CURRICULUM VITAE

Curriculum Vitae

Communication Address

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Santanu Paul | santanupaul15@gmail.com | +91-8822980383 | santanu.paul92

Education

Doctor of Philosophy in Mechanical Engineering *January 2013-August 2018*
Monash University, Australia and ***Indian Institute of Technology Bombay, India***

- Scholarship: IITB-Monash Research Academy
- GPA: 8.63/10
- **Specialization**: Mechanical Engineering, **Area of Research**: Additive Manufacturing
- Advisor: Prof. Wenyi Yan (Monash University) and Prof. Ramesh Singh (IIT Bombay)
- Ph.D. Dissertation Title: *Laser Surface Cladding for Structural Repair*
- Coursework:

Laser Material Processing	*Fracture Mechanics*

Master of Technology in Mechanical Engineering *July 2010-October 2012*
Indian Institute of Technology Delhi, India

- GPA: 7.355/10
- Major: Thermal Engineering
- Advisors: Prof. M R Ravi and Prof. B Premachandran
- M.Tech. Thesis Title: *Experimental Study on Film Heating of a flat surface*
- Coursework:

Advanced Thermodynamics	*Viscous Fluid Flows*
Radiation and Conduction Heat Transfer	*Applied Mathematics*
Convection Heat and Mass Transfer *Finite Element Method*	*Thermal System Simulation and Design* *Heat Exchangers*

**January 2010-July 2010*: Graduate Aptitude Test in Engineering (GATE 2010) examination and admission to IIT Delhi Master of Technology program

Bachelor of Technology in Mechanical Engineering *July 2005-January 2010*
National Institute of Technology Surat, India

- GPA: 7.9/10
- Major: Mechanical Engineering
- Advisor: Prof. R D Shah
- Undergraduate Project Title: *Numerical simulation of gas turbine combustion chamber*
- Coursework:

Theory of Machines	*Fluid Mechanics*
Mechanics of Solids	*Heat and Mass Transfer*
Kinematics and Dynamics of Machines	*Computer Aided Design and Manufacturing*
Material Science and Metallurgy	*Production Technology*
Thermodynamics	*Computational Fluid Flow and Heat Transfer*

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Research Experience

Post-Doctoral Associate

Department of Mechanical Engineering and Materials Science, University of Pittsburgh, Pittsburgh, USA — *October 2018-May 2022*

Project Title: Inherent Strain Sequential and Congressional Plus-Up AM Monitoring
Funding source: U.S. Department of Defense (DoD)
Status: Ongoing

- Simulate Cold Metal Transfer (CMT) technique for Wire Arc Additive Manufacturing (WAAM) deposition for Inconel alloy using Computational Fluid Dynamics (CFD)
- Developed volume of fluid (VOF) model coupled with solidification macro (Ansys Fluent UDF) to simulated evolving melt pool geometry in CMT process
- Developed Discrete Phase (DP) model to simulate birth, growth, movement and coalesce of droplets, melt pool formation

Tools used:

- Ansys Fluent + User Defined Functions (UDF)
- C++

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Project Title: Wire Arc Additive Manufacturing of Advanced Steam Cycle Components Using Location Specific Design Enhanced by High-Throughput Experiments and Machine Learning
Funding source: U. S. Department of Energy (DoE) University Coalition for Fossil Energy Research (UCFER) program
Status: Ongoing

- Process modeling of CMT based WAAM process to predict Type I residual stresses in complex shape components
- Predict grain texture and distribution in complex shaped components using DDD model
- Developing machine learning based global-local technique to predict Type III (grain scale) residual stresses in additively manufactured complex shape components

Tools used:

- APDL
- MATLAB
- IronPython
- Fortran 95

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Project Title: Prediction of Microstructure Evolution in DMLM processed Inconel 718 with Part Scale Simulation
Funding source: National Aeronautics and Space Administration (NASA) Early-Stage Innovations (ESI)
Status: Completed
Objectives achieved:

