# REVIEW ON MELTING OF MULTIPLE METAL MATERIALS IN ADDITIVE MANUFACTURING

ANDRIANI C.
*School of Mechanical and Aerospace Engineering, NTU Additive Manufacturing Centre, HW1-01-05, 2A Nanyang Link*
*Singapore, 637371, Singapore*

CHUA C.K., LIU Z. H., ZHANG D. Q., SING S.L.
*School of Mechanical and Aerospace Engineering, NTU Additive Manufacturing Centre, HW1-01-05, 2A Nanyang Link*
*Singapore, 637371, Singapore*

**ABSTRACT**:
The Additive Manufacturing technologies that are capable of joining dissimilar metals have gained popularity in the past decade because of the advantages they possess over the traditional joining technologies. This paper presents the current state-of-art in laser/electron beam melting of multiple metal materials, specifically through powder bed multi-material processing of metal. The deposition mechanisms discussed are drop-on-demand deposition system and hopper deposition system for laser melting and bottom feeding via a recoater for Electron Beam Melting.

**KEYWORDS:**

3D Printing, Additive Manufacturing, Rapid Prototyping, Selective Laser Melting, Multi-material, dissimilar metals, Review, electron beam melting

## INTRODUCTION

### Background

Additive Manufacturing (AM) is a process of adding and joining materials to produce physical objects from a 3D model data, layer upon layer, instead of conventional subtractive manufacturing methodologies (Chua et al. 2010). AM technologies are believed to meet the increasing demand and complexity of today's products. However, present AM technologies need to be refined in order to be comparable with the traditional manufacturing. One shortcoming of most commercially available AM technologies is their lack of ability to produce multi-material products, especially for multiple metal materials, which is an important feature for manufacturing industries nowadays (Wohlers 2011).

Dissimilar metals are difficult to join because of their differences in physical properties and chemical composition. Traditional metal joining technologies such as metal fastening, adhesive bonding, and welding may no longer be able to meet the requirement of today's products (Messler 1995). Even the more advanced welding processes using electron beam, ultrasonic, and laser have their own limitations (Messler 1997). It was investigated that using traditional joining technologies, there are many failures such as fatigue and/or corrosion occurring at welded joints, local weakening of mechanical properties of the components, and highly inefficient due to the additional material that needs to be added to the structure (Lebacq et al. 2002).

*Proc. of the Intl. Conf. on Progress in Additive Manufacturing*
*Edited by* Chua Chee Kai, Yeong Wai Yee, Tan Ming Jen and Liu Erjia

ISBN: 978-981-09-0446-3 :: doi:10.3850/978-981-09-0446-3_134

The recently developed Multiple Material Additive Manufacturing (MMAM) may be the answer to address these issues, as it may improve mechanical properties and provide additional functionality in the resulting parts (Gibson et al. 2010). With this feature, AM technologies will gain superiority over the traditional joining of dissimilar materials. The development of MMAM technologies is potentially beneficial to many applications and industries. Desired properties will be achieved when multiple metal materials are combined. A few examples in terms of applications are thermal conductivity in conformal cooling channels, good mechanical properties such as high hardness, high temperature resistance properties in turbines engines and thermal insulation coatings, optical properties in laser telecommunication systems, dielectric and magnetic properties in antenna and meta-materials, chemical properties in fuel cells and batteries, and sonic properties in acoustics systems (Mohammad et al. 2013). The current state-of-art in laser melting of multiple metal materials will be reviewed specifically in the area of powder bed multi-material processing of metal, in accordance to ASTM F2792-12a.

## POWDER BED MULTI-MATERIAL PROCESSING OF METAL

### Drop-on-demand deposition system

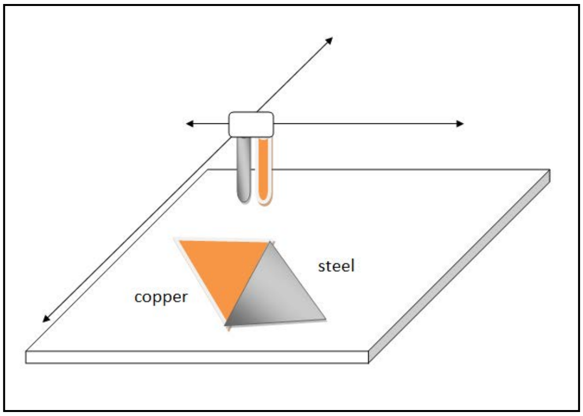

Figure 1. Drop-on-Demand system

Drop-on-demand system, one of the predominant modes used for material droplet creation has been successfully developed to be capable of dispensing multi-material micro-droplets on demand to build 3D structures (Li et al. 2009). For multi-material printing, print heads usually include several separate nozzles, which are fed with different materials and are separately controllable (Sun et al. 2010). Beal (2007) experimented the use of functionality-graded materials (FGMs) to build injection moulds by solid free-form fabrication (SFF) technologies. Metal material in the form of powder is to be fused or pre-sintered under a laser spot.

