Metal Matrix Composites by Additive Manufacturing

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Metal Matrix Composites (MMCs) are materials that combine a continuous metallic matrix with a second reinforcing phase, typically made of ceramic, with a goal to create a new material with properties unavailable using either of the individual constituents. One of the characteristic features of MMCs is that the reinforcement bears a significant fraction of the applied load, thus offering enhancements in strength and stiffness simultaneously [1]. An attractive class of MMCs are light metals such as aluminum reinforced with hard and stiff ceramic particles such as alumina providing stiff yet lightweight composite. One of the main drawbacks of MMCs is their poor machinability. Therefore, very near-net shape manufacturing techniques such as additive manufacturing (AM) by selective laser melting (SLM) represents one of the potential ways of producing MMCs. The high specific stiffness of MMCs combined with AM topology optimization creates added synergy in producing metallic composites that offer high strength and stiffness while being lightweight.

One of the main challenges in manufacturing MMCs via SLM is the fact that the wetting of Al_2O_3 by molten aluminum is very poor, raising the question if it is possible, using SLM, to achieve good bonding between the aluminum matrix with the reinforcing particles – the key prerequisite of achieving strong and tough MMC. Therefore, a preliminary study focused on the investigation of the AlSi12 – Al_2O_3 interface quality was first performed. Selectively laser melted material samples made using powder beds of aluminum alloy AlSi12 (particle size 20-60 µm) mixed with 2.5vol% of Al_2O_3 particles (particle mean size 10 µm) were prepared. Figure 1 shown below represents one cross-section view from a 3D FIB volume reconstruction of a representative volume of the 3D printed MMC. It shows a continuous AlSi12 matrix with two separate Al_2O_3 particles and a void in the right bottom corner. The figure clearly shows that the AlSi12 – Al_2O_3 interface may be locally very good, despite the fact that molten aluminum does not wet Al_2O_3. This is enabled by the so-called Maragoni convection that appears in the melt pool caused by local temperature gradient and chemical concentration difference [2]. A vigorous Maragoni convection disrupts the native oxide layer of AlSi12 particles and stirs Al_2O_3 particles in the molten metal. Thus, due to the resultant capillary forces the liquid metal surrounds and wets Al_2O_3 particles.

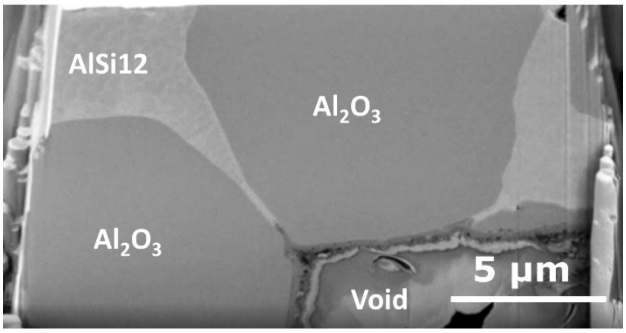

Figure 1: A cross-section view from 3D FIB volume reconstruction of a representative volume of the 3D printed AlSi12/ Al_2O_3 MMC.

Showing that SLM may lead to good AlSi12 – Al_2O_3 interface, the work focused towards increasing the volume fraction of Al_2O_3 up to 15vol% and optimize the SLM parameters to minimize the total porosity. To this end, a large parameter window of laser power and speed was explored using Design of Experiment rules, keeping the powder layer thickness constant (30 µm). Single laser-track walls (4x4 mm) were manufactured as shown in Figure 2. A good quality single laser-track walls with continuous and homogenous morphology as shown in Figure 2 were observed only for the highest energy densities.

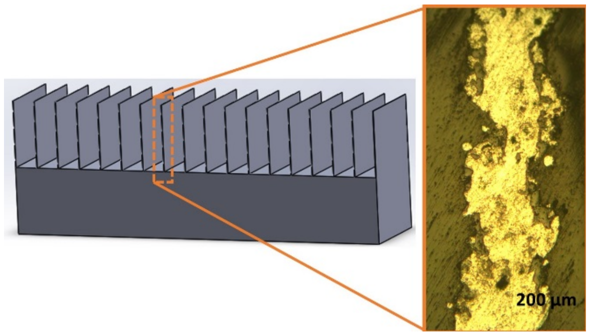

Figure 2: Design of single laser-track walls manufactured and the best quality observed wall with 15vol% of Al_2O_3 is shown.

Laser parameters that led to the printing of continuous laser tracks were subsequently used to print 10 mm^3 cubes while varying the hatch distance. The hatch distance overlap near 50% provided the so far best obtained result for 15vol% Al_2O_3 MMC. Figure 3 shows the resulting microstructure that exhibited less than 10% porosity and reinforcing particles with good bonding to the AlSi12 matrix. It was observed that during the process, Al_2O_3 particles were melted and some even recombined to form larger particles compared to the particles present in the feedstock.

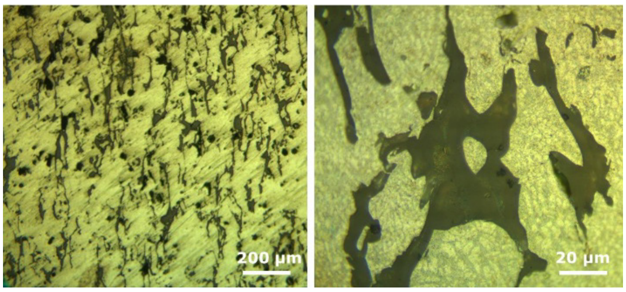

Figure 3: Microstructure of 15vol% Al_2O_3 of 3D printed MMC using the so far optimized laser parameters and 50% hatch distance overlap.

In conclusion, we show that SLM is a promising technology for manufacturing MMCs. In combination of the Maragoni convection and optimized printing strategy, the poor wetting between Al_2O_3 and molten aluminum may be overcome providing good matrix-reinforcement bonding. So far we were able to produce particle reinforced MMCs with as much as 15vol% of Al_2O_3 particles with porosity lower than 10% in as-built condition without any post-treatment. Aluminum-based MMC with 15vol% of Al_2O_3 reinforcement has a potential to have 25% higher specific stiffness compared to metallic alloys. The further work focused on applying Hot Isostatic Pressing (HIP) to further decrease the porosity is ongoing.

[1] N. Chawla, K.K. Chawla, Metal matrix composites, Springer, New York, 2006.

[2] J. Berthier, Micro-Drops and Digital Microfluidics, A volume in Micro and Nanotechnologies, Elsevier, 2013.