- Developed the Discrete Dendrite Dynamics (DDD) model for part scale microstructure prediction in AM
- Establish process-microstructure-property relation for Inconel components fabricated by Powder Bed Fusion (PBF) process

Tools used:

- EOS M290
- Ansys Programming Development Language (APDL)
- MATLAB
- EBSD

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Project Title: Integrated Computational Materials and Mechanical Modeling for Additive

Manufacturing of Alloys with Graded Structure Used in Fossil Fuel Power Plants
Funding source: National Energy Technology Laboratory-U.S. Department of Energy (NETL-DOE)
Status: Completed
Objectives achieved:

- Predicted grain texture of the entire part (~<50mm) for dissimilar alloy (Inconel740H + Mild Steel) deposition by Wire-Arc AM (WAAM) process using DDD model
- Establish process-microstructure-property relation for WAAM deposited dissimilar alloy part
- Developed coupled thermomechanical finite element (FE) based model to predict temperature cycles, and residual stress distribution for plasma based WAAM process for deposition of dissimilar alloys
- Developed ductile damage model to predict mechanical behavior due to gradient alloy composition in WAAM deposited dissimilar alloy part
- Interface design with minimum residual stress for gradient alloy composition in dissimilar metal deposition in WAAM

Tools used:

- Abaqus Explicit
- APDL
- MATLAB
- EBSD

**August 2018-October 2018*: Post-doctoral application, interview, J1 visa processing, travel India-USA

Graduate Research Assistant
Department of Mechanical and Aerospace Engineering, Monash University, Australia
Department of Mechanical Engineering, IIT Bombay, India

Topic: Metallo-thermomechanical model of laser cladding *November 2015-August 2018*

- Residual stress characterization:
  - Volume average Residual Stress characterization using Neutron diffraction experiments at *ANSTO, Sydney*
  - Local Residual Stress characterization using micro-focus X-ray diffraction at *IIT Bombay*
- Derive interrelation between microstructural transformations and residual stresses developed in laser cladding
- Measurement of mechanical behavior of H13 at elevated temperature and low strain rates using dynamic thermomechanical simulator *Gleeble* at *IIT Bombay*
- Development of a 3D fully coupled metallo-thermomechanical model of laser cladding in ABAQUS® for prediction of residual stresses. Salient features include:
  - Thermo-kinetic model to predict in-process solid-liquid transformation and microstructural changes, modelled using *UEXPAN subroutine*
  - Strains due to differential thermal expansion and subsequent contraction between clad and substrate, modelled using *UEXPAN subroutine*
  - Transformation induced plasticity and Volumetric dilation strains due to metallurgical transformation, modelled using *UEXPAN subroutine*
  - Mechanical behavior of substrate and deposited clad approximated using Johnson Cook plasticity model, *UMAT subroutine*
- Identify critical clad height for deposition corresponding to favorable residual compressive stresses in the clad
- Development of process maps to identify optimal deposition conditions

Tools used:

- Abaqus CAE + User subroutines
- IronPython

- ❖ Fortran 95
- ❖ EBSD
- ❖ Brucker D8 Discover X-ray diffractor
- ❖ Gleeble thermomechanical simulator

Topic: Thermomechanical analysis of laser cladding *January 2013-October 2015*

- Pre-placed laser cladding of Co-Ti powder on AISI 4140 steel using Fiber laser at *IIT Bombay*
- Thermal model of pre-placed laser cladding to predict clad geometry, dilution and HAZ considering molten metal spreading via. *Tanner's Law*
- Powder injection laser cladding at *Monash Centre of Additive Manufacturing (MCAM)*
- Metallurgical analysis using *Energy Dispersive X-ray Spectroscopy (EDS)*, *Electron Backscatter Diffraction (EBSD)* and *Scanning Electron Microscope (SEM)*
- Thermal model of powder injection laser cladding to predict clad geometry, dilution and HAZ considering molten metal spreading via. *Tanner's Law*
- Thermomechanical model in ABAQUS® to predict residual stress due to differential thermal expansion-contraction. Salient features include:
  - Moving heat source modelled using *DFLUX subroutine*
  - Powder injection modelled using *Element Birth Technique*
  - Vaporization of clad elements by increasing thermal diffusivity

