

REPORT ON RESEARCH STAY – 01/2021 to 02/2021

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My overall experience in Ingolstadt:

Arriving in Ingolstadt was easy. Munich's Airport has a bus leaving south for the Donau in 3-hour intervals. Previously the X109 left the airport every hour or so, however, its departure schedule, like many other things, has changed due to the pandemic. In fact, I am certain that for this same reason I was, and am, not able to experience the usual Ingolstadt. So, I bit the reader to take in mind that some impressions described here are results of the current global situation. One particular aspect of the situation is the mandatory quarantine required from all travelers coming from "risk countries". The full list of what is considered risk countries may be found on Robert Koch-Institute's (RKI) homepage. As for the quarantine, one must consider if the place in which you will be moving in is in living conditions, for example, if it has furniture in it. Also, for the 14 days quarantine, supplies are necessary, thus someone should buy them for you since you must, accordingly to the present law, go from the airport direct to the apartment and stay there for the whole period. In my case, the AWARE program kindly assigned a student to deliver supplies for me during it, while the landlord also left some for the first days. If you are moving to a place with more people in it, make sure they know that they will also have to go into quarantine before you move in, so they have to plan for it.

Accommodations in Bayern are more expensive than in other parts of Germany. An apartment with a single room may vary in price from 400 euros up to 580. I would not recommend the newcomer to go for cheaper ones, because, unless they are shared, they are likely to have something wrong with them. Be aware, therefore, that when it comes to apartments, great deals are extremely unusual to come by, being more likely scams than anything else. However, not everything is bad news, due to Corona, it was and still is quite easy to find a good place to stay, since most students went back to their hometowns and, therefore, many good spots became available. There are several websites that one can use to look for a place to stay. I recommend always reading the full ad before sending an e-mail, so neither your time nor the renter is wasted. One must also aware be of extra fees like Condo and alike, they can be expensive. Other than this, I recommend renting a place in one of these five neighborhoods: *Nordost (Josephsviertel; Schlachthofviertel)*, *Mitte (Altstadt; Brückenkopf)*, *Nordwest (Richard-Strauss-Straße; Gabelsberger; Nordbahnhof)*, *Münchener Strasse (Antonviertel)*, *Südost (Monikaviertel)*. The closest to THI the better and having a supermarket in the near is always a good choice.

Locomotion in Ingolstadt – for students – is done mostly by bike, or on foot, so I recommend buying a bike already on your first weeks here, anything between 90 and 150 euros should do. The other option is taking the bus, which is quite good and punctual, as expected, but this may be expensive when taken on a daily basis. There is no tram system, however, connections to other cities by train are good, especially if they lie North or South of Ingolstadt as there is a mainline running through it.

Formalities or bureaucracy are unavoidable, so to make this process easier, I strongly recommend to every newcomer to ask the AWARE team about everything you have a doubt about. They are efficient and will help you with everything they can, given that you are polite, of course. Also, make sure that you have all the required documents before leaving your homeland. I had no major problem, but it would have been much easier to get my high-school grades when I was in Brazil. Once in Germany, enrollment at THI was simple, the staff from AWARE was – again – of great help, in less than two hours most of the enrollment procedure was done. Germany has different types of

insurances, and specific ones are required for different contracts and situations. These insurances are sometimes hired separately, which may not be so on the land where the student comes from, therefore, he or she must be aware of which ones are required, and check if the right one was indeed hired. When having an urgent question to any government organization outside THI, a good tip is to just call them, do not wait for an e-mail reply. Some public officers may take weeks to answer a single email but will answer promptly if you call them, present yourself, and go direct to the point, if you are not confident in your skills in the German language, ask someone to make the call for you.