### Hopper deposition system

### Multi compartment hopper deposition in the x-axis

Another powder bed multi-material processing of metal is by creating compartments in the hopper and filling the different compartments with different types of powder and thus allowing material to be varied along the x-axis(Beal et al. 2007). Hopper-nozzles are designed for depositing thin layers of multiple patterned materials followed by selective laser sintering for consolidation to desired densities(Kumar et al. 2004).

The laser processed the multi-composition powder bed that was previously loaded with powders from the multi-compartment hopper, as seen in Figure 2. As the laser scanned the powder bed, the powder was fused and bonded to the previous added layers. After processing a layer, the powder bed was lowered and the powders were spread over the previous layer and the laser was set to fuse the powder to form a new layer. This process was numerically controlled and continued until the completion of the part (Beal et al. 2007).

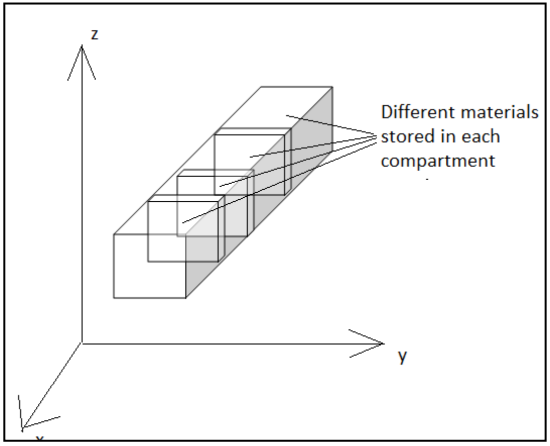

Figure 2. Multi compartment hopper deposition in the x-axis

**Multi compartment hopper deposition in the z-axis**

The SLM equipment used in this work is from SLM Solutions and comes with a recoater consisting of a dispensing mechanism that works with two rotating chambers where a silicon blade is installed beneath and between them as shown in Figure 3(a). As each chamber rotates, a controlled amount of powder is released onto the substrate surface in front of the silicon blade for deposition by defining the number of chamber rotations. In addition, recoating on the fly can also be chosen where the amount of powder is controlled by the speed of the recoater and rotating chambers. In this work, a centre separator was designed and introduced within the recoater as illustrated in Figure 3(c), two different materials can then be stored and deposited by only allowing each rotating chamber to dispense the corresponding powder in their respective coating direction. Figure 4 shows some steel/copper samples produced in this manner.

Steel and copper alloy were chosen because the strength and corrosion resistance of stainless steel combined with the high conductivity of copper makes the composite ideal for many applications. An application for copper and stainless steel laminate is for the walls of fusion reactors (Leedy and Stubbins 2001). The high conductivity of copper makes it a good heat sink and stainless steel's strength makes it suitable as structural support with excellent corrosion resistance. Moreover, the need for intricate water-cooling channels to be imbedded throughout the wall makes AM a potentially ideal technique to fabricate these laminated panels with conformal cooling channels (Dimitrov et al. 2010, Spierings et al. 2012, Wang et al. 2012).Copper and stainless steel composites also have applications in automobile, rail and aviation industries (Yilmaz and Celik

2003), cookware and wires for specialized purposes such as high field pulsed magnets (Pantsyrnyi et al. 2000).

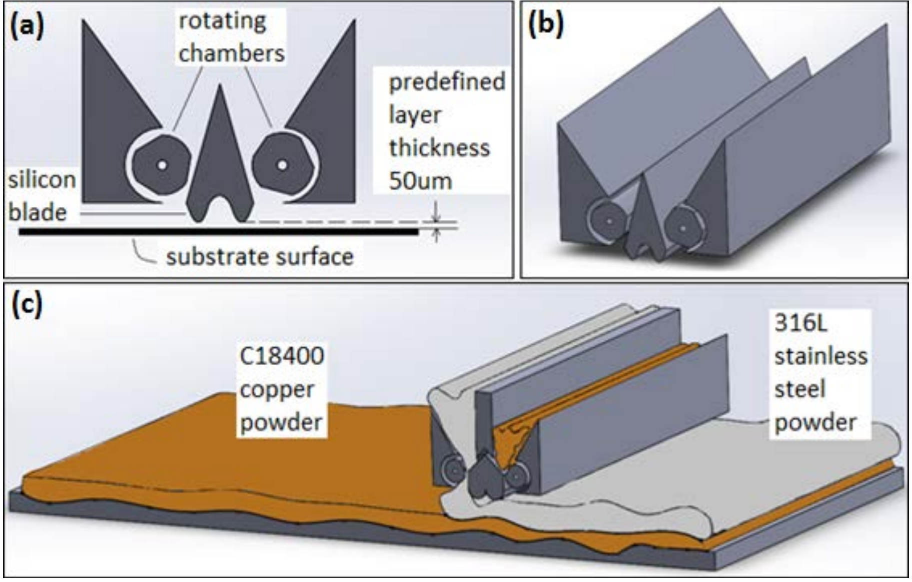

Figure 3. (a) Powder dispensing mechanism, (b) isometric view of recoater and (c) illustration of multi material powder deposition.

