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<th>Review of Multi-material Additive Manufacturing</th>
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ABSTRACT: Recently, Additive Manufacturing (AM) has seen a surge in interest with companies using the technology for prototyping and functional parts. It offers certain advantages over its traditional manufacturing counterpart. However, AM’s capabilities can be further enhanced by incorporating multiple materials in its processes. This paper presents the progress on the advances in multiple materials in different AM methods.

KEYWORDS: Additive Manufacturing, Multi-material, Powder Metallurgy

INTRODUCTION

Background

Additive Manufacturing (AM) is a manufacturing process which builds objects from 3D model data by adding layer by layer of material (F2792–12a 2012). AM holds many advantages over traditional manufacturing. One advantage of AM allows for intricate parts to be built. A model can be designed using Computer-Aided Design (CAD) software and sliced into cross-sections to be constructed on each layer before they are joined together as a single part (Chua et al. 2010). However, to further capitalize on the benefits of AM, Multiple Material Additive Manufacturing (MMAM) technology will have to be further developed. Parts produced from MMAM can have improved mechanical properties such as increased in strength, thermal or electrical conductivity in desired areas. MMAM also allows of easy to remove support structures. For example, soluble support materials are being used in Fused Deposition Modeling (FDM).

For polymers, multiple materials are commonly used in FDM and inkjet processes. In FDM, materials are extruded via nozzles in a molten state (Chua et al. 2010). Depending on the viscosity of the material, different extrusion techniques are used (Yan et al. 2003). For high viscosity materials, a high pressured air extrusion design is used. Conversely, for low viscosity material, a solenoid nozzle will be used. Multiple materials are easily incorporated by adding extra nozzles for the additional materials and the results proved to be promising (Espalin et al. 2014).

Joining of metals proved to be more complicated than polymers due to the higher melting point of metals. There are traditional methods of joining different metals together by the process of welding, adhesive bonding and mechanical fastening (Kah et al. 2014). However, complexities arises when it comes to joining dissimilar metals due to differences in their physical and metallurgical material characteristics. Large differences in thermal expansion eventually leads to unwanted residual
stresses while the chemical incompatibility leads to brittle intermetallic compounds (Sun et al. 1996). Table 1 shows the differences in physical properties of some commonly used metals (Brandes et al. 1999). The thermal expansion coefficient of Aluminium almost is twice that of Iron, while the thermal conductivity of Copper is more than ten times that of Iron. These differences will lead to residual stresses in a part made of a combination of these materials.

Table 1. Physical Properties of Common Metals

<table>
<thead>
<tr>
<th>Metal</th>
<th>Melting Point (K)</th>
<th>Density (kg/m³)</th>
<th>Thermal conductivity (0-100°C) (W/mK)</th>
<th>Thermal Expansion Coefficient (0-100°C) (x10⁻⁶/K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>933</td>
<td>2700</td>
<td>238</td>
<td>23.5</td>
</tr>
<tr>
<td>Cu</td>
<td>1358</td>
<td>8960</td>
<td>897</td>
<td>17</td>
</tr>
<tr>
<td>Fe</td>
<td>1809</td>
<td>7870</td>
<td>78.2</td>
<td>12.1</td>
</tr>
<tr>
<td>Ti</td>
<td>1940</td>
<td>4500</td>
<td>21.6</td>
<td>8.9</td>
</tr>
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</table>

MMAM may provide solutions that conventional manufacturing methods is lacking when it comes to joining dissimilar metals. Other than improving mechanical properties, MMAM allows for additional functionality in the resulting part (Gibson et al.). Part performance can be enhanced by applying the most suitable material in targeted regions. The potential benefits from MMAM is that it can be processed in a single step. Some of the applications where this technology can be applied are enhancing thermal conductivity in confirmal cooling channels, high hardness and high temperature resistance properties in turbine engines and inclusion of embedded components such as resistors and other electronic devices (Vaezi et al. 2013).