Acquiring a Visa takes time, especially if you are not coming to Germany under the student status. After checking if you have all documents, it is necessary to book an appointment. For this, one must use the website of Ingolstadt's prefecture, which is well organized and with clear explanation. The dates available usually are one month away, so check your deadlines. I would suggest attempting to book the appointment even before arriving in Germany, but please check with THI and the *Amt für Ausländerwesen und Migration* if this is allowed before doing such. The employees in the immigration office do not speak English, because maybe they are instructed not to, but most of them try to speak clear German once they see you are having trouble with the language. Nonetheless, if you are not confident in your German skills, you are allowed to take an interpreter with you, even during Corona times. After a successful visa appointment, which is likely if you come prepared, the visa takes up to 6 weeks to be issued. In the case where your current Visa, or stay permit, expires before the new document's arrival, you will be given a *Fiktionsbescheinigung* on the appointment, which is a stay permit valid for the interstice.

The city is relatively small, but it has everything, most big supermarket chains are present. Food shops are available in all ethnicities, so some will surely suit your taste. I recommend trying new ones, instead of looking for options from your home country. This will not only be cheaper but also fun. Cooking is also considerably cheaper than ordering it, therefore, looking for an apartment with a good kitchen may be a good idea. I cannot, unfortunately, comment on THI's university restaurant (*Die Mensa*) since it was closed during Corona. The *Mensa* would be a good option in normal times, from what I have heard. Also, instead of buying food only from the main supermarket chains, one can go for the Asiatic food shops or alike, some even sell ingredients from Latin America, such as tapioca and *guaraná*.

During Corona, the streets are considerably empty of pedestrians even at the weekends, no parties or agglomerations are allowed. However, there some other options to expend your free time, such as taking a walk around the Donau, visiting the Baggersee and the Auwaldsee, or riding a bike to Neuburg. I would also recommend visiting Regensburg on a free weekend, it is a different city, and a change of pace and environment could be a good idea during these lockdowns. The ice cream shops there are great, and the Walhalla memorial is nearby. From there, it is possible to have a great view from the Donau while having a picnic in the shade. However, lack of socialization may also become a problem after a while, which can even delay the process of learning the local language. A solution to this which I could recommend is to look for a "tandem" partner, one can then walk the city while practising the language and make a friend while studying.

At last, if the student must perform research activities during his or her stay at THI, which is most likely, I recommend knowing when each technician, doctorand and supervisor will be at the university. This way the student can better plan his or her activities and get the proper – and required – instructions on each machine. Note also that one cannot work alone in the laboratories, because if some accident comes to pass it is safer to have someone nearby to provide first aid. Without planning, this normally limits the time that the researchers can expend in the lab, delaying schedules. The time not spent in the laboratory and that still necessary to complete the workload is being expended in the home office.

Research – Context, executed activities and future steps:

Nickel-base superalloys and metal matrix composites (MMC) are of interest to key industry sectors present in both Brazil and Germany, such as aerospace and energy production. With the development and dissemination of additive manufacturing processes based on laser technology, these materials gained considerable room for improvement. The research done in the two months supported by the AWARE program was inserted in a broader project that studies how the reinforcement of nickel-base superalloys by the addition of a ceramic particulate through laser additive manufacturing (LAM) can enhance the material's thermo-mechanical properties while reducing its density. This topic was devised from Dr Eng. Georges Lemos doctor thesis, which was performed at THI but did not explore the possibilities provided by additive manufacturing. Instead, he used mechanical sintering to process the mentioned materials and, nonetheless, achieved promising results. From these results, Prof. Dr.-Ing. Ulrich Tetzlaff got in contact with me through Prof. Dr.-Ing. Márcio Celso Fredel, from the Federal University of Santa Catarina (UFSC), and proposed that I performed my master thesis on the topic. This was an opportunity that I gladly accepted, given that not only was it a chance to strengthen the bonds between THI and UFSC, but also because I had an interest in continuing researching Nickel-based superalloys, and had access to additive manufacturing equipment that THI lacked; thus, each institution's expertise and equipment came to complement the other's. During my master thesis, I produced samples that were preliminarily analysed in Brazil, and that formed results used to finish my master degree, however, these samples could only be fully tested in Ingolstadt. The final goal was to lighten a superalloy while retaining or enhancing its mechanical, such as resistance to creep and thermos-mechanical fatigue.

