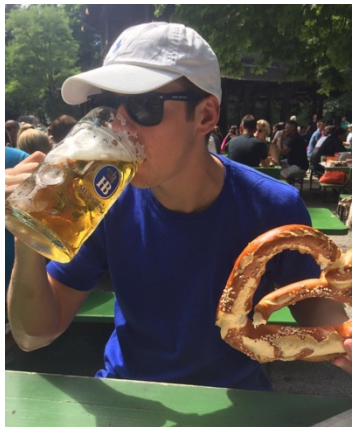
Armourers & Brasiers Non-Technical report
Linde Gas, Munich
Oliver Brown, Jesus College

Having finished my first year of natural sciences at Cambridge, I was already set on pursuing materials science. Before my second year summer, I had two main aims; to experience new culture through travel, and to develop skills in a scientific placement to complement my degree. When I first found out about the CaMPUS initiative, I was astounded that such an amazing opportunity was available for me to combine my two main summer ambitions. I put together an application for Linde in Munich right away, mainly due to the location being the epicentre for the Bavarian way of living and the fact that the placement focused on 3D printing. Speaking to my director of studies confirmed my decision, and it will be one that I will never look back on.

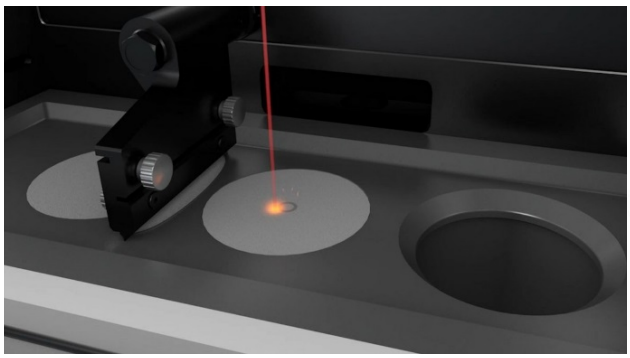
On my first day in Munich, I decided to grab the initiative and try to immerse myself into the culture by doing a walking tour, before settling down into my working routine the next day. My tour guide was called Patty Small, a rather ironically named larger-than-life American-Bavarian, and she showed us the Bavarian way around town. Although there are catholic churches and religious statues all over Munich, she made clear the main thing that Bavarians truly worship: beer. She told stories about how the life of a young prince was saved, how the opera house repeatedly burnt down and how Bavarian monarchs started Oktoberfest; the root of all of these stories being – you guessed it – beer. What struck me most was the sense of community that the Bavarians create; the Munich Biergarten (beer garden) atmosphere is like no other, even with laws in place to allow patrons to take in their own picnic food to enjoy alongside a cold one (like me on the right).


Small man or big beer?

This sense of community is prevalent all across Bavaria and it carried into my working environment. The welcome I received from the colleagues was more than I could have hoped for – by the end of the first week I had been shown the ropes at Linde, been taken to the biggest Biergarten in Munich, and shared a work BBQ with the Additive Manufacturing (AM) department. It was raining outside on the day of the BBQ but, being engineers, my colleagues decided to use the laser milling machine in the lab for ventilation!

Our research team was a group of six, spread over two cosy offices in the AM department. We all got to know each other very well, proving beneficial to both my social and working environment. The team consisted of me, two supervising PhD students, two master's students and a bachelor's student, being French, German, Thai, Chinese and Spanish respectively. The broad mix of nationalities, while sounding like the start of some terrible joke, led to learning so much about each other's cultures. English being the common language made it very simple for me to communicate, and having only had a rusty German GCSE to my name, I was thankful that it wasn't entirely necessary for the placement. I found it more beneficial to practice outside the workplace, although many Germans grasped that I was English straight away. I persevered to try to speak, with "Ich muss mein Deutsch verbessern" – I have to improve my German – probably being my most commonly spoken phrase.

Now for the science; the lab works with a Laser Powder Bed Fusion (LPBF) printer. In short, a laser selectively melts some parts of a flat powder bed which become fused together, a lot like welding. The building platform then lowers a small amount (width of a human hair small) and another thin, flat layer of metallic powder is swept on. The process repeats, with the laser building up the final product layer by layer, as is demonstrated below.



