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3D printing of multiple metallic materials via modified selective laser melting

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ABSTRACT

Selective laser melting (SLM) is a powder bed layer-by-layer fusion technique mainly applied for additive manufacturing of 3D metallic components of complex geometry. However, the technology is currently limited to printing a single material across each layer. In many applications such as the manufacture of certain aero engine components, conformably cooled dies, medical implants and functional gradient structures, printing of multiple materials are desirable. This paper reports an investigation into the 3D printing of multiple metallic materials including 316L stainless steel, In718 nickel alloy and Cu10Sn copper alloy within a single build-up process using a specially designed multiple material SLM system combining powder-bed with point by point powder dispensing and selective material removal, for the first time. Material delivery system design, multiple material interactions, and component characteristics are described and the associated mechanisms are discussed.

Introduction

Selective laser melting (SLM) uses a high power laser beam to fully melt powdered material spread on a flat surface, layer-by-layer, to build three dimensional solid models with a high density and well bonded structures based on a CAD file [1–3]. SLM can produce components of variety of materials including metals, ceramics and polymers, while Laser Metal Deposition (LMD), Wire and Arc Additive Manufacturing (WAAM), and Electronic Beam Melting (EBM) are only suitable for printing metallic materials [4]. Existing SLM processes using flat bed powder spreading techniques are only suitable for printing a single material across each layer, thus unsuitable for printing multiple material components, while there may be engineering needs to print multiple materials for specific applications where different material properties are required at different locations, such as aero engine components, medical implants, and dies/moulds.

A critical requirement in multiple material SLM is to deposit at least two discrete powder materials within one layer. A double powder spreading system driven by piezoelectric transducers was applied in a SLM system to fabricate a Fe/Al–12Si dual material structure [5]. Investigators from Singapore demonstrated SLM processed 316L SS/C18400 copper alloy and AlSi10Mg/C18400 copper alloy samples on a commercial SLM system [6,7]. A double ring blade assisted powder spreading system was also applied to sintering parts made of silver/copper [8]. However, none of the deposition methods mentioned above can produce multiple materials over the same layer.

Dissimilar materials must be dispensed locally on the same layer and across different layers at the required location to achieve real 3D material gradient structures and mutiple materials. Lappo et al applied a manual vacuum cleaner to remove powders in required locations and spread the second powder by a roller to fill the same location [9]. Their experiment showed that such an approach caused serious cross-contamination outside the desired second powder deposition region and made multiple material layers shifting. A new 'powder recoating-vacuum cleaning-sieving' approach was described for multiple material SLM in which the classic roller mechanism was used to spread the multiple materials [10]. Such a system is difficult to be realized in practice due to unavoidable material cross-contamination during repeated powder spreading and vacuum cleaning procedures.

Ultrasonic vibration assisted dry powder dispensing has been investigated widely for different applications [11–15]. The studies demonstrated that dry powder flow rates can be effectively and accurately regulated by controlling the electrical pulses to the piezoelectric transducer. Selective area deposition of different dry powder materials was achievable by employing programmed ultrasonic vibration without sophisticated material pre-mixing preparation. The first demonstration of a multiple nozzle ultrasonic powder deposition method without the use of traditional flat powder bed spreading, for Cu/H13 powder selective laser melting was reported by researchers from The University of Manchester in 2008 [16]. The laser printed samples produced were 2D structures.

Until now, there have been no scientific publications showing 3D printing using SLM with multiple materials within a single layer based on dry powder delivery. A suitable discrete multiple powder delivery system for SLM should be a hybrid system combining the traditional powder bed delivery mechanism and a point-by-point

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powder deposition mechanism. Such a combination is not only required to dispense multiple materials on the same processing layer, but is also needed to generate stable support structures required for complex 3D component printing.

This paper demonstrates a new approach for multiple material SLM by combining powder-bed spreading, point-by-point multiple nozzles ultrasonic dry powder delivery, and point-by-point single layer powder removal to realize multiple material fusion within the same layer and across different layers. In this work, multiple metallic material components 3D printing via SLM was demonstrated. It would also have the potential to print metal–ceramic–polymer components.

Experimental materials and procedure

Materials

Gas atomized spherical 316L stainless steel powder (LPW-718-AACF, 10–45 μm, LPW Technology Ltd., UK), In718 nickel alloy powder (LPW-316-AAHH, 10–45 μm LPW Technology Ltd., UK), and Cu10Sn copper-alloy spherical powder of 10–45 μm diameters (Makin Metal Powders Ltd. UK) were used in this investigation. The substrate plates used were ground finished 304 steel sheets of 120 mm diameter and 12 mm in thickness.

