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SCIENTIFIC AND TECHNOLOGICAL CHALLENGES OF LAYER MANUFACTURING PROCESSES FOR POLYMER COMPONENTS 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 study: Additive manufacturing processes taking the basic information form computer-aided design (CAD) file to convert into the stereolithography (STL) data file. Today additive layer manufacturing processes are playing a very vital role in manufacturing parts with high rate of effectiveness and accuracy. CAD software is approximated to sliced containing information of each layer by layer that is printed. The main purpose of the study is to discuss the scientific and technological challenges of additive layer manufacturing processes for making polymer components production through various technological parameters and problem-solving techniques of layer manufacturing processes.

Main findings: Additive layer manufacturing is simply another name for 3D printing or rapid prototyping. As 3D printing has evolved as a technology, it has moved beyond prototyping and into the manufacturing space, with small runs of finished components now being produced by 3D printing machines around the world. Additive layer manufacturing (ALM) is the opposite of subtractive manufacturing, in which material is removed to reach the desired shape

Methodology Used: The continuous and increasing growth of additive layer manufacturing processes to discuss with different experimental behavior through simulations and graphical representations. In ALM, 3D parts are built up in successive layers of material under computer control. In its early days, 3D printing was used mainly for rapid prototyping, but it is now frequently used to make finished parts the automotive and aerospace sectors, amongst many others.

The originality of study: At the present time, the technologies of additive manufacturing are not just using for making models with the plastics but using polymer materials. It is possible to make finished products developed with high accuracy and save a lot of time and there is the possibility of testing more models.

Keywords: *Additive Layer Manufacturing, 3D Printing, Rapid Prototyping, Polymer Components, CAD Model, SLS.*

INTRODUCTION

Additive Manufacturing is defined by Merriam-Webster dictionary as a methodology by which a product is made from raw materials by hand or machinery, through systematic steps with a clear division of labour, using machinery powered by mechanical and electric means. Additive manufacturing, an emerging technology, is a sub-set of the overall manufacturing ecosystem that has the potential to revolutionize the way we make products and consume them (Zhou, C., et al. (2011)). There exist, plenty of online articles and publications related to additive manufacturing (also known as 3D printing). One of the suggestions, made by many casual observers of this technology in popular media, is that additive manufacturing will lead to equalization of manufacturing process capability, thereby economically a flat world. Scientific and technological challenges of additive manufacturing processes evaluated through different parameters of CAD modeling. Basically, this work is done on the study of various layer manufacturing processes for polymer components metal tool production.

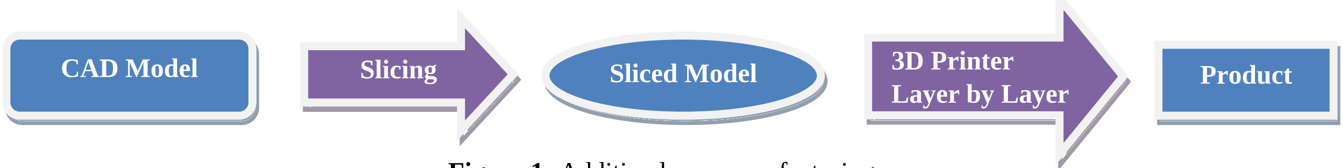

Figure 1: Additive layer manufacturing.

