

## Max Plank Institute für Eisenforschung Non-Technical Report

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Before beginning this report I would like to first thank the Worshipful Company of Armourers and Brasiers for their generous bursary that helped me pay for my rent and flights to Germany. I would also like to thank all those at the Department of Materials Science and Metallurgy who helped organise the logistics of the placement as well as Dr. Frank Stein and Dr. Vivek Devulapalli for hosting me at the Max Planck Institute für Eisenforschung (MPIE). It has been a tremendously insightful experience that has helped me shape my future plans to hopefully continue on to complete a PhD in Materials Science, and I am extremely grateful for this incredible opportunity.

## At the institute

Having finished the 2nd year of my Bachelor's course in Naturals Sciences, I decided to, at least for the summer, let go of the hand of the carefully structured course that guided me into the world of Materials Science and enter the wilderness of scientific research. Contrary to my previous experiences in science, the outcome of this project was not determined from the start. I spent my first week planning and reading what had already been done in the field and which routes were taken to achieve those results. And so with a vague idea of where I could end up, I eventually set out to investigate the "Mechanical properties and hydrogen embrittlement of equiatomic CoCrFeNi with nanoparticle additions of TiN and TiO<sub>2</sub> for applications in the hydrogen economy".

I was presented with a sample of CoCrFeNi which had been 3D printed via Laser-Powder Bed Fusion (L-PBF) with additions of 800nm TiN nanoparticles. The microstructure was very unique with regions (a) and (b), from now on referred to as channels, in Figure 1.A tracing out the path of the laser which enclosed large grains (c) which from now on will be called cubes.

To study the behaviour of the microstructure, I poked it to see how it would react. Arrays of nanoindents were made on each of the samples and hardness maps were created, with each pixel corresponding to a particular indent as seen in Figure 1.B. This was then compared to Electron Back-Scatter Diffraction (EBSD) images on the indented sample to identify whether cubes and channels behaved differently. Unfortunately, I was not able to use the Scanning Electron Microscope (SEM) to take the EBSD images myself as the only SEM at the department that I could feasibly learn to operate within the two months was spooked by my arrival and decided to break the same day I stepped foot in the institute. Not deterred by this setback, I dedicated my time to nanoindentation and the subsequent data analysis. To truly determine whether a separation in hardness existed between the cubes and the channels, I used a machine learning algorithm called K-Means Clustering to find out how many groups existed within my data and which points belonged to them as seen in Figure 1.C where cubes and channels do in fact separate into two groups.

Another twist in the journey came in the form of the hydrogen charging results. Instead of hardening, softening was observed and even more strangely, the cubes seemed to soften more than the channels, which was contrary to expectations. I was able to propose mechanisms for the behaviour, however, more tests need to be performed to determine where the hydrogen sits in the material and what it does to it. With hydrogen growing in popularity as a clean fuel, already being utilised in buses in my home city of London and in German trains, finding safe and the most efficient materials for hydrogen storage and transfer is of paramount importance as we battle against pollution and climate change, and I am very proud to have contributed in an area I feel so passionately about.



Figure 1: A) EBSD of CoCrFeNi with TiN nanoparticle additions, B) Hardness map with each pixel corresponding to one indent, C) K Means clustering of the hardness map



Figure 2: Setting up the nanoindentation for 3 samples. The experiment took 3 days to complete as the thermal drift had to be below 0.5nm/s