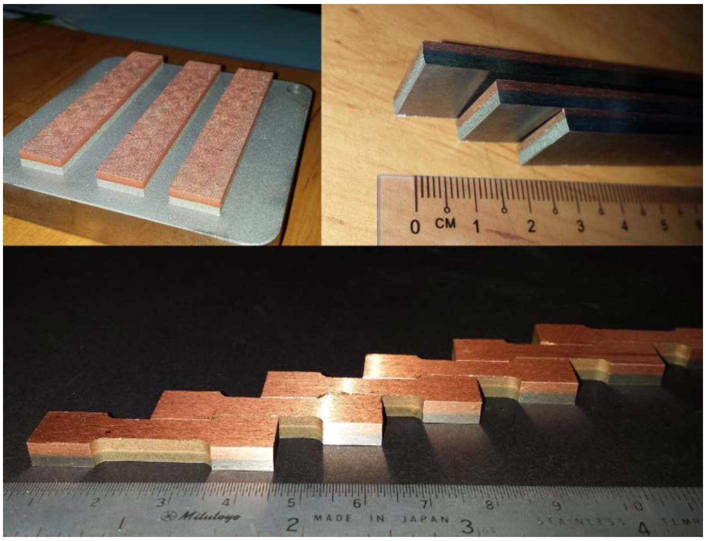

Figure 4. Steel/Cu tensile and parts produced by SLM using the proposed multi material deposition in NTU Additive Manufacturing Centre (NAMC).

### 2.3 Electron Beam Melting (EBM)

The more recent technology in multiple metal materials processing is electron beam melting (EBM). EBM technique is similar to Selective Laser Melting (SLM), the difference being that

EBM melts powdered metal inside a vacuum using an electron beam instead of a laser in a chamber of inert gas (Murr et al. 2012). In a latest research, a novel method was developed that provided solutions to some of the complications for the multi-material fabrication using EBM. In that experiment, copper parts were first produced in phase 1 of the production. A substrate plate is then milled with the exact dimensions of the copper parts and installed above the copper parts. These copper parts were then revealed to be part of this substrate plate. Phase 2 of the production involves the melting of Ti64 alloy directly above the copper part. As a result, this method was utilised to produce simple cylindrical multi-material parts, built with their longest axis in the Z and X directions, using discrete builds with pure copper and Ti-6Al-4V (Terrazas et al. 2014).

Advantages of using EBM include high-energy efficiency due to vacuum that prevents oxidation of reactive metals and alloys and also microstructures obtained from EBM fabricated components exhibit improved mechanical properties similar to those of the wrought material (Murr et al. 2009). Moreover, by maintaining at elevated temperatures, the occurrence of thermally induced residual stress, segregation, and the appearance of non-equilibrium phases in the finished parts will be minimised (Thijs et al. 2010).

Even with the success of using EBM, there is still a room for improvement. In the research mentioned above, there are still discrepancies observed in the microstructure and the hardness of copper and Ti-6Al-4V, due to the processing conditions during the fabrication of multi-material EBM parts, which are very different from to the normal EBM process, when using single materials (Terrazas et al. 2014). Therefore, a more extensive research should be done in order to improve this method and material flexibility in AM technologies.

## SUMMARY AND CONCLUSION

The current development of laser melting of multiple metal materials has been reviewed. Through MMAM technologies such as Drop-on-Demand deposition system, Hopper deposition system and bottom up feeding system in the Electron Beam Melting, different metal materials can be joined together in a much efficient way compared to traditional joining technologies. Having said that, the hopper deposition system developed by NAMC shows the most potential to be successful in joining dissimilar metal materials among the other methodologies. This is due to its capability to deposit material not only in x-axis direction, but also in z-axis direction. The research done by NAMC has brought us one step closer towards fabricating multiple metal materials that is able to modify specific properties in the fabricated components and provide higher flexibility in the design stages. Future work at NAMC will further develop MMAM in both x and z directions.

