3T additive manufacturing

How to industrialise the development of CuCrZr for additive manufacturing

Recent developments in the AM industry have created an extraordinary opportunity for material and machine enhancements.

This is mostly due to the advent of new players, acquisitions and growth in demand for challenging designs. However, one trend is undeniable. Customers are continuing to come to terms with the capabilities and opportunities of additive manufacturing.

Copper alloy development at 3T additive manufacturing ltd (formerly 3T RPD Ltd) is a great example of showing how creating a product does not need to stop at the AM machine level. 3T-am started this journey back in 2014 when we wanted to make a non-grey metal heat exchanger for our trade shows. To our absolute amazement, the Copper part was 100% dense with very few DoE runs on blocks. This became a game changer for 3T. However, very quickly we found out that the electrical conductivity of seemingly pure Copper powder was less than 50% of the IACS standard.

Upon further analysis, it was seen that the certificate of conformity had strategically omitted 1.5% phosphorus content. Those who are aware of Copper processing will know that phosphorus is added to Copper as a flux to lower the surface tension for better brazing and welding. Phosphorus is more potent in dropping the conductivity than oxygen for the same weight percent. Our initial success was cut short when we tested the same DoE runs on OFHC Copper from a reputable company that specialises in the material.

We achieved lower density but same electrical conductivity. A valuable lesson was learnt during this.

400W on the EOS M280 was insufficient to achieving 103% IACS electrical conductivity that is achievable in OFHC Copper via conventional routes.

At the same time, it became apparent that if you could have an additive which would decrease the thermal conductivity in the melt, but then could precipitate afterwards, it would give rise to almost 100% dense parts. Enter GRCop84, 8wt% Nb and 4wt% Cr which both disrupt the electron arrangement of Copper sufficiently to decrease the conductivity (see Figure 1). We had a project in 2015 to develop a component using GrCop84. This was the perfect alloy for the AM process.

We achieved 100% dense parts with over 320W/m.K thermal conductivity.

This, of course, was only possible with the appropriate emphasis on the heat treatment and the physics of the process.

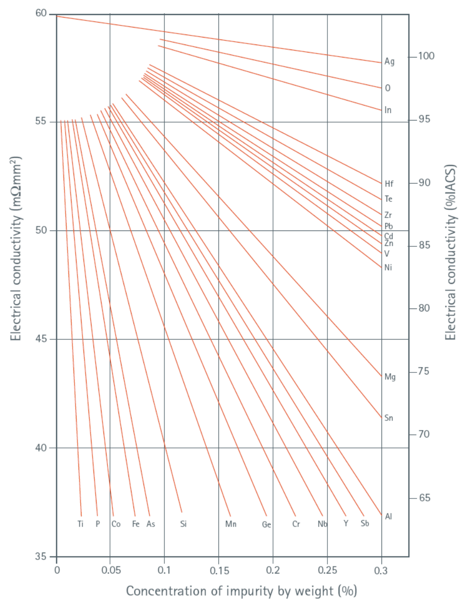

Figure 1: Electrical conductivity of Copper vs alloy elements.

Since then, we have focussed on CuCrZr which is more cost effective than GrCop84 and is not as restrictive on both applications and location.

We have been able to achieve electrical conductivity in the high 90s with various heat treatment processes. Nowadays, our comfortable level with fewer heat treatment steps achieves 75-80% IACS and over 300W/m.°C of electrical and thermal conductivity respectively.

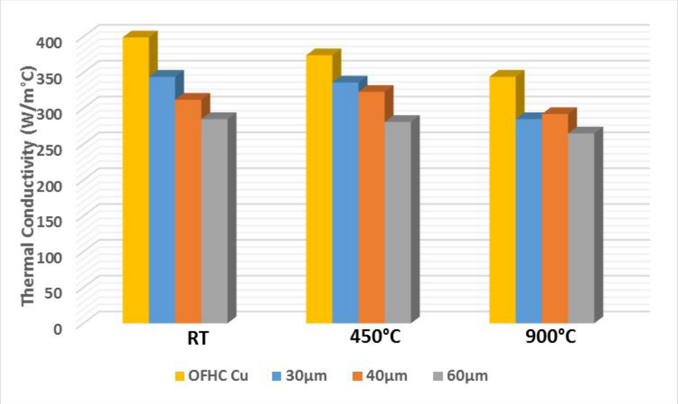

Figure 2: Thermal conductivity of CuCrZr processed at 3T in comparison to wrought OFHC Copper[2].

Copper has the best (or worst) physical properties when it comes to LPBF/DMLS. That is high thermal conductivity and high reflectivity when in liquid form.

What this means is that very little energy goes into the system that can assist with pore closure and densification during deposition.

While I was working at the University of Sheffield, we worked with the Arcam EBM process in 2012 on pure Copper. With minimal DoE we achieved electrical conductivity of over 90% of IACS standard. Of course, in the Arcam system which we ran the process at 700°C and with no reflectivity issues, this was a breeze.

Dr Ian Halliday, former CEO of 3T had a great analogy of the Copper process in laser AM. He described the heat transfer system as a bucket (melt pool) with a hole. If the water going in the system from a tap is at an equal to, or less than that of water going out of the hole, you then have a non-process. As you increase the flow from the tap, more of the water stays in the bucket (melt pool). There comes a point where the water rate from the tap is so high that it causes splashes (back reflection) which is both wasteful and, possibly dangerous.

So, the problem from the leak can be solved from both sides: higher water flow from the tap (higher laser power) and a way to restrict the flow from the bucket hole (using a mild steel platform instead of a pure Copper one).

All these obstacles aside, we have been able to generate a customer base whose requirements are very demanding and specific. The properties shown have been achieved using 3T's internal value chain fully. The 3T team has found which powder suppliers give rise to optimal input to our products, what are the best parameters for our machines, what is the best heat treatment to stabilise the parts, and then achieve the desired properties.

Throughout this journey we have focussed on one key point - the customer.

By understanding their requirement, we have been able to further streamline the process and understand truly what the shortcomings of the conventional manufacturing routes are and how to overcome ours.

It is obvious that the AM process could benefit from more energy on the current EOS M280. How much extra energy is needed to achieve the desired density is unknown.

There are literature values for conventional welding, but these do not consider all other issues involving copper in powder form, argon flow in the EOS M290 machine, layer time etc. However, what we know for sure is that decreasing the heat out of the system makes the M290 capability go further.

While others were too busy going for Copper baseplates for better part bonding (remember Copper and its high therma conductivity?) we were using steel platforms. And yes, we build enough stock to remove the Fe affected area.

While others were going for fancy laser wavelengths for better absorption, we focussed on the existing infra-red as it is the best understood and easiest to control.

However, how much of the 1kW laser we need to make a huge improvement to our process in both performance and speed remains to be seen after our work with the 1kW equipped EOS M290.

Our approach to productionising Copper alloys for AM is three pronged. Firstly, we need to make CuCrZr as affordable as ANY other equivalent AM material such that we show benefit on performance at no impact on price. Secondly, we need to continue to optimise the surface roughness in the internal cooling channels to less than 5µm via post processing. Finally, there are more Copper alloys out there which are better suited to customer applications which we need to explore to gain significant market share.

We are looking to develop other Copper alloys if the industry pull is right.

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