Tools used:

- ❖ TruLaser Cell 7040 (4kW CO_2 laser at Monash Centre for Additive Manufacturing, MCAM)
- ❖ SPI Fiber laser integrated cladding setup at Machine Tools Laboratory, IIT Bombay
- ❖ Abaqus CAE + User subroutines

Project Assistant
Department of Mechanical Engineering, IIT Bombay, India

Flexible Reconfigurable Fiber Laser Systems for Micro-Scale Materials Processing *October 2012-December 2012*

- Design optical setup for fiber laser system
- Parametric studies for Micro-Scale Material Processing

Tools used:

- ❖ SPI Fiber laser integrated cladding setup at Machine Tools Laboratory, IIT Bombay

Experience with Proposal Writing

- Independently submitted, won, and collaborated for residual stress measurement on AM processed parts using Neutron Diffraction experiments at the *Australian Nuclear Science and Technology Organization (ANSTO)*. Research proposal title: *Residual stress analysis in laser cladding of crucible steel (CPM 9V) on H13 tool steel for die repair application*
- Proposal title: *Towards Sustainable Manufacturing at the Microscale: Addressing Some Scientific and Technological Issues*. Funded by DST- INR 30 million. PI: Prof. Ramesh Singh (IIT Bombay) for *Swarna Jayanti Fellowship*.
- Proposal title: *Three Dimensional Free-form Repair for Steel Dies via Laser Cladding*. Funded by Centre of Excellence in Steel Technology (CoEST)-INR 5 million. PI: Prof. Ramesh Singh (IIT Bombay).
- Proposal title: *Decohesion of over molded thermoplastic copper lead frames*. Funded by Valeo (France)-€ 16000. PI: Prof. Ramesh Singh (IIT Bombay).
- Proposal title: *Novel Laser Powder Bed Fusion Process for Fabricating Crack-Free Tungsten Alloy Components with Tunable Microstructure and Surface Characteristics*. Funded by NASA- ESI. PI: Prof. Albert To (University of Pittsburgh), Co-I: Dr. Sneha Narra (Worcester Polytechnic Institute), Collaborator: Dr. Kevin P. Chen (University of Pittsburgh).
- Proposal title: *Microstructure-aware thermomechanical model to predict residual stress additive manufacturing of Ti6Al4V alloy*. Funded by NASA- ESI. PI: Prof. Albert To (University of Pittsburgh). $500,000.

- Proposal title: *Microstructure-based constitutive model to predict residual stress Additive Manufacturing of Ti6Al4V*. Funded by NSF. PI: Prof. Albert To (University of Pittsburgh). $1,349,853.

Teaching Experience

1. Department of Mechanical Engineering and Materials Science, University of Pittsburgh
   - Course: Mechanics of 3D Printed Materials and Structures
     - Role: Developed course content (Spring 2021)
     - Level: Graduate

2. Department of Mechanical Engineering, IIT Bombay
   - Course: Laser Materials Processing.
     - Role: Instructor, Developed course content (Spring 2014-2017)
     - Level: Undergraduate + Graduate
   - Course: Manufacturing Processes
     - Role: Instructor (Fall 2014-2017)
     - Level: Undergraduate

3. Department of Mechanical Engineering, IIT Delhi
   - Course: Advanced Thermodynamics
     - Role: Teaching Assistant (Fall 2011)
     - Level: Undergraduate

Skills

Theory:
- Non-linear FEA
- Continuum Plasticity
- Discrete Dendrite Dynamics
- Computational Fluid Dynamics
- Crystal Plasticity

Numerical Analysis:
- ABAQUS CAE + User Subroutines
  - DFLUX, USDFLD, UMAT, UEXPAN,
- ANSYS Workbench + APDL,
- Fluent User defined functions (UDFs)
- DANTE Heat Treatment Simulation software

Programming Skills:
- IronPython,
- MATLAB,
- FORTRAN 95,
- Wolfram Mathematica 7,
- C/C++,

