Institution: Coventry University
Unit of Assessment: 12
Title of case study: Application of laser shock peening in aerospace applications
Period when the underpinning research was undertaken: June 2014 onwards

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 Michael Fitzpatrick	Pro-Vice-Chancellor	2014- present
Dr Niall Smyth	Research Fellow	2014- present
Dr Bilal Ahmad	Research Fellow	2016- present
Dr Suraiya Zabeen	Research Fellow	2014-2018
Dr Kashif Khan	Associate Professor	2017-present

Period when the claimed impact occurred: January 2019 onwards

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

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

Research at Coventry University since 2014, has developed new knowledge on the applications of laser shock peening (LSP) to engineering materials, particularly aerospace aluminium alloys. This has enabled industry to implement safely the method in repair and life extension operations. As a result of our research, the US Air Force has been able to develop LSP for an airframe repair application with significantly lower cost than has been achievable in the past. Laser shock peening is now approved by Airbus for use in repair operations and Airbus has commissioned a bespoke system for airframe repair based on our research.

2. Underpinning research (indicative maximum 500 words)

Fitzpatrick (Professor) has researched laser shock peening for damage repair and life enhancement of aerospace materials, funded by Airbus and the US Air Force, with support from Alcoa (now Arconic), from 2014 - present. Ahmad, Smyth, and Zabeen (Research Fellows) have supported this research, all of which has been undertaken with industry funding. The group has published over 20 papers on LSP in the current REF period; in addition, one joint patent has been awarded with Airbus and a further two patent applications have been submitted. Fitzpatrick was awarded the Tom Bell Surface Engineering Medal of the Institute of Materials, Minerals, and Mining in 2020, “in recognition of excellence and outstanding contribution of an individual in surface engineering”.

Our work jointly with Airbus and the Air Force Research Laboratory, was recognized through the award of a Collaborative R&D Agreement in 2018, to develop an integrated modelling and experimental approach to assess the generation of residual stress from laser shock peening and its effect on fatigue of aerospace aluminium alloy.

The key questions that have been addressed by our research are:

- What are the factors influencing the generation of residual stress in aluminium alloys, in different component geometries and with different design requirements?
- How do the residual stresses interact with in-service loading to provide fatigue life benefit?

• What developments to the implementation of laser peening in the manufacturing environment can be made to improve its applicability inside a fabricated airframe, for example by the removal of the need to use water in the process?

The research programmes encompassed:

Study of the use of laser peening as a crack retarding feature in aerospace structures (R5) This was supported by two Airbus-funded PhD students. This research used a combination of experiment and modelling to quantify the use of laser peening for slowing the growth of long (centimetre-scale) cracks in aerospace aluminium. The optimum geometry and placement for crack-retarding peened patches was determined. That work led to ongoing research on the use of laser peening to redirect and arrest a growing crack.

Study on the effect of changes in material properties on the stresses generated by laser peening (R 2, 4). This was funded by the US Air Force Research Laboratory, through their European Office of Research and Development, under three separate contracts from 2014 onwards. This work was undertaken in collaboration with the two major global industrial laser peen suppliers, Metal Improvement Company (MIC) and LSP Technologies (LSPT). The outcomes highlighted the need for accurate material characterization to inform modelling of the peen process. The large amount of data generated is being used for the development of machine learning algorithms for selection of process parameters.

Modelling of the laser peen process (R1, 6, 7). This was funded by the US Air Force Research Laboratory, in collaboration with the Universida Politécnica de Madrid, and Columbia University. As well as supporting the development of physics-based models of the peening process and demonstrating the need to incorporate materials cyclic properties in the model, we demonstrated the limitations of the eigenstrain-based approach – that extrapolates residual stress from coupon experiments – in cases where boundary effects become dominant.

Identification of the effects of laser peening on materials response, including the application of novel techniques for the imaging of residual strain fields (R 3, 5, 6). This was cross-cutting research supported by Airbus and the US Air Force Research Laboratory, with the additional support of a Science and Technology Facilities Council (STFC) Facility Development Studentship for the development and application of the new neutron imaging beamline (IMAT) at the UK's ISIS national neutron facility. Alongside the use of conventional methods for analysis of residual stress, we used IMAT to perform novel Bragg-edge strain imaging at high spatial resolution to demonstrate, with rapid measurement, the influence of process parameters on the strain fields produced by laser peening.

In addition, we are working with Airbus to develop technologies for the replacement of water in the manufacturing environment where laser peening will be deployed (patent awarded jointly to Airbus and Coventry) https://patents.google.com/patent/EP3202523B1/en; plus two additional patents filed collaboratively by Coventry and Nottingham Trent Universities.

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

(R1) Langer, K., Olson, S., Brockman, R., Braisted, W., Spradlin, T., Fitzpatrick, M.E. (2015) 'High Strain Rate Material Model Validation for Laser Peening Simulation', Journal of Engineering https://doi.org/10.1049/joe.2015.0118

(R2) Zabeen, S., Langer, K., & Fitzpatrick, M.E. (2018) 'Effect of texture on the residual stress response from laser peening of an aluminium-lithium alloy', Journal of Materials Processing Technology, 251, 317-329 https://doi.org/10.1016/j.jmatprotec.2017.07.032

(R3) Ramadhan, R.S., Syed, A.K., Tremsin, A.S., Kockelmann, W., Dalgliesh, R., Chen, B., Parfitt, D., Fitzpatrick, M. E. (2018) 'Mapping Residual Strain Induced by Cold Working and by Laser Shock Peening using Neutron Transmission Spectroscopy', Materials and Design, 143, 56-64. https://doi.org/10.1016/j.matdes.2018.01.054