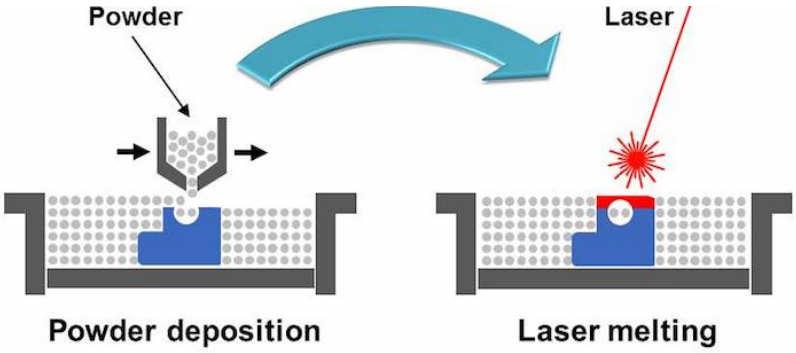


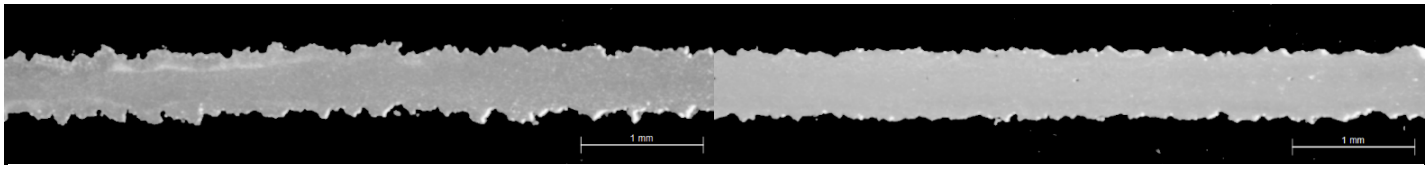
Diagram of how the LPBF Process works.

Within the first couple of weeks, I was essentially reading scientific papers and conducted literature reviews on both the surface tension of the molten metal created by the laser and the resulting porosity of the process. This gave me a handle on

The best part about working in the lab – dressing up like a ghostbuster.

the theory behind the LPBF process and allowed me to contribute ideas on further projects which my colleagues were pursuing. Meanwhile, helping the other students to conduct their own respective projects allowed me to gain skills on how to use the machinery available at Linde, including porosity measurement software, a heavy-duty rotary saw used for cutting finished samples off the building platform, and of course the 3D printer itself.

I decided to focus on the influence of the atmosphere on thin walls of titanium alloys, and to create the thinnest possible structures that could be made by varying laser parameters, such as its speed and power, and gaseous environment. The difficulty with this was that the printer we were using is only built for pure argon atmospheres, so some modification had to be done to the gas pumping system before we could try the process with low density gas mixtures, such as those containing helium. The thinnest we could make under pure argon conditions were around 0.5 mm – about the same width as your average grain of salt. This is quite thin, but it should have been only 50 µm (10x thinner), which is what we programmed on the design software, so we found evidence of a systematic offset. This was caused by the laser melting too much of the powder bed due to the poor conduction from the thin wall, which could not carry away heat as effectively as a larger sample. Having found the limit to spatial resolution, we set ourselves to minimising the roughness of the walls, and by playing with different laser parameters and gaseous atmospheres, we found some positive results.



Shows qualitative decrease in surface roughness from left to right upon experimenting with (classified) laser parameters. Left shows the best parameters for a bulk sample - things behave differently on a smaller scale.

The best thing about this kind of research is that the results could have such a palpable impact on the fast-growing industry of 3D printing. Probing the limits of the printing resolution will continue to be a challenge for researchers and it was amazing to be a part of the effort. I'm still not sure if I want to continue further research in materials science beyond a Master's, but this has seriously made me consider going on into further study, especially if it could make breakthroughs in new, cutting-edge technology with the potential to be utilised in a vast range of applications.

Outside of the lab, the Alps were my closest friend (despite discovering my crippling fear of heights). The hikes were incredible, the views breath-taking and nothing if not worth the uphill struggle. I was also part of a company run which ended running directly into the iconic Munich Olympic Stadium. Having ran competitively when I was younger, it was a great honour to be able to run on the same track as the greatest athletes of 1972 (a happy me pictured below). And, surprise, surprise, they gave everybody a beer as a reward for finishing.

Enjoying a free beer in the Olympic stadium and at the summit of Auerspitz, wondering how on Earth I would get back down.

Embarking on the CaMPUS initiative and living in a different country is something that I couldn't recommend trying enough. I learnt specialist skills that will aid me in my academic studies and no doubt have an impact on my future career. I experienced amazing culture, cuisine to die for and made life-long friendships in the workplace.

I would like to thank Linde for the opportunity of allowing me to work with such cutting-edge technology, the Materials Science department at Cambridge for organising the placement, and of course the Worshipful Company of Armourers & Brasiers, without whom I could not have gone on this life-changing adventure.