Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 36 (2015) 187 – 192

www.elsevier.com/locate/procedia

CIRP 25th Design Conference Innovative Product Creation

Design for Metallic Additive Manufacturing Machine with Capability for "Certify as You build"

Jyoti Mazumder[a]

[a]*University of Michigan, Ann Arbor, Michigan 48109, USA*

* Corresponding author. Tel.: 1-734-647-6824; fax: 1-734-647-9379. *E-mail address:* mazumder@umich.edu

Abstract

Although, additive Manufacturing (AM) has been hailed as the "third industrial revolution" by The Economist magazine [April-2012], the first patent on Stereo-lithography was awarded in 1986. An enabling technology which can build, repair or reconfigure components layer by layer or even pixel by pixel with appropriate materials to match the performance will enhance the productivity thus reduce energy consumption. Innovative product such a metallic composites with negative co-efficient of thermal expansion has already been demonstrated. The capability to form a three-dimensional object directly form digital data reduces many intermediate steps in manufacturing and, therefore, potentially an attractive and economic fabrication method. This is very suitable for low volume manufacturing.

The major challenge for design of additive manufacturing machine is on line "Quality assurance" due to its application in low volume manufacturing. Statistical quality control is not applicable due to low volume. Moreover, any new innovative product has to go thorough a long process of certification before adaptation, especially for Aerospace and medical device industry.

This paper presents the design methodology for Smart Metallic Additive Manufacturing System (s-AMS). In-situ optical diagnostics and its capability to integrate with the process control is a prudent alternative. The two main groups of AM are powder bed (e.g. Laser Sintering) and pneumatically delivered powder (e.g. Direct Metal Deposition [DMD]) to fabricate components. DMD enables one to deposit different material at different pixels with a given height directly from a CAD drawing. The feed back loop also controls the thermal cycle. New optical Sensors are being developed to control product health and geometry using imaging, cooling rate by monitoring temperature, microstructure and composition using optical spectra. Ultimately these sensors will enable one to "Certify as you Build". Recently the author and his group have developed a technique to analyze the plasma spectra to predict the solid-state phase transformation, which opens up the new horizon for the materials processing and manufacturing. Flexibility of the process is enormous and essentially it is an enabling technology to materialize many a design. Conceptually one can seat in Houston and fabricate in Haifa. This paper discusses the in-situ diagnostic methods and its integration in the design of the machine.

Peer-review under responsibility of the scientific committee of the CIRP 25th Design Conference Innovative Product Creation

Keywords: Additive manufacturing

1. Introduction

Additive Manufacturing (AM) has been hailed as the "third industrial revolution" by Economist magazine [April-2012]. Additive Manufacturing (AM) builds up a material to suit the service performance in a layer by layer or even pixel by pixel with appropriate materials to match the performance, which will enhance the productivity and thus reduce energy consumption. Flexibility and capability of producing near net shape critical components directly from Computer Aided Design (CAD) is partly responsible for its attraction.

There is wide spectrum of processes under the umbrella of Additive manufacturing. For metallic components two main types are: Powder bed based processes such as Selective Laser Sintering (SLS) and pneumatically delivered powder based processes such as Direct Metal Deposition (DMD). Both processes have their relative strength and weaknesses. However, one common problem is postmortem quality

Peer-review under responsibility of the scientific committee of the CIRP 25th Design Conference Innovative Product Creation
doi:10.1016/j.procir.2015.01.009

assurance is not adequate for the AM since it also offer an unique opportunity to take corrective action layer by layer and pixel by pixel. On line diagnostics and process control has the tremendous potential to reduce waste, cost and conserve energy. In this paper, we will focus on the metallic 3-D printing such as DMD process, which already incorporated closed loop control [2-3] for deposition height. It can control process in case of overbuilt but not under built. Present technique also does not monitor any defect formation such as porosity, micro-cracks, composition or phase transformation. On the other hand parts built with correct dimension but with above-mentioned defects will not be acceptable either. Therefore, in this paper we describe how we monitor defects such as micro-voids, cracks, composition and phase transformation and use those as an input to control the DMD and 3-D printing process. Result will be a comprehensive closed loop control system producing parts with proper quality assurance.

In addition to quality assurance, the cycle of consumer taste for a product is shortening, and therefore, the need for the industry to go to the market with shorter lead-time is becoming more of a necessity than a desire. Concurrently desire for improved performance at cheaper cost puts conflicting demands on design engineers. For example, more people want cheaper and safer air travel that requires lighter planes with lower fuel consumption plus higher load-carrying capacity. It is not smart to just scale up a present design to increase capacities. Thinking out of the box is a must to engineer materials with properties to match the performance desired by modern consumers. Synthesis of Topological design, Heterogeneous CAD and Direct Metal Deposition (DMD) offer opportunities to engineer material properties to match desired performance [4].

2. Design Drivers and Present state of Art

The main design driver for the 3-D printing and additive manufacturing has been creation of 3-D component with accuracy, speed and economics of production.

DMD offers simultaneous deposition of multiple materials as well as repair and reconfiguration. Closed loop control was first introduced in DMD and it has relatively higher deposition rate than SLS. In this paper we will mainly focus on DMD type process. With maturity of additive manufacturing and recent intense attention devoted to the field, another design driver beginning to catch imagination is in-situ diagnostics to create a new paradigm of “Certify as you Build”. It is extremely important for low volume production for critical and costly components.

2.1. What is Direct Metal Deposition (DMD)?

It is a Solid Freeform Fabrication (SFF) technique that enables production of realistic components with 0.01-inch accuracy, and properties similar to wrought materials with close to 100% density. Direct Metal Deposition, or DMD, is a layer based additive manufacturing process that uses a high powered laser to melt powdered metals and make deposits, with the objective of making fully dense three dimensional objects. The laser beam is focused just above a metal substrate surface, where the deposition is to occur. A coaxial powder stream is focused into the melt pool formed at the substrate surface. This powder is melted upon entry into the melt pool. The substrate is attached to a CNC multi-axis system, and by moving it around, a two dimensional layer can be deposited. By building successive layers on top of one another, a three-dimensional object is formed. Any designed structure can be fabricated layer by layer from a digital database.

Closed Loop DMD is a synthesis of multiple technologies including lasers, sensors, a Computer Numerical Controlled (CNC) work handling stage, and CAD/CAM software and cladding metallurgy. Direct Metal Deposition, developed in the Center for Laser Aided Intelligent Manufacturing (CLAIM) at the University of Michigan [4, 5], is a laser-cladding-based process that makes fully dense freeform metallic parts layer by layer (Fig.1). The key characteristic of the DMD process, which distinguishes it from other similar laser-cladding-based SFF processes, is the integrated feedback system. Closed loop control of the DMD process is useful not only to achieve near net shape but it also provided additional control over temperature history and thus microstructure.

Fig. (1a): DMD machine protype;

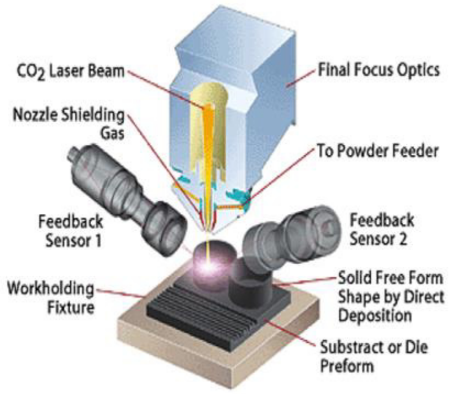

Fig.(1b): DMD process with active height controller