AM SET UP DESCRIPTION

The ability to design a part and manufacturing using 3D printing equipment may indeed be considered as the realization of this hypothesis. Selective laser sintering (SLS), laser-engineered net-shaping (LENS), micro-casting, laser-based additive manufacturing (three-dimensional laser cladding), and shape deposition 65 manufacturing (SDM) are some important layer-manufacturing processes for the rapid prototyping/manufacturing system. In the one-step laser cladding, the powder material is injected continuously into a laser molten pool and melts to form a clad track on the surface of the substrate. A layer is formed successively by tracks deposited side by side (Mueller, B. (2012), Vaezi, M., et al. (2013)). A variety of materials including metals, cermets, ceramics, and composite claddings have been successfully deposited to develop potential in the non-equilibrium synthesis of advanced functional materials, alloy development and free-form near-net-shape manufacturing. Composite surface layers have been produced by injection either ceramic particles or a mixture of metal and ceramic powders at a certain ratio, into the laser molten pool (Mueller, B. (2012), Vaezi, M., et al. (2013)). Hard particles such as WC, TiC, SiC, and CrB2 are usually employed to improve the wear resistance of the engineered surfaces. WC particles are distinguished by a minimal plastic deformation capacity, a low thermal expansion and a high wet ability by molten metals. With a high content of hard particles, the deposited surfaces are relatively rough and a high crack rate cannot be avoided. This result may be overcome with the use of solid-state Nd: YAG lasers that allow improved control of the cladding process at low heat input (Mueller, B. (2012)). High-power lasers in conjunction with a powder-feeding technique have been used to produce functionally graded materials (FGMs) by the successive deposition of different clad layers. However, the large differences in thermal and physical properties between metals and ceramics cause serious problems in the fabrication of metal/ceramic FGMs by laser cladding Huang, (P., D. Deng, and Y. Chen. (2013), Mueller, B. (2012)). Since the heating and the cooling rates are rapid during laser cladding, the cracks form more easily not only at the interfacial regions between different constituents but also within the ceramic particles. There are difficulties in controlling the porosity and cracking in some cases, and the chemical interaction between the matrix and ceramic particles due to high temperatures involved in laser cladding. In this paper, a feasibility study has been carried out to produce a FGM FSW-tool consisting of WC-based creamed and H13 tool steel using the laser-based additive manufacturing technique. A graded distribution of WC particles was realized by adjusting the flow rate of different powders for successive layers.

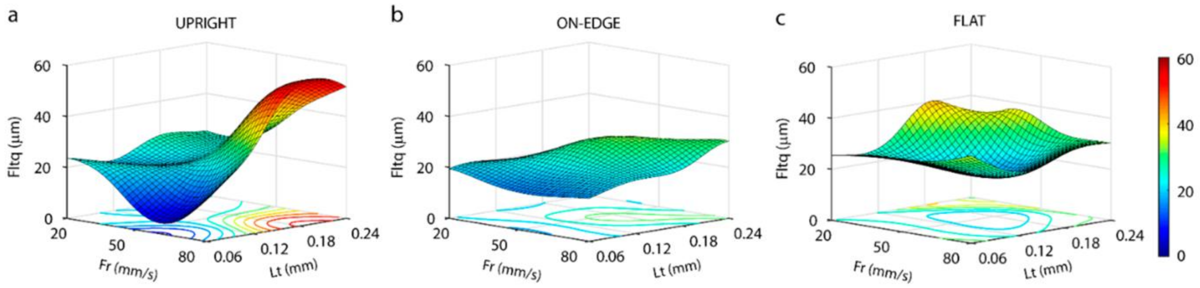

Figure 2: Schematic diagram of the laser-based additive manufacturing system setup used in different simulation investigation (a) Upright variation (b) On edge variation & (c) Flat variation.

All the microhardness tests are carried out using a Vickers microhardness tester and a 500-g load for 15 sec on polished specimens. For microstructural observations, all the samples are selectively etched using a modified reagent consisting of hydrofluoric acid and nitric acid. All the friction-stir welds have been made in a butt-weld configuration using a laser-deposited FSW tool and an FSW machine as stated in our previous paper (Sakly, A., et al. (2014)).

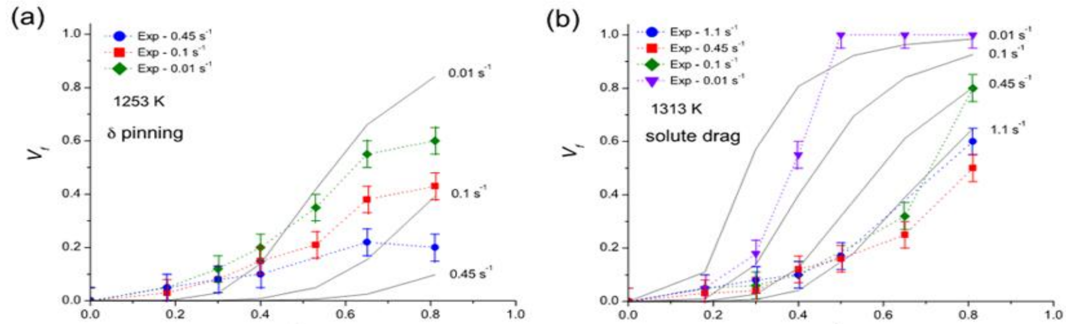

Figure 3: Experimental behavior of polymer components production at different CAD tools 1(a) & 1(b) Stress-strain variations at various points). As the graph (a) showing the effect of different experimental point variations in pining and (b) showing the effect of different experimental point variations in solute drag condition.