## REFERENCES

1. Beal, V. E., P. Erasenthiran, C. H. Ahrens and P. Dickens (2007). "Evaluating the use of functionally graded materials inserts produced by selective laser melting on the injection moulding of plastics parts." Proceedings of the Institution of Mechanical Engineers Part B-Journal of Engineering Manufacture **221**(6): 945-954.
2. Chua, C. K., Leong, K. F. and Lim, C. S. ( 2010). Rapid Prototyping - Principles and Applications. Singapore, World Scientific Publishing Co. Pte. Ltd.
3. Dimitrov, D., A. Moammer and T. Harms (2010). Cooling channel configuration in injection moulds. Boca Raton, Crc Press-Taylor & Francis Group.

4. Kumar, P., J. K. Santosa, E. Beck and S. Das (2004). "Direct-write deposition of fine powders through miniature hopper-nozzles for multi-material solid freeform fabrication." Rapid Prototyping Journal **10**(1): 14-23.
5. LeBacq, C., Y. Brechet, H. R. Shercliff, T. Jeggy and L. Salvo (2002). "Selection of joining methods in mechanical design." Materials & Design **23**(4): 405-416.
6. Leedy, K. D. and J. F. Stubbins (2001). "Copper alloy-stainless steel bonded laminates for fusion reactor applications: crack growth and fatigue." Materials Science and Engineering a-Structural Materials Properties Microstructure and Processing **297**(1-2): 19-25.
7. Li, L., M. Saedan, W. Feng, J. Y. H. Fuh, Y. S. Wong, H. T. Loh, S. C. H. Thian, S. T. Thoroddsen and L. Lu (2009). "Development of a multi-nozzle drop-on-demand system for multi-material dispensing." Journal of Materials Processing Technology **209**(9): 4444-4448.
8. Messler, R. W. (1995). "The challenges for joining to keep pace with advancing materials and designs." Materials & Design **16**(5): 261-269.
9. Messler, R. W. (1997). "Joining technologies for the next century: Drivers and directions." Assembly Automation **17**(1): 56-&.
10. Murr, L. E., E. V. Esquivel, S. A. Quinones, S. M. Gaytan, M. I. Lopez, E. Y. Martinez, F. Medina, D. H. Hernandez, E. Martinez, J. L. Martinez, S. W. Stafford, D. K. Brown, T. Hoppe, W. Meyers, U. Lindhe and R. B. Wicker (2009). "Microstructures and mechanical properties of electron beam-rapid manufactured Ti-6Al-4V biomedical prototypes compared to wrought Ti-6Al-4V." Materials Characterization **60**(2): 96-105.
11. Murr, L. E., S. M. Gaytan, D. A. Ramirez, E. Martinez, J. Hernandez, K. N. Amato, P. W. Shindo, F. R. Medina and R. B. Wicker (2012). "Metal Fabrication by Additive Manufacturing Using Laser and Electron Beam Melting Technologies." Journal of Materials Science & Technology **28**(1): 1-14.
12. Pantsyrnyi, V., A. Shikov, A. Vorobieva, N. Khlebova, I. Potapenko, A. Silaev, N. Beliakov, G. Vedernikov, I. Gubkin, N. Salunin, N. Kozlenkova and M. Polikarpova (2000). "Cu-Nb and Cu/stainless steel winding materials for high field pulsed magnets." Ieee Transactions on Applied Superconductivity **10**(1): 1263-1268.
13. Spierings, A. B., G. Levy, L. Labhart and K. Wegener (2012). Production of functional parts using SLM - Opportunities and limitations. Boca Raton, Crc Press-Taylor & Francis Group.
14. Sun, J., R. Yang, K. K. Tan, J. Y. H. Fuh, Y. S. Wong and J. H. Ng (2010). "Performance characterization of drop-on-demand micro-dispensing system with multi-printheads." Microsystem Technologies-Micro-and Nanosystems-Information Storage and Processing Systems **16**(12): 2087-2097.
15. Terrazas, C. A., S. M. Gaytan, E. Rodriguez, D. Espalin, L. E. Murr, F. Medina and R. B. Wicker (2014). "Multi-material metallic structure fabrication using electron beam melting." International Journal of Advanced Manufacturing Technology **71**(1-4): 33-45.
16. Thijs, L., F. Verhaeghe, T. Craeghs, J. Van Humbeeck and J. P. Kruth (2010). "A study of the micro structural evolution during selective laser melting of Ti-6Al-4V." Acta Materialia **58**(9): 3303-3312.
17. Wang, L., Q. S. Wei, P. J. Xue and Y. S. Shi (2012). Fabricate mould insert with conformal cooling channel using selective laser melting. Progress in New Materials and Mechanics Research. X. C. Deng and X. F. Dong. Stafa-Zurich, Trans Tech Publications Ltd. **502:** 67-71.
18. Yilmaz, O. and H. Celik (2003). "Electrical and thermal properties of the interface at diffusion-bonded and soldered 304 stainless steel and copper bimetal." Journal of Materials Processing Technology **141**(1): 67-76.