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HIGH PERFORMANCE COMPUTING AND PROCESS CONTROL OF ADDITIVE LAYER MANUFACTURING METHODS FOR POLYMER PRODUCT METAL TOOLS PRODUCTION

Rohit Pandey[1*], Sandeep Salodkar[2]

[1*]Mechanical Engineering Department, Amity School of Engineering and Technology, Amity University Madhya Pradesh, Gwalior M.P., India; [2]Mechanical Engineering Department, Faculty of Engineering and Technology, Dr. A.P.J. Abdul Kalam University, Indore M.P., India.

Email: [*]pandeyrohit1988@gmail.com

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Abstract

Purpose of the study: Additive layer manufacturing is basically different from the traditional formative manufacturing process where a complete structure can be constructed into designed shape from layer to layer manufacturing rather than other methods or casting, forming or other machining processes. Additive layer manufacturing is a highly versatile, flexible, and customizable.

Methodology: In this paper, we discussed high-performance computing and process control of AM methods by using different parameters. The significant interest in making complex, innovative and robust products by using AM methods to great extent to deal with work is needed in AM challenges relevant to key enabling technologies namely different materials and metrology to achieve functionally and reproductive ways.

Main Findings: In this paper, we discussed major processes that highly accurate and the key applications, challenges and recent developments of future additive Am processes.

Applications of this study: Additive layer manufacturing methods to develop the most highly and controlled methods for producing a variety of complex shapes and structures. The significant role of AM layer technology is to make produce the most economical and highly effective methods. In this study, we compared different AM methods for achieving the most highly and controlled methods of AM technology.

Novelty/Originality of this study: Today manufacturing trends are very highly impacted by technologies globalizations. Various manufactures are using layer manufacturing into their best practices so that they can be changes in the global economy and manufacturing.

Keywords: *Polymers, Additive Layer Manufacturing, 3D Printing, Rapid Prototyping, CAD, Machining, FDM.*

INTRODUCTION

An Additive Manufacturing (AM) technology is the production ability to make multi-material components. By using this technique, multiple types of materials can be used for the fabrication of a single part. Components with specially tailored functionally graded, heterogeneous or porous structures and composite materials have been some of the achievements of this method (Derakhshani, M., T. Berfield, and K.D. (2018)). A wide range of materials such as metals, plastics, and ceramics has been used in various AM methods to obtain multi-material products in order to match the current requirements of the industry which would not be gained otherwise (Venkataraman, N., et al. (2000)). AM techniques have the potential of being applied to multiple materials manufacturing in nature. Various studies performed to investigate the possibility of applying multi-material production for different AM methods (Lous, G.M., et al. (2000)). The process of producing multi-composite materials by layer manufacturing AM can either be performed during the material deposition process or by a hybrid process in which the combination of different materials can be performed before or after AM as a previous or subsequent stage of production of a component. (Gardan, J. (2016))

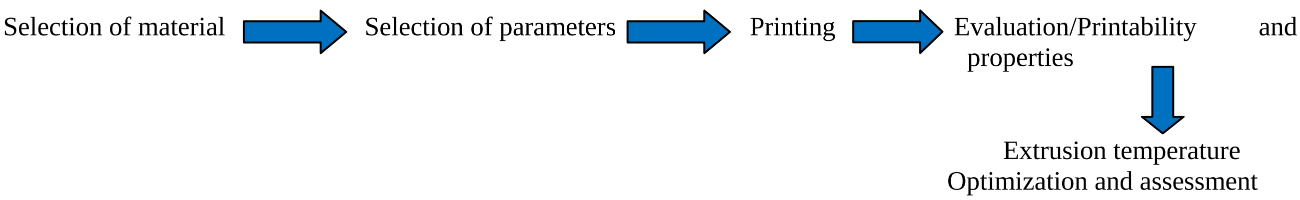

Figure 1: Process selection protocol of additive manufacturing for polymer filament fabrication.