The WC particles in the deposited FGM provides high wear resistance, while the H13 tool steel exhibits an excellent combination of hardness and toughness at elevated temperatures. Experimental procedures Figure 2 shows the schematic diagram of the laser-based additive manufacturing system setup used in this investigation. A 1kW continuous-wave Nd: YAG laser with a 200-mm focusing optics is used to deposit the powders. Recently developed computer-controlled powder feeders are used for dosing and feeding the powder mixture into the desired composition, and allow for an exact setting and continuous change of the powder mixture during the cladding process. The feed rate of each of the powders and laser parameters are controlled automatically. The standard methods of metallography are applied to obtain microstructural and compositional analyses of the FGMs. (Sugavaneswaran, M. and G. Arumaikkannu,(2016)), Raman, R. and R. Bashir, (2015))

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With additive processes, α+ is typically close to 1. With subtractive processes, α- can range from 1 to 40. This introduces an interesting contrast between the two processes. With additive processes, the minimization of feedstock is beneficial. The less material in the part, we hypothesize that the lower the cost and faster the manufacturing time. In contrast, with subtractive processes, the close the part is to the billet size, the less material is removed, the faster the build size, the lower the cost. Therefore, for additive processes, the key variable is the mass of the part (M part), whereas, with subtractive processes, the key variable is the volume of subtracted material [M Processed = (α- - 1) M part]. We can use these two terms and evaluate the overall cost of making a unit product with due consideration of costs of energy, labour, design, capital, tooling, material feedstock and failure to meet the targeted need. The details of the cost model are presented in Appendix A. Sensitivities are illustrated by considering machining (-) and FDM (+) process for manufacturing plastics. The breakeven conditions are calculated as a function of buy-to fly ratio for machining and number of parts made using the data shown in Figure 2: Typical values used for breakeven analysis Details 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, ($/hr) 50 Design Engineer Labour, ($/hr) 80 Design Cycle Time, (h) 80 Capital Cost, ($/h) 50 Feed Stock Cost, ($/kg) 1 Tooling Cost, ($) 20,000 1 Failure Cost, ($) 1 Rate of Failure, (% 0.0001).

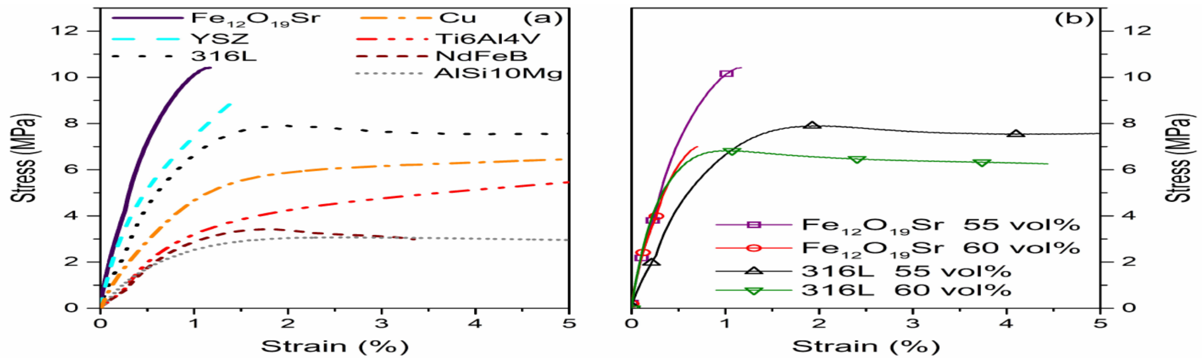

Figure 4: Physical behaviour of polymer components production at different materials in stress-strain (%).

