Development of Micro-Plasma Transferred Arc Wire Deposition Process for Additive Layer Manufacturing Applications

A THESIS

Submitted in partial fulfillment of the requirements for the award of the degree

of

DOCTOR OF PHILOSOPHY

by

SUYOG JHAVAR

DISCIPLINE OF MECHANICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY INDORE

March 2014

Indian Institute of Technology Indore
Academic Office
Thesis submitted on 22 March 2014
for T. Parihar
Dy. Registrar, Academic Affiars

INDIAN INSTITUTE OF TECHNOLOGY INDORE

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **Development of Micro-Plasma Transferred Arc Wire Deposition Process for Additive Layer Manufacturing Applications,** in the partial fulfillment of the requirements for the award of the degree of **DOCTOR OF PHILOSOPHY** and submitted in the **DISCIPLINE OF MECHANICAL ENGINEERING, Indian Institute of Technology Indore**, is an authentic record of my own work carried out during the time period from July 2010 to March 2014 under the supervision of **Prof. N. K. Jain**, Professor, Discipline of Mechanical Engineering and **Dr. C.P Paul**, Scientist-F, Raja Ramanna Centre for Advanced Technology, Indore.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other institute.

(Suyog Jhavar)

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

(Dr. C.P. Paul) 19/03/2014 **(Prof. Neelesh Kumar Jain)**

Suyog Jhavar has successfully given his Ph.D. Oral Examination, held on 29th May 2014

29/05/2014 29/5/2014
Signature of Thesis Supervisors
Date:

29.5.14
Convener, DPGC
Date:

S. Mukherjee 29/5/2014
May 29, 2014
Signature of PSPC Members
Date:

Signature of External Examiner
Date: 29. 5. 2014

Abstract

ALM is an advanced manufacturing technology in which material is deposited and joined layer by layer to (i) produce new net-shaped or near net-shaped components; or (ii) to add delicate features to the existing components. Each layer is created by rapid solidification of deposition material over the stationary or moving substrate. The deposition material can be supplied in the form of liquid and/or solid (i.e. powder, wire, pellets, foil, etc.). The bonding strength between the substrate and the deposition material varies depending on the deposition energy, deposition volume, deposition pattern and interaction time between the deposition and substrate material. Continuous demand for precise and faster production of the complicated 3D-components in an economical, energy-efficient, material-efficient and environmental-friendly manner forces the researchers to develop enhanced ALM processes. The type of energy source is one of major factors differentiating various ALM processes. Laser, electron beam and electric arc are the major energy sources used widely for the ALM of metallic materials. Laser and electron beam are more precise energy sources than the electric arc therefore they are preferred for miniature sized deposition. But, a major drawback is their poor energy conversion efficiency which causes higher energy consumption for fabrication of components, tooling and related applications. Use of energy efficient sources and increase in the deposition rates are the two major concerns for ALM processes. Micro-arc based deposition is one of the recent ALM techniques having prospective applications in repairs and fabrication at meso-scale.

This thesis reports on the development of μ-PTA as cost effective and energy efficient alternative process for small sized deposition. An experimental setup was developed to deposit a wire of 300 μm diameter of AISI P20 tool steel on the substrate of the same material, which is one of the most commonly used materials used for various applications. Experiments at two stages were conducted to indentify important process parameters generating regular and smooth single bead geometry. The process was further explored to determine the highest possible deposition rate for fabrication of straight walls through multi-layer deposition. Further investigations on enhancing the deposition quality in μ-PTA process by approximating deposition geometry as an elliptical arc was prepared with an objective to predict its cross-sectional area and to optimize the deposition overlap between the successive tracks. The model was validated using the experimental apparatus developed for μ-PTA wire deposition

process. The predictions were compared with the previously developed models deposition geometry considering it as an arc of parabola, circle and cosine function.

The μ-PTA deposition process experimentally was found to be capable fabricating straight walls having total wall width of 2.45 mm and effective wall wi of 2.11 mm. The deposition efficiency was found to be 87% for the maximu deposition rate of 42 g/h. The microscopic examination and micro-hardne measurements revealed that the deposited wall is free from cracks, porosity, inclusior This study thus confirms the capability of μ-PTA as an alternative ALM process comparison to the existing high energy deposition processes used for meso-sca fabrication. Use of finer wire can further reduce the deposition size enabling μ-PT wire deposition process to fabricate miniaturized parts. The validation of theoretic modeling proved the superiority of the elliptical function based model over th previously existing models for predicting cross-sectional area and overlap of th deposition track for μ-PTA wire deposition process. The performance of μ-PTA wir deposition process was found to bridge the gap between high energy beam base processes and other arc based processes.