MULTI-MATERIAL POWDER METALLURGY

Functionally Graded Material

The use of deposition head in AM processes has proven to be more suitable in incorporating MMAM. One such process is the Laser Engineering Net Shaping (LENS). It can be used to produced Functionally Graded Material (FGM) that consists of a gradual change in composition of materials as the part is being built (Bandopadhyay et al. 2008). In LENS, there are multiple powder feeders with feed rates being independently controlled. To fabricate a FGM, the feed rate of one material starts from the maximum and gradually decreases to zero, while the other material increased from zero to the maximum. Figure 1 shows the schematic diagram for LENS.

The advantage of having gradual change in composition for multi-material systems is to allow for smooth transition of thermal stresses along the build direction and minimize the stresses concentration at the interface (Liu et al. 2003).
Multiple Recoating System

Powder bed technologies such as Selective Laser Melting (SLM), Selective Laser Sintering (SLS) and Electron Beam Melting (EBM) have recoating features to lay the powder evenly on the substrate. The laser or electron beam will proceed to melt or sinter the powder before the next layer of powder is recoated (Murr et al. 2012). By adjusting the recoating system, it is possible to achieve multiple material in one print job using these powder bed technologies.

Figure 1. Laser Engineering Net Shaping process.

Figure 2. (a) Multiple recoating system, and (b) multi-material part produced.
One of the solutions to powder bed multi-material processing is the addition of another powder feeder as shown in Figure 2 (Regenfuss et al. 2007). The system has two cylindrical bores which serves as the powder supply. They will move with reference to their pivots and lay their respective powder onto the substrate when required. This allows for parts to vary in material along the z-axis.

A similar approach was done using SLM. Many works have been carried out using SLM, such as on titanium alloy (Sing et al. 2016). For the experiment, ‘SLM 250HL’ from SLM Solutions was used. The machine came with a recoater with two rotating chambers used for dispensing powder shown in Figure 3. Based on the direction of recoating (forward or backward), the designated chamber will rotate and release the desired powder onto the platform (Liu et al. 2014). The downside of these mechanisms is that they only allow for variations of materials along the build direction. There are restrictions on achieving a full three dimensional multi-material parts as shown in Figure 4 (Ott et al. 2010).

![Figure 3. Powder dispensing mechanism.](image)

![Figure 4. (a) One dimensional multi-material part, and (b) three dimensional multi-material part.](image)
Vibrational Feeder System

To improve on the multi-material process on SLM, a different approach to powder deposition can be used. Dry Powder Printing (DPP) is a promising technique for dispensing fine powder (Chianrabutra et al. 2014). It is based on channeling the vibration energy to assist the flow of powder via a nozzle. Powder is contained in a feeder where it will form a stable dome at the nozzle tip due to particle-particle friction and particle-wall friction. An external stimulant, in the form or vibration, will cause the dome structure to break away, thus allowing for powder flow. Continuous vibration will keep the powder from flowing out. Once the vibration stops, the dome structure will be reformed, ceasing the flow.

This method of delivery gives high resolution and delivers the powder to selective regions. It reduces the contamination as the amount of powder released is minute. To add on more materials, it only requires additional dispensing system to be added. Interface studied using this technique proved to achieve good bonding using micro-hardness, tensile tests and Energy Dispersive X-ray Spectroscopy (EDS) analyses (Al-Jamal et al. 2008).

The disadvantage of this method is that it is time consuming. Since DPP is capable of dispensing small amount of powder, it will require a long time to fill a large area on the platform. This will result in different cooling rates of the surface depending on the DPP process. It is only suitable when manufacturing parts which require small amount of secondary material.

CONCLUSION

MMAM has shown to have high potential in SLM technology. It combines the freedom of material selection with the design freedom. This gives it a superior advantage as compared to conventional manufacturing. However, the current focus is to develop a method to implement a suitable powder delivery system into the current SLM technology. The approach on modifying the recoating system is able to manufacture multiple material part in a shorter time as compared to using a vibrational feeder. However, there exists a tradeoff between the production time and the freedom of material selection. New methods will have to maximize the benefits of both factors.

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REFERENCES