Experimental Skills:
- EOS M290
- TruLaser Cell 7040
- Fiber laser optics assembly and operations,
- CNC operations

Statistical Analysis:
- OriginLab,
- Minitab, TSL-OIM™,

Awards and Recognitions

- ***NAMRI/SME Outstanding Paper Award*** at NAMRC-44 by Society of Manufacturing Engineers (SME) in 2016.
- Neutron beam time at the *Bragg Institute Neutron Beam Facility* by Australian Nuclear Science and Technology Organization (ANSTO) in 2016.
- Field work grant for Neutron Diffraction analysis at ANSTO by the IIT B-Monash Research Academy, Mumbai, India in 2016.
- Travel grant for participating in NAMRC-45 by Science and Engineering Research Board (SERB), India in 2017.

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Academic Achievements

- Achieved above 99.9 percentile among ~60000 candidates in Mechanical Engineering paper in the most competitive Graduate Aptitude Test in Engineering (GATE 2010).
- Ranked in the top 1% among ~0.4 million candidates in the prestigious All India Engineering Entrance Examination (AIEEE), 2005.

Professional Affiliations/Activities

- Member: ASME
- Editor: *Frontiers in Manufacturing Technology*.
- Reviewer of high impact research journals: *Additive Manufacturing*, *Materials and Design*, *Journal of Manufacturing Processes*, *Surface and Coatings Technology*, *Manufacturing Science and Engineering*, *Computational Design and Engineering*
- Collaborated with Dr. Anna Paradowska of ANSTO, Sydney for Neutron Diffraction experiments to characterize residual stresses in additively manufactured metal parts

Publication List

Publications

Book Chapters

[B1]. **Paul S.**, Singh R., Yan W. Finite element simulation of laser cladding for tool steel repair in "Lasers based Manufacturing". Springer 2015; ISBN: 978-81-322-2352-8 (Online)

Peer Reviewed Journals

[J1]. **Paul, S.**, Liu, J., Strayer, S. T., Zhao, Y., Sridar, S., Klecka, M. A., Xiong, W & To, A. C. (2020). A Discrete Dendrite Dynamics Model for Epitaxial Columnar Grain Growth in Metal Additive Manufacturing with Application to Inconel. Additive Manufacturing, 101611. https://doi.org/10.1016/j.addma.2020.101611 **Impact Factor: 11.632**.

[J2]. **Paul S.**, Singh R., Yan W. Thermal model for additive restoration of mold steels using crucible steel. *Journal of Manufacturing Processes*. 24(2), pp. 346-354. 2016. DOI: 10.1016/j.jmapro.2016.06.012. https://doi.org/10.1016/j.jmapro.2016.06.012 **Impact Factor: 5.684**.

[J3]. **Paul, S.**, Singh, R., Yan, W., Samajdar, I., Paradowska, A., Thool, K., & Reid, M. (2018). Critical deposition height for sustainable restoration via laser additive manufacturing. Scientific reports, 8(1), 1-8. https://www.nature.com/articles/s41598-018-32842-z/ **Impact Factor: 4.996**.

[J4]. **Paul S.**, Gupta I., Singh R. Characterization and Modeling of Microscale Preplaced Powder Cladding via Fiber Laser. *Journal of Manufacturing Science and Engineering*. 137 (3), pp. 031019. 2015. https://doi.org/10.1115/1.4029922 **Impact Factor: 3.901**.

[J5]. **Paul S.**, Thool K., Singh R., Samajdar I., Yan W. Experimental characterization of clad microstructure and its correlation with residual stresses. *Proceedia Manufacturing*, 10(C), pp. 804-818. 2017. https://doi.org/10.1016/j.promfg.2017.07.081. **Impact Factor: 1.794**.

[J6]. Kattire P., **Paul S.**, Singh R., Yan W. Experimental characterization of laser cladding of CPM 9V on H13 tool steel for die repair applications. *Journal of Manufacturing Processes*. 20(3), pp. 492-499. 2015. https://doi.org/10.1016/j.jmapro.2015.06.018 **Impact Factor: 5.684**.