(R4) Zabeen, S., Langer, K., Fitzpatrick, M. E. (2018) 'Effect of alloy temper on surface modification of aluminium 2624 by laser shock peening', Surface and Coatings Technology,347,123-135. https://doi.org/10.1016/j.surfcoat.2018.04.069

(R5) Pavan, M., Fitzpatrick, M.E., Furfari, D., Ahmed, B., Gharghouri, M (2019) 'Fatigue Crack Growth in a Laser Shock Peened Residual Stress Field'. International Journal of Fatigue,123,157-167. https://doi.org/10.1016/j.ijfatigue.2019.01.020

(R6) Angulo, I., Cordovilla, F., García-Beltrán, A., Smyth, N. S., Langer, K., Fitzpatrick, M.E., Ocaña, J. L. (2019) 'The Effect of Material Cyclic Deformation Properties on Residual Stress Generation by Laser Shock Processing'. International Journal of Mechanical Sciences ,156,370-381. https://doi.org/10.1016/j.ijmecsci.2019.03.029

(R7) Langer, K., Spradlin, T. J., Fitzpatrick, M. E. (2020) 'Finite Element Analysis of Laser Peening of Thin Aluminium Structures'. Metals, 10, 1,93 https://dx.doi.org/10.3390/met10010093

Grants:

(G1) Advancing laser shock peening application for fatigue life enhancement (2018-20) Funded by the US Air Force Office of Scientific Research. CU awarded £143,352.45.

(G2) Laser shock peening methods for complex engineering components (2017-20) PhD studentship funded by Airbus. £45,000 awarded to CU.

(G3) Behavior and Sustainability of Laser Shock Peening Induced Residual Stresses in Complex Fatigue Loading (2017-20) Funded by US Air Force European Office of Research and Development. £60,987.97 awarded to CU.

(G4) Development and application of neutron transmission imaging for strain mapping in aerospace applications (2015-19) Funded by Science and Technology Facilities Council, as an ISIS Facility Development Studentship. £41, 380

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

The aerospace industry is constantly seeking technologies to enhance the lifetime of airframe structures, both for new designs and for aircraft types already in operation. One of the critical factors for metallic structures is extending the lifetime of parts that are subject to fatigue cracking during their lifetime. Damage-tolerant design for aircraft seeks to have a complete understanding of the fatigue behaviour of the structure, recognising that cracks will initiate and grow in certain locations, and implementing robust systems of inspection to detect cracks before they can grow and cause failure. New technologies and design concepts are aimed at reducing the incidence of crack initiation, and/or slowing a crack once it has initiated.

Laser shock peening (LSP) is a surface treatment technology that uses a sequence of high-power-density laser pulse to locally vaporise a sample surface to generate a plasma shock that is driven into the surface by use of a confinement layer, usually a water film. The method is applied extensively in aero-engine applications by all the major manufacturers, but its cost, relative inflexibility in application, and the effort required to optimise it for deployment on a new material, have meant that there are few other large-volume commercial applications.

The method is of high interest for use in airframes. The US Air Force implemented Laser Shock Peening as an urgent remedial measure to the Lockheed-Martin F22 in order to solve a design problem on the wing attachment lugs of the initial variants to ensure the aircraft would meet their operational lifetime goal.

Over this REF period, the research at Coventry has underpinned developments in LSP to move it from a specialist, costly method, to one that can be deployed more readily without extensive up-front bespoke process design.

Work in Fitzpatrick's group at Coventry has advanced understanding on how commercial laser shock peening (LSP) technology generates residual stress in aerospace aluminium alloys; how that residual stress can be tailored to obtain benefit in slowing growing fatigue cracks; and how models of the LSP process need to account for cyclic hardening properties of the material peened. We have also studied the application of the eigenstrain technique, which allows for low-computational-effort prediction of residual stress, in terms of factors that limit its applicability and that has influenced decisions on how to deploy the method in aircraft structural design.

The outcomes of the research have informed the application of LSP as a manufacturing tool, as well as for use in repair, either where fatigue hotspots are identified in-service, or as a means to arrest growing cracks.

In parallel, we have been working on developments of modelling techniques in support of the experimental programme. This has not only informed the development of ab initio physics-based models, but has also set the strategic direction for programmes looking to implement LSP in new applications.

"One program initiated by Coventry that was of particular value was a study into the limitations of the eigenstrain method of prediction for residual stress. The program was instigated by Coventry, and funding secured to recruit expertise at Columbia University at Coventry's suggestion, following a PhD program at Coventry where the results were of such immediate interest to AFRL that we employed the student on graduation. The subsequent work highlighted critical issues in the use of the eigenstrain method for any application involving interfaces or discontinuities. This was used to develop "best practice" guidelines for use internally and with our contractors." (S1)

As a result of our research:

• the US Air Force Research Laboratory has developed a validated capability for deployment of laser peening in new applications for life extension. "The improvements in our predictive modelling have allowed this application to be developed without the extensive experimental campaigns that have been necessary previously. Without being able to use LSP in this application, the Air Force would have been faced with a far more costly repair program or retirement." (S1)

• Airbus is progressing the application of laser peen technology through to implementation in manufacturing, maintenance and repair. "As a result of the work undertaken at Coventry, laser peening has moved to TRL6 and we have commissioned a bespoke system for potential airframe repair in the near future." (S2)

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

S1. Testimonial letter of support from the Airframe Technical Advisor, Airframe Research & Technology, AIRBUS Operations GmbH, Kreetslag 10, 21129 Hamburg, Deutschland.

S2. Testimonial letter of support from Integration Lead, AFRL Integrated Planning Branch, Plans and Programs Directorate, US Air Force Research Laboratory, Wright-Patterson Air Force Base, Ohio.