PHASES FOR EVALUATING TECHNOLOGICAL CHALLENGES OF LAYER MANUFACTURING PROCESSES FOR POLYMER COMPONENT PRODUCTION

Economic Drivers for Adoption of AM and Challenges A review of Google trends of the search term "additive manufacturing" or "3D printing" will demonstrate the popularity and curiosity of this technology across the world. Nevertheless, there are no guidelines for manufacturers to answer the question, to be or not be additive in the future? The decision to adopt a promising new technology in industries driven by two sets of people: (a) early adopters and innovators who have a vision for the utility of new technology to improve the quality of life and (b) industries who will adopt new technology due to its potential economic advantage within their product line. In this section, we will use an economic metric to evaluate the decision making to switch from traditional to additive manufacturing for a given set of boundary conditions (Liu, W. et al. (2017)). The same arguments will be used to provide perspective on the ongoing research and development with respect to the additive manufacturing science and technology. One of the fundamental differences between additive and subtractive processes is the nature of how the material is handled during the process. With the additive manufacturing process, the volume of the part is important and with subtractive the volume of the removed material is important. The ideal metric connecting all processes is the "buy to fly" ratio (α). This is the ratio of the volume of the billet needed to manufacture the part to the volume of the part. This can be defined for both (α-) subtractive (e.g. machining) and (α+) additive manufacturing (fused deposition modeling) processes. (Moon, J., et al. (2001), Myers, K., et al. (2015))

(a) Baseline Evaluation: First, let us evaluate the applicability of the above economic model by considering the variation of the buy-to-fly ratio of fused deposition modeling (FDM) only for making a part that weighs 0.5 kg. With a condition of =1, the additive manufacturing process becomes viable when the increases above 32. The above example confirms the notion that additive manufacturing is indeed relevant for complex geometries and when the buy-to-fly ratio is high due to material costs. This notion was validated by recent work by Arcaute, K., B. Mann, and R. Wicker, (2010) during the manufacturing of aerospace titanium part. Although very revealing, the comparison is indeed one dimensional. We need to consider sensitivity to other factors outlined cost model. These complex interactions are evaluated systematically by changing the cost of FDM feedstock, tooling for FDM design deposition rate and cost of failure starting from the reference condition (=1). Let us evaluate these interactions in depth below. (Melcher, R., et al. (2006))

(b) Effect of Material Feedstock Costs: Many arguments (Wicker, R.B., and E.W. MacDonald. (2012)) are made in the literature that the cost of the FDM feedstock is indeed higher than that of a 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

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prototyping only. Interestingly, our analyses show 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. (Miyanaji, H., N. Momenzadeh, and L. Yang, (2018))

(c) FDM tooling cost: In the reference condition shown in Figure 2a, 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. (Bártolo, P.J. (2011), Xu, M., et al. (2010))

(d) 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 labours rate of $500/hr, the transition curves (Figure 2b) mimics the same condition that is based on increased tooling cost. Under these 7 conditions, the FDM process again becomes viable only when the number of parts increases above 600 or more. This demonstrates that we need robust CAD design tools that are compatible with a wide range of AM equipment. This is indeed the current trend followed by CAD software developers (Park, H., et al. (2005), Sherwood, J.K., et al. (2002)).

(e) Sensitivity to Manufacturing Deposition Rate: 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 0.3 kg/hr to 1 kg/hr, the transition was decreased from 30 to 1.5. This hypothesis is supported by the publication by Roland Berger (Sakly, A., et al. (2014)). 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 (Liu, G., Z. Xie, and Y. Wu, (2011)).

(f) Sensitivity to Failure Cost of Additively Manufactured Part: The roots of FDM and other AM processes can be traced to rapid prototyping, where the focus is only making a particular shape or geometry to validate the design criteria. Therefore, the adoption of the FDM process for structural loading conditions has been a limiting factor. One of the recurring problems is related to poor properties in the Z-direction (Zhou, M., et al. (2016)) due to creation of many interfaces between beads and layers that become the potential site for crack initiation (Liu, W., et al. (2016), Miyanaji, H., S. Zhang, and L. Yang, (2018)). If we assume a failure rate of 10% (for every 10 products one part fails to meet the performance requirement) a complex part made by the FDM process and cost of failure to be $500, the transition from machining to FDM process becomes again unviable! Interestingly, the FDM process never reaches a asymptotic relation as seen in other conditions. (Myers, K., et al. (2015), Doyle, M., et al. (2015))