The specific alloy processed by Georges, and the one which I came to work with, is the polycrystalline Ni-Cr superalloy Inconel X750, while the reinforcement inserted was microscopic titanium carbide. This superalloy is applied in gas turbines that are in use in both countries; any improvement in this material could benefit both. The samples that I brought to Ingolstadt were manufactured by laser Directed Energy Deposition or I-DED. There were mainly four samples, which are depicted below in Figure 1. Each sample is composed of a substrate which is the 9-mm thick plate below the uneven block that is the deposition.



Figure 1 – I-DED manufactured samples brought for testing at THI

These samples were to be microstructurally analysed through electron microscopy, heat-treated, had their phases identified through X-Ray diffractometric (XRD), and finally, be thermo-mechanically tested on compressive creep at THI. Other secondary samples were also brought to Ingolstadt, but these were mostly used to calibrate and practice the analysis techniques that were to be applied to the main samples. These techniques were scanning electron microscopy and X-ray diffractometry. However, I must say that the execution of these tasks was not planned to be done exclusively on these two months alone, but throughout my doctoral thesis, which was planned to follow, and that fortunately will. There was uncertainty in this topic due to lack of funding, but I am glad to state that I was approved in a scholarship program while I was in Ingolstadt, much due to the support supplied by the AWARE program. My degree is ought to come from a cooperative doctorate program between the THI and *Universität Bayreuth*, the latter represented by Prof. Dr.-Ing. Uwe Glatzel.

A few weeks after my arrival at THI, the four main samples were sent to be cut by electrical discharge machining (EDM), as, understandably, there were no means to cut them at THI. A slice of each sample then cut was taken for the analysis of the as-processed microstructure; this and all further steps were done at THI by myself. A macrography, taken on an optical microscope, depicting one of these sample's cross-section is presented in Figure 2.

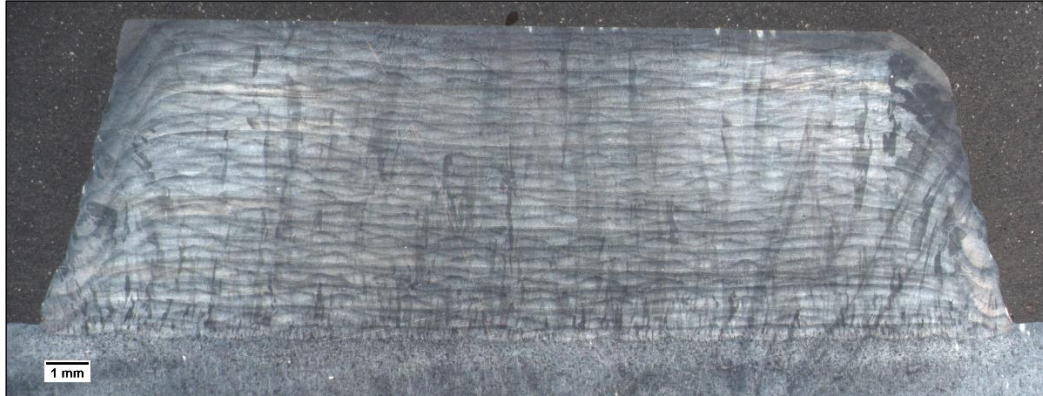


Figure 2 – Macrography of one of the samples transversal section showing preferential grain orientation.

The polished surface presents many scratches from polishing since the metallographic procedure for this new material is still being optimised. Nonetheless, one can see the grain structure of the material, which shows a considerable texture by the many grains that go from the bottom of the deposition to its top. Such phenomenon is usual in additive manufacture materials, however, its intensity or at least the size of the oriented grains is diminished by the addition of carbides, which work as grain nucleators. This statement can be backed by the literature but also based on a fact that was omitted up to this point. Two of the four samples brought from Brazil are made of pure Inconel X750 to allow microstructural comparison between the pure material and the MMC. The texture and the crystalline lattice's distortion are currently being quantified for both conditions, reinforced material and pure Inconel, by XRD in THI's PANalytical Empyrean system. A diffractogram was taken from the slices, while another one, shifted 90° in regard to the previous, was taken from the top of the sample. Comparing diffractograms, two of which are exemplified in Figure 3, not only further confirms both materials anisotropy but will also allow quantifying the lattice.

