduce ***55kg*** of solid stock to ***10kg*** generating high waste stream. GHG emissions for production of the solid stock alone generates ***6t*** of CO_2. By comparison, metal powder stock used to 3D print the OGV generates ***0.3t*** of CO_2 which is ***5%*** of that produced from solid stock because only the material needed is used, with waste stream below ***10%*** of that produced from solid stock. Further CO_2 and waste reductions are possible by reducing the finish machining allowance which means 3DP to higher precision.

Enterprise generation - new Intellectual Property in 3DP
The 3DP workflow [3.1] was applied in the design and manufacture of Ankle Foot Orthotics which led to the creation of new IP centred on 3DP for healthcare, UK Patent No.1817926.7 (Joint orthosis with resiliently deformable hinge). An International Patent with application No.PCT/GB2019/053097 was submitted in June 2020 to extend the UK patent internationally.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[5.1] Founding Director, Premtech Ltd (25-01-2021).

[5.2] Managing Director, Addqual Limited (20-01-2021).

[5.3] Operations Manager, Florida Turbine Technologies (UK) Ltd (06-11-2017).

[5.4] University of Derby Membership of Mobility Goes Additive: https://mobilitygoesadditive.com/membership/ (16-12-2019).

[5.5] A Final Evaluation of Enabling Innovation: A Final Report to the University of Nottingham (25-02-2019).

[5.6] Application Engineer, Addqual Limited – Employment in Additive Manufacture Testimonial (23-11-2020).

[5.7] MSc in Additive Manufacture - Student Testimonials, Student Numbers and Conference Poster Paper.

Note: all URLs accessed and correct as of 18-12-2020.