Working in an international group with members from China, India, and Germany, to name just a few, I realised that the friendliness and helpfulness that initially drew me to the Materials department at Cambridge were, in fact, a qualities of the wider Materials Science community. Every week, snacks from a different country were placed in the "Aquarium" (the communal kitchen which has one completely glass wall so everyone inside looks like fish in an aquarium) for everyone to taste. I gained invaluable insight from those more experienced than me discussing everything from the academic lifestyle, cultures and traditions around the world, to, my favourite, football during our lunch breaks. One of the main reasons behind picking Max Planck for my placement was that I wanted to improve my German which I really enjoyed studying at school. I had a lot of fun taking part in Deutsch Donnerstag with some of my Spanish coworkers, where we would try to make conversation at lunch only in German. The great communal environment where I could freely discuss my project,

obtain suggestions, and justify my approach to the project improved my understanding of the materials I was working with and the methods that could be used to study them. I ended my stay at the Max Planck Institute with a presentation during the weekly departmental seminar. Whilst initially finding it daunting to speak to a room full of doctors and professors as a lowly bachelor student sitting at the bottom of the food chain, I was quickly reassured by the smiles and approving nods of the people

who had helped me and treated me as an equal over the last couple of months. Having documented my journey along the way, and despite encountering a few dead-ends and an uncertain footing a few times, I believe I have contributed to the map of the science in this area and am eager to hear about how this is continued in the future.

## Beyond the institute

The hospitality and generosity shown to me at the institute extended also beyond it as I was always invited to join in activities with my colleagues outside working hours. During my first week, I was invited by Prof. Scheu and Prof. Dehm to their house for a barbeque with one of the research groups within the department. It was a great opportunity to meet new colleagues over a beer and delicious grilled food, immediately feeling integrated into the MPIE community.

In Düsseldorf I rediscovered my passion for reading, and each weekend I would pick a different park to read in and explore the city along the way. Among my favourite spots was the Altstadt (old town) with its traditional German breweries that served the local Altbier, a dark and rich ale with a thick texture that was served in small 250ml glasses carried around on trays that could hold around 50 at a time. A true German experience!



Figure 3: Work hard play hard. Despite braving the ride, I decided to sit closer to the anchor point (right) to not reach the same height as thrill-seeking Vivek (left)



Figure 4: Channeling my inner photographer at Volksgarten in Düsseldorf

I joined Vivek and his wife on a trip to the annual Düsseldorf Kirmes which is a huge summer fair with countless rides, food stands, and of course, beer gardens designed to assert the city's status as the capital of the North Rhine-Westphalia state against its arch-rival Cologne. Breaking through my acrophobia, I was convinced to go on some of the more extreme rides at the fair; luckily, I didn't eat dinner beforehand. The Kirmes finished with ground-shaking fireworks which I enjoyed with a well-earned Bratwurst. The Deutschland Ticket not only provided me with monthly public transport in Düsseldorf, but with regional transport in the whole of Germany for just  $\leq 49$ . I committed high treason by first visiting Cologne and was confronted by the awe-inspiring cathedral as soon as I exited the station. The highlight of my visit was my tour of the oldest fragrance factory, Farina Haus, which produced the original Eau de Cologne. Now I can proudly say that I smell like Napoleon.



Figure 5: Summer barbeque

Hamburg gave me a true port city welcome with a storm arriving just as my train pulled in, which provided a great ambiance for my visit to the International Maritime Museum. My final trip was a visit to Berlin to reunite with an old classmate of mine from school. I spent my time reliving the history of this incredible city through all its landmarks and will return soon as 2 days was certainly not enough. The wonderful two months were capped off with the annual MPIE barbeque. With the fire started with what can only be reasonably described as a flamethrower and the department directors on beerpouring duty, the party flowed into the evening filled with games and delicious homemade food.

I would like the thank the whole MPIE community, and especially Vivek, for making me feel so welcome over the summer. I have made many friendships that I will cherish greatly, and I look forward to meeting everyone again wherever we may end up in the future.

Once again, I would like to thank the Worshipful Company of Armourers and Brasiers for their generous financial support, the Department of Materials and Metallurgy in Cambridge for developing the CaMPUS scheme, and MPIE for hosting me. Living independently in a foreign country has helped me grow as a person, improve my language skills, and truly immerse myself in German culture. I have developed a lot as a Material Scientist and this placement has affirmed my decision to continue with Materials hopefully for a Master's degree and beyond.