Figure 1 shows the various steps for making components by using the layer manufacturing technique. Composite processes can be used to produce heterogeneous scaffolds and functionally graded materials (FGM). Production of tailor-made gradient multi-phase or porous materials is one of the features of layer manufacturing methods. As a result, different types of properties can be obtained within one single integrated part. Moreover making polymer components with composite material, the required properties of desired materials can be added with compensating for some other types their restrictions. (Kalita, S.J., et al. (2003), Choi, J.-W., et al. (2010), Ervin, M.H., L.T. Le, and W.Y. Lee, (2014))

DIFFERENT SCALE ADDITIVE LAYER MANUFACTURING TECHNOLOGY

(a) Problem Statement: AM processes basically have three fundamental limitations: (i) AM processes build-up to minimum 20 cm^3/minute; (ii) Size of the parts comparatively medium size (< 1000 cm^3 in volume); (iii) The polymer materials are expensive ($100/kg) feedstock. These process limitations polymers and metal AM technology are transforming biomedical devices and aerospace industries are making a large variety of variety products, respectively. The significant development in cost, high speed and size or any environmental chamber, may open new applications such as earthmoving, transportation, energy and oil and gas applications. (Sochol, R., et al. (2016))

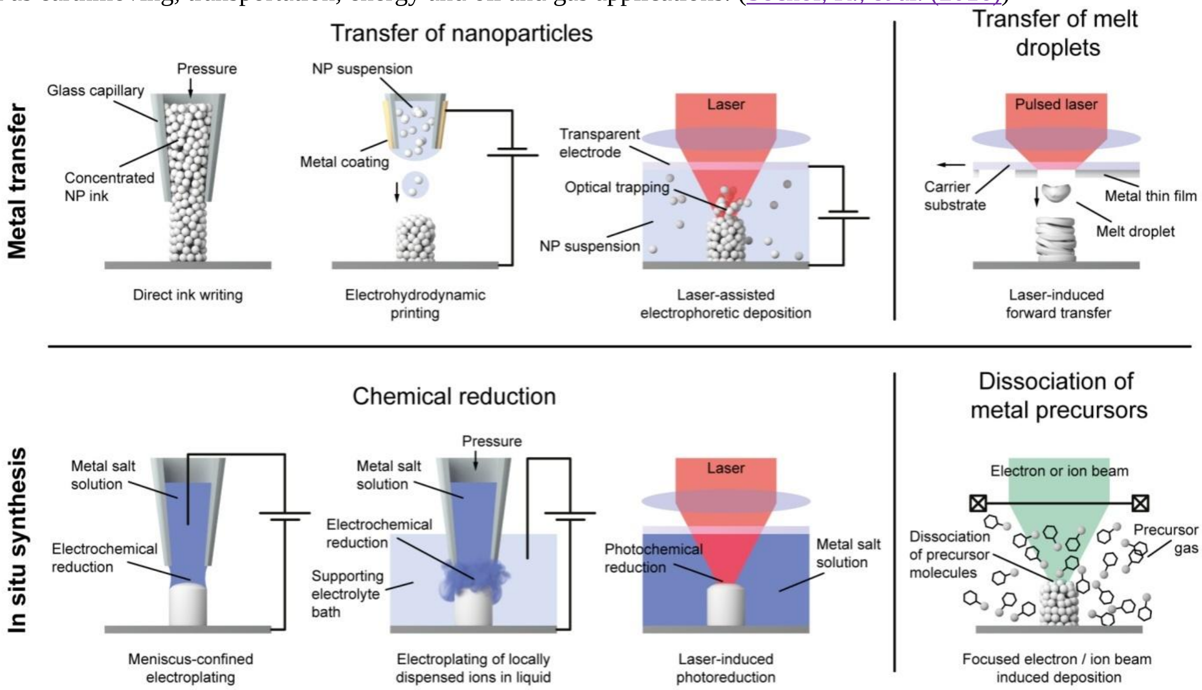

Figure 2: Functional processes of different AM processes for multi-materials (BAAM) methodology. (a) The first part is the metal transformation of nanoparticles and (b) the second part is in suit synthesis in chemical reduction and dissociation metal precursors.