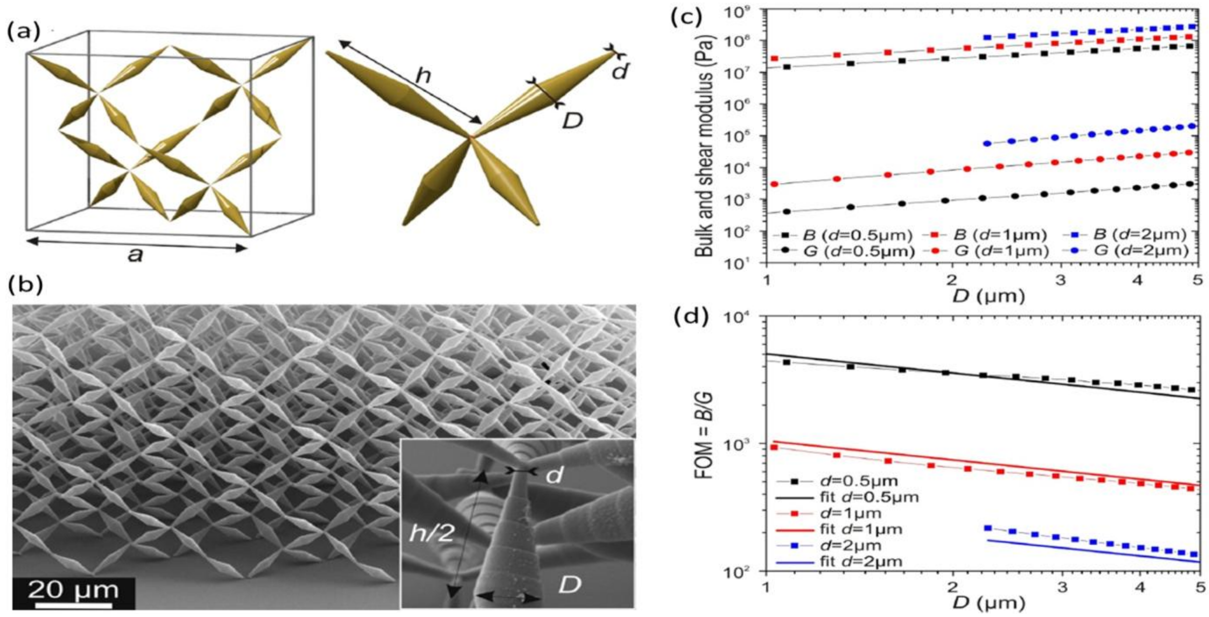

Figure 5: The perspective investigation of additive manufacturing for polymer components tools (a) Showing the metal tool behaviour in the various investigation of FDM process (b) Bulk and shear modulus characteristics behaviour (c) Polymer metal tool crystal structure characteristics of 20μm (d) Comparison of different simulated properties FOM= B/G, D (μm).

DICUSSUION AND CONCLUSION

An economic model was proposed to evaluate the transition from subtractive with additive manufacturing (AM) process for a given component based on the buy-to-fly ratio, as well as, costs of energy density, design, labour, deposition rate and the failure rate of AM part. These economic drivers suggest the following critical research and development directions for the rapid adoption of additive manufacturing. This sensitivity calculation clearly shows that the quality and consistency of mechanical properties from FDM parts need to be increased to similar levels of traditional manufacturing. The above breakeven analyses clearly indicate that the transition from subtractive to additive manufacturing technologies is related to science and technology development in the following four areas. (i) Technologies might be developed for large scale and high productivity additive manufacturing. (ii) The process and material controls have to be developed a-priori for ensuring high-quality property with minimal trial and error experiments. (iii) Verification and validation of AM components through multi-scale ex-situ characterizations of microstructure and residual stress have to be ubiquitous. (iv) A-priori design of processing parameters has to be performed using high-performance computational tools, due to the large scope of processing variables, as well as, the use of non-standard complex geometries. Some of the research and development directions to address the above topics are discussed briefly. The conclusion shows the transition from traditional to additive manufacturing and better findings of using break-even analysis for economical model. (Wang, C., et al. (2012))

FUTURE SCOPE

With the increasing use of technology, additive layer manufacturing is a more efficient and tangible method for producing parts. There are growing numbers of uses and demo stream business benefits and development of 3D printing technology. The 3D printing industry is currently worth around $9.5 billion, and the prediction that the additive layer manufacturing industry will be worth $ 60.2 billion by 2030.

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