[J7]. Gupta N., Ahirrao S., **Paul S.**, Singh R. Modeling of micro-scale fiber laser hardening process and optimization via statistical approximation of the engineering models. *International Journal of Precision Engineering and Manufacturing*, 16(11), pp. 2281-2287. 2015. http://dx.doi.org/10.1007/s12541-015-0350-4. **Impact Factor: 5.671**.

[J8]. Wagh, Y. R., **Paul, S.**, Gupta, N., & Singh, R. K. (2018). Metallurgical and tribological investigation of micro-scale fibre laser-based surface hardening. *International Journal of Mechatronics and Manufacturing Systems*, 11(2-3), 120-134. 10.1504/IJMMS.2018.092869 **Impact Factor: 1.26**.

[J9]. Jimenez, X., Dong, W., **Paul, S.**, Klecka, M. A., & To, A. C. (2020). Residual Stress Modeling with Phase Transformation for Wire Arc Additive Manufacturing of B91 Steel. JOM, 1-9. https://link.springer.com/article/10.1007/s11837-020-04424-w **Impact Factor: 2.471**.

Peer Reviewed Conferences

[C1]. **Paul S.**, Singh R., Yan W. Thermal model for additive restoration of mold steels using crucible steel. Proceedings of the 44th SME North American Manufacturing and Research Conference (NAMRC 44). June 27-July 1, 2016. Virginia Tech. Blacksburg, Virginia, USA.

[C2]. **Paul S.**, Liu J., Chen Q., Wang X., Xiong W., Klecka, M., To A., Part-scale Coupled Process-microstructure Model for Additive Manufacturing of Nickel Alloy. Presented on 08/14/2019 at the 30th Annual International SFF Symposium in Austin, Texas USA

[C3]. **Paul S.**, Thool K., Singh R., Samajdar I., Yan W. Experimental characterization of clad microstructure and its correlation with residual stresses. Proceedings of the 45th SME North American Manufacturing and Research Conference (NAMRC 45). June 4-8, 2017. University of Southern California, Los Angeles, USA.

Publication List

[C4]. **Paul S.**, Ashraf K., Singh R. Residual stress modeling of powder injection laser surface cladding for die repair applications. Proceedings of the ASME 2014 International Manufacturing Science and Engineering Conference (MSEC 2014). June 9-13, 2014. Detroit, USA. Paper No. MSEC2014-4029. pp. V002T02A092, Volume 2. DOI: 10.1115/MSEC2014-4029. ISBN: 978-0-7918-4581-3.

[C5]. **Paul S.**, Vundru C., Singh R., Yan W. Numerical analysis to determine critical height for multi layered laser cladding for die repair applications. 9th Australasian Congress on Applied Mechanics (ACAM9). November 27–29, 2017. University of New South Wales. Sydney. Australia.

[C6]. **Paul S.**, Vundrua C., Singh R., Yan W. Numerical analysis of multi layered laser cladding for die repair applications to determine residual stresses and hardness. Proceedings of the 46th SME North American Manufacturing and Research Conference (NAMRC 46). June 18-22, 2018. Texas A&M University, College Station, Texas, USA.

[C7]. **Paul S.**, Singh R., Yan W. Thermo-mechanical modeling of laser cladding of CPM 9V on H13 tool steel. Proceedings of the 5th International and 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014). December 12-14, 2014. Indian Institute of Technology Guwahati, India.

[C8]. Gupta I., **Paul S.**, Singh R. Characterization of micro scale pre-placed powder cladding via fiber laser. Proceedings of the International Conference on precision, Meso, micro and Nano Engineering (COPEN 8). December 13-15, 2013. National Institute of Technology Calicut, India.

[C9]. **Paul S.**, Singh R., Yan W. Thermal Modelling of Powder Deposition in Powder Injection Based Laser Cladding for Die Repair. 9th International Conference on Precision, Meso, Micro and Nano Engineering (COPEN 9). December 10-12, 2015. Indian Institute of Technology Bombay. India.