(b) Approach: In order to demonstrate the concept, a big area additive manufacturing (BAAM) methodology was developed by researchers for plastic components 3D printing. The first decision in this development was to use lower-cost pellets of Acrylonitrile Butadiene Styrene (ABS) was selected using pre-processed high-cost filaments of polymers. For example, material costs range from under $3/lb. for carbon fiber (CF) reinforced ABS to $20/lb. for CF U item. The use of the larger nozzle changes the thermal behaviour of the extrusion conditions. Conventional fused deposition modeling systems are going from various melt temperature at the extruder level to the room temperature in experimentally 220 msec.

(c) Demonstration: In the next step, the above technology was exercised for two example applications for manufacturing prototype automobiles and mould form sheet metal fabrication (see Figure 2b & 2c). For the manufacturing of prototype automobiles, ORNL researchers partnered with Local Motors and Cincinnati Incorporated to manufacture an electric vehicle. Most traditional automobiles are assembled exceed to 10,000 parts. The Strait used the BAAM technology to reduce manufacturing within 60 parts. The design procedure based on a body structure and structured that has weighed experimentally 400 kg and took experimentally 40 hours to produce. Table 1 shows the descriptions of typical values used for breakeven analysis for machining and FDM of layer manufacturing processes. (Grimoldi, A., et al. (2016), Xie, D., et al. (2010))

Table 1: Typical values used for breakeven analysis

Description	Machining	FDM
Mass of Part, (kg)	0.5	0.5
Mass Rate, (kg/h)	1	0.031287
Energy Density, (MJ/kg)	2.78	25.78
Labour Cost, ($/hr	50	50
Design Cycle Time, (h)	80	80
Capital Cost, ($/h)	50	50
Feed Stock Cost, ($/kg)	1	1
Tooling Cost, ($)	20,000	1

Failure Cost, ($)	1	1
Rate of Failure, (%)	0.0001	0.0001
Buy to Fly Ratio Range	1 to100	1 to 1.2

(d) Effect of Material Feedstock Costs: Many arguments (Ibrahim, M., et al. (2006)) are made in the literature that the cost of the FDM feedstock is indeed higher than that of the block of the same material made by the traditional manufacturing process. Based on the above, the arguments can be made that FDM is only applicable to prototyping only. Interestingly, our analyses (see Figure 1b) shows that even if we increase the cost of the material from 1 to 100 dollars, the transition conditions from machining to are affected only marginally. However, the cost of the material feedstock may be related to the quality of the feedstock, which becomes crucial in other evaluations of potential failures in parts. (Ko, S.H., et al. (2010), Zhu, F., et al. (2015))

(e) FDM tooling cost: The FDM processes are indeed economical in the prototyping costs. However, it is well known that even in the FDM process, the cost of the tooling may increase depending upon the complexity of the product geometry. For example, by increasing the tooling cost to 20,000 dollars, the FDM becomes unviable under these conditions; the FDM can be viable only if the tooling was used for manufacturing 600 or more parts. (Haldar, A., K.-S. Liao, and S.A. Curran, (2014))

(f) Designer Cost: Although the additive manufacturing process is simple, the need for robust pre-process design has become critical. For example, poor design of supporting parts within CAD parts may lead to failure of AM part with severe overhangs within the geometry. As a result, the designer of AM parts has to be very proficient with CAD tools, performance criteria, selection of material, as well as, nuances of AM technology. In contrast, the machining processes are indeed standardized and the designer just needs to define the surface roughness condition, which is easily interpreted and achieved by machine tool operators. If we increase the cost of employing a design engineer with labour rate of $500/hr, the transition curves mimics the same condition that is based on increased tooling cost. (Mengel, M. and I. Nikitin, (2010))