Experimental system description

A multiple material SLM system was designed and manufactured in this study (see Fig. 1). An x–y–z galvo scanner (Nutfield, 3XB 3-axis) was used to scan the laser beam with an 80 μm focused beam spot size generated from a 500 W Ytterbium single-mode, continuous wave (CW) fibre laser (IPG Photonics, YLR-500-WC) of a 1070 nm wavelength over the target powder bed. A multiple powder delivery system was comprised of a traditional roller assisted powder bed delivery mechanism spreading the main building powder material (316L in this study), and a point-by-point micro-vacuum selective material removing system for selective, precision single layer powder removal at specific locations, and several ultrasonic dry powder dispensers depositing In718 and Cu10Sn powders respectively according to the designed pattern. The ultrasonic powder dispensers were mounted on an x–y linear stage along with the micro-vacuum selective powder remover. The process operation was in an inert gas environment filled with nitrogen or argon gas having an oxygen gas level less than 0.3% monitored with a real-time oxygen sensor. Before filling in the inert gas, the operation chamber was vacuumed down to 40 Pa with a vacuum pump. A fume exaction system was built into the system to remove fumes generated. Although the system had a built-in pre-heating facility, this was not used in the present investigation. A schematic diagram of the experimental set up is shown in Fig. 1.

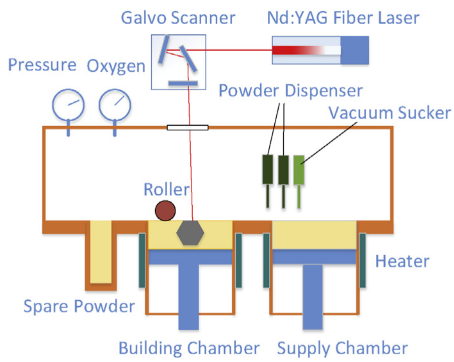

Fig. 1. Schematic diagram of the multiple material SLM system.

Multiple material component printing process and procedure

Fig. 2a describes the multiple material SLM process implemented in this investigation. Firstly, the main powder material, i.e. 316L was spread for one layer of 50 μm thickness over the substrate with a motorized roller and powder leveling blades. Then the laser beam melted the desired areas. A selective powder removal process then took place to remove powders of a single layer thickness in defined areas, using the micro-vacuum system. The second/third material powders (In718/Cu10Sn) were then dispensed into the vacuum sucked areas using the ultrasonic powder dispensers and then melted by the laser beam and bonded with the already melted material. Finally, the building platform moved down a distance equal to the layer thickness. All above six steps were repeated until the whole 3D model was fabricated.

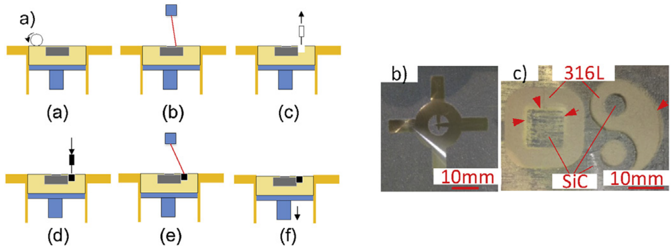

Fig. 2. a) The process flow chart of multiple materials SLM, b) A vacuum cleaned pattern, c) a 316L box and half Yingyang pattern produced by selective powder deposition on a SiC powder layer before laser fusing.

Fig. 2b shows a selective single layer material removal pattern using the micro-vacuum system. Fig. 2c demonstrates an example of multiple material deposition combining powder bed spreading (SiC), selective powder removal and selective powder deposition (316L) before laser fusion. There were some margins close to the edges as indicated by the red arrows, due to the width of the expanding zone of the vacuum sucking nozzle being larger than the tool path offset value [17]. Such a problem was solved by vacuum sucking tool path optimization in the following experiments.

Since there have been no software tools for multiple material SLM, a new data preparation procedure and tool was developed. As illustrated in Fig. 3, a multiple-material component was considered as an assembly, comprised of a set of single material parts. All these parts were designed with special features on the material interface to enhance the bond. They were then assembled into a single component. At the SLM process data preparation stage, the individual material geometry was converted into an STL format. A global support structure was then created after all the STL files for each material were assembled. Subsequently, slicing and hatching took place for each material separately and the results were exported into the laser control system. The tool paths and CNC G-codes for the selective powder vacuum removal and ultrasonic powder delivery were prepared by a proprietary CNC CAM software tool.

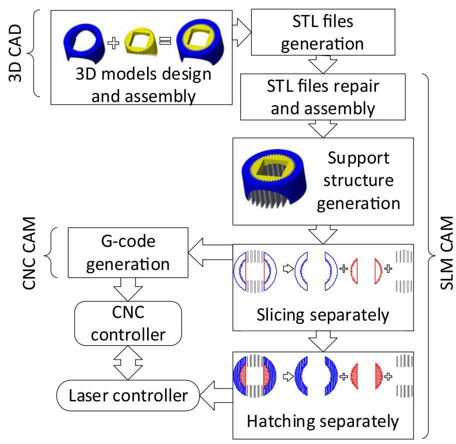

Fig. 3. Illustration of the data preparing procedure for multiple material SLM.

The laser process parameters for fusing three materials used in this investigation are presented in Table 1. These were derived from preliminary experiments to achieve optimum melting quality and processing efficiency.