[C10]. **Paul S.**, Xiong W., To A. C. Grain-scale Residual Stress Modeling in Wire Arc Additive Manufacturing of Haynes 282 Super Alloy. MS&T21: Materials Science & Technology Conference. October 17-21, 2021. Columbus. Ohio. USA.

[C11]. Glunt K., Dong W., **Paul S.**, To A. C. Residual stress induced cracking modeling. MS&T21: Materials Science & Technology Conference. October 17-21, 2021. Columbus. Ohio. USA.

Google Scholar profile

PhD. Thesis link

References

- Prof. Albert C. To.
  Title: William Kepler Whiteford Professor.
  Affiliation: Department of Mechanical Engineering and Materials Science.
  University of Pittsburgh.
  Address: 508 Benedum Hall
  3700 O'Hara Street
  Pittsburgh, PA 15261. USA.
  Tel: (+1) 412-624-2052
  Fax: (+1) 412-624-4846
  e-mail: albertto@pitt.edu
  URL: http://www.pitt.edu/~albertto/
  Relationship: Post-Doctoral Advisor

- Prof. Wenyi Yan.
  Title: Professor and Director of Research.
  Affiliation: Department of Mechanical and Aerospace Engineering. Monash University.
  Address: G09, 17 College Walk, Clayton Campus.
  Monash University. Clayton VIC3800. Australia.
  Tel: (+61) 03 9902 0113
  Fax: (+61) 03 9905 1825
  e-mail: wenyi.yan@monash.edu
  URL: http://users.monash.edu.au/~wyan/
  Relationship: Ph.D. Advisor

- Prof. Ramesh Singh.
  Title: G. K. Devarajulu Chair Professor &
  Associate Dean (II)-Infrastructure Planning and Support.
  Affiliation: Department of Mechanical Engineering.
  Address: Machine Tools Laboratory. IIT Bombay.
  Powai. Mumbai-400076. India.
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  URL: http://www.me.iitb.ac.in/~ramesh/
  Relationship: Ph.D. Advisor

- Prof. Wei Xiong.
  Title: Associate Professor.
  Affiliation: Department of Mechanical Engineering and Materials Science.
  University of Pittsburgh.
  Address: 606 Benedum Hall.
  3700 O'Hara Street
  Pittsburgh, PA 15261. USA.
  Tel: (+1) 412-383-8092
  Fax: (+1) 412-624-4846
  e-mail: weixiong@pitt.edu
  URL: https://www.pitt.edu/~weixiong/index.html
  Relationship: Project PI

Project list

Project period	Project brief
02/2021-01/2023 (ongoing)	PI: Wei Xiong (MEMS, Pitt) Co-PIs: Albert C. To Agency: **DOE – NETL** Title: Wire Arc Additive Manufacturing of Advanced Steam Cycle Components Using Location Specific Design Enhanced by High-Throughput Experiments and Machine Learning Support: **$600,000** (co-PI, 24%) Description: This research aims to simulate the part- and grain-scale residual stress in Haynes alloy parts deposited by the wire-arc additive manufacturing process.
11/2018-10/2020 (completed)	PI: Wei Xiong (MEMS, Pitt) Co-PIs: Albert C. To, Michael Klecka (United Technologies Research Center) Agency: **DOE – National Energy Technology Laboratory (NETL)** Title: Integrated Computational Materials and Mechanical Modeling for Additive Manufacturing of Alloys with Graded Structure Used in Fossil Fuel Power Plants Support: **$749,853** Description: This research aims to develop an integrated computational materials and mechanical modeling method to design additive manufactured alloys with graded structure for components of fossil fuel power plants.
01/2017-01/2020 (completed)	PI: Albert C. To Co-PIs: Wei Xiong (MEMS, Pitt), David Conover (ANSYS) Agency: **National Aeronautics and Space Administration (NASA)** Title: Prediction of Microstructure Evolution in DMLM Processed Inconel 718 with Part Scale Simulation Support: **$500,000** Description: The objective of this research is to understand the process-microstructure relationship of Inconel 718 produced by the direct metal laser melting (DMLM) process.