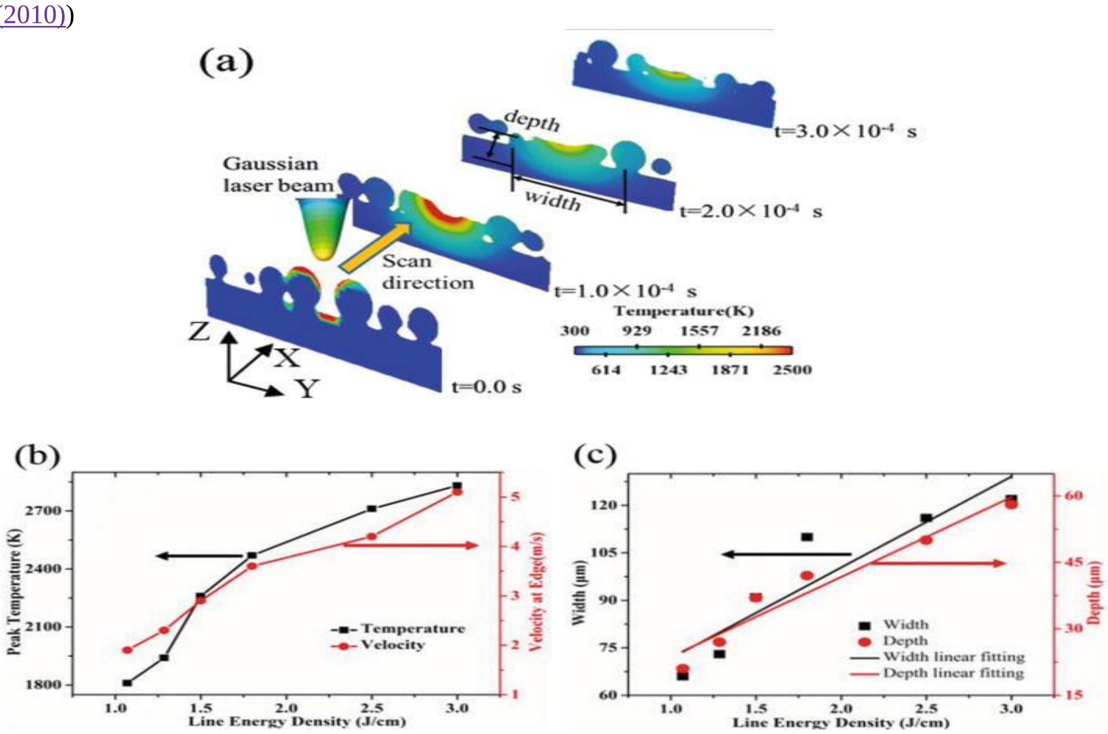

Figure 3: Heat and mass transfer in the FDM process (3a, 3b & 3c).

(g) Sensitivity to Manufacturing Deposition Rate: As seen from the table 1, the FDM deposition rates are very small. As a result, the productivity of additive manufacturing is indeed low and limits its feasibility only to prototyping conditions where one faces very high values. However, if we can increase the deposition rate, the transition points can be reduced. For example, by increasing the deposition rate from 0.2 kg/hr to 1.5 kg/hr, the transition was decreased from 20 to 1.5 (see Figure 2b). This hypothesis is supported by the publication by Roland Berger (Murr, L.E. (2016)). However, the technology for increasing the deposition rate while maintaining the geometric control is still in its infancy. Some of the recent research and development related to this topic will be discussed in the next section. (Faes, M., et al. (2016))

Table 2: Comparison of selected Additive Layer Manufacturing Processes

	SLA	SLS	LOM	FDM	SMS	3DP
Materials	Polymers	Metals, sand, thermoplastics(PA13, PD,PP)	Foils (paper, polymers, metals,	Thermoplastics (ABS,PC, ABS-PC-	Thermoplastics (PA16)	Thermoplastics, cast sand, cement

			ceramics)	blend, PPSU)		
Component size (mm)	500x500x400	600X320X520	520x700x500	400x500x500	200x287x500	510x620x402
Accuracy	<0.03	0.03-0.1 mm	0.10 mm	0.15 mm	0.02-0.10 mm	0.2/500x520 dpi
Cooling and curing-off time	Curing time up to 15 min	Bulk geometry (No cooling-off)	Depends on geometry	curing time up to 20 min	Bulk geometry	curing time (No cooling-off)
Commercially available since	1988	1990	1991	1992	2001	1997
Costs (E€)[b]	120	140	150	50	150	30
Relative sample pre costs[(c)]	medium	Moderate medium	Medium to moderate high	Lower to moderate high	Medium to moderate high	Very low

(h) High-Performance Computational Modelling Problem Statement: In, additive manufacturing components like (tapes, powder and wires) converted into other finished products by manipulating them using other various energy sources. These conventional energy sources are including photons, plasma, electrons and phonons, interact with these materials leading to deformation, melting and moderate highly strain rate deformation to consolidate into different ways (Ko, S.H., et al. (2010)). Theses interactions are build up a variety of complex shapes and structures expected target properties (Qin, H., J. Dong, and Y.-S. Lee,(2017)). Additive layer manufacturing methods resort back to trial and error optimization practices similar to different conventional manufacturing. The number of different variables in electron beam AM can reach greater than 105 (high-dimensional if the path dependency is considered) for achieving the optimization of a futile attempt. (Delannoy, P.-E., et al. (2015), Delannoy, P.-E., et al. (2015))

(i) Approach: The optimization of additive manufacturing processes for a wide range of applications can be possible by developing integrated process modeling capable of capturing the fundamental phenomenon, as well as, provide access to these for rapid process optimization. To developed the HPC (High-Performance Computing) tools are developing and including recent features (1) the melting process with heat transfer media (2) Steep temperature gradient of heat and transfer through high liquid-solid interface velocity (Ibrahim, M., et al. (2006)), (3) microstructure evolution and deformation of polymers materials and (4) thermo-mechanics (Wang, J. and L.L. Shaw, (2006)). In this paper, a high-performance computational heat and mass transfer were used for a predicted variation of melt-pool shape during electron beam additive manufacturing of Ti6Al4V alloys material. This type of simulation results is performed by using Truchas code from LANL (Los Alamos National Laboratory) (Li, L., et al. (2009)) with different and appropriate user routines for path specification. (Sanchez-Romaguera, V., M.-B. Madec, and S.G. Yeates, (2008), Kim, M., et al. (2014), Kim, H., Y. Zhao, and L. Zhao, (2016))

SUMMARY AND CONCLUSION

Potential confirmation of this need was demonstrated with big area additive manufacturing of polymer composites for automation prototype and recent tooling applications. Minimize the trial and error AM process design and development, in-situ optical and thermal sensing methodologies have been constructed, developed, and demonstrated in the most frequent and highly effective way. These measurements can also be used to control the thermal gradients and liquid-solid interface velocities to achieve site-specific microstructure control. This was demonstrated in Fused Deposition Modelling (FDM) powder-bed additive manufacturing of alloy 718 by inducing site-specific columnar and miss oriented solidification grain texture through the volume of the build and to induce these site-specific microstructural changes, a-priori design of processing parameters have to be done without trial and error experiments. To meet the advanced requirement of AM methods to develop the most highly and controlled methods for producing a variety of complex shapes and structures. The significant role of AM layer technology is to make produce the most economical and highly effective methods. In this study, we compared different AM methods for achieving the most highly and controlled methods of AM technology.

FUTURE SCOPE

Today manufacturing trends are very highly impacted by technological globalization. Various manufactures are using layer manufacturing into their best practices so that they can be changes in the global economy and manufacturing. AM methods quickly contributing greatly to success in making various types of parts. Layer manufacturing can save time and money. It can also use in medical fields to save lives and expected growth of \$3.12 billion from 2012 to 2024, according to the global manufacturing sector. (1) Speed of production (2) Quality of products (3) Surface finish (d) Strength and mechanical properties are improving by using these methods.

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