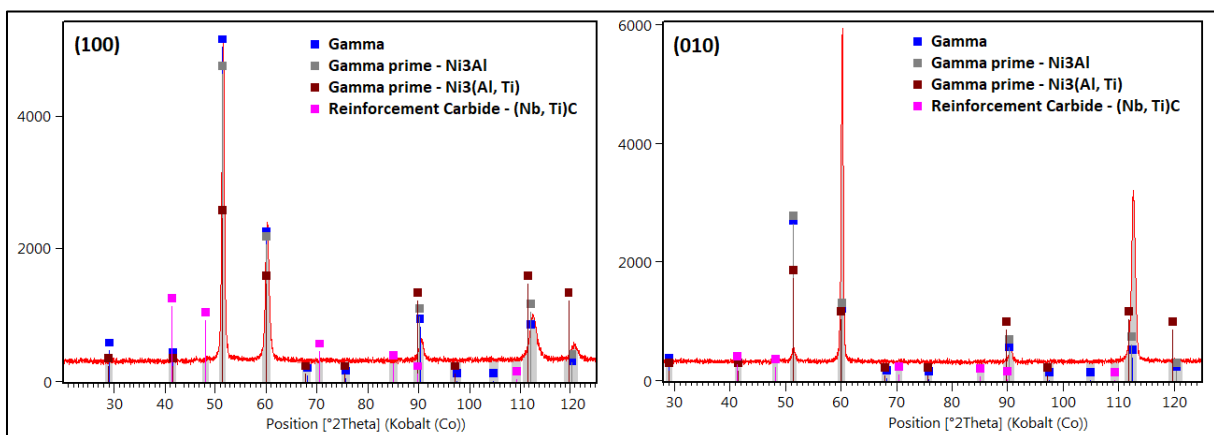


Figure 3 – XRD results from the same sample but in orthogonal orientation. Grain texture is evident by the differences in diffraction peak height, especially at 53° and 60°.

Six cylinders were also to be cut from each sample, resulting in a total of 24 cylinders, of which half were heat-treated with the standard heat treatment for Inconel X750. These cylinders are the creep test samples mentioned before and, since their length is not yet right, they are currently being machined to be fit for testing. Each heat treatment takes three to four days to be concluded. The other

half of such cylinders is also to be heat-treated, however, a heat treatment specially designed for these additively manufactured samples was deemed necessary since the microstructure of the additive manufactured samples are not exactly equivalent to the one of a hot-rolled Inconel X750, material to which the standard heat treatment was designed. Two candidates for this new heat treatment are in test, for such the previously mentioned slice are being used, as to not expend the cylinders unnecessarily. Currently, attempts are being made to analyse this new material on the Scanning Electron Microscope (SEM) available at THI, but since these are essentially novel materials, difficulties are being met on defining a metallographic procedure that allows observation of the fine phases which give this superalloy its strength. Until such can be done, the remaining un-treated cylinders will not be heat treated.

Parallely, and again with Professor Tetzlaff's help, contact was established with Fraunhofer IGCV (*Institut für Gießerei-, Composite- und Verarbeitungstechnik*), from Augsburg, where more samples are planned to be produced, now by SLM. These samples will be for my Doctor thesis as well as any related work. Selective laser melting is a process less dependent on powder flowability, while also having a higher geometry precision than I-DED. If one analysis in depth the results we have achieved so far, it becomes evident that these are process characteristics that will greatly benefit this research line as they will not only bring the technology being developed close to the industrial application but also allow a broader range of processing conditions. The first appointment at Fraunhofer IGCV was already attended, when powder rheology measurements were made, and a second is scheduled to happen shortly when a part of the samples will be produced. An application for the BayWiss program is also being prepared in the meanwhile, also having to be counted as an activity. This program supports cooperative Doctor studies made between universities and *Technische Hochschule*, precisely the case in which I face myself. Hopefully, an approval will be met soon.

Other activities were also performed aside from these research steps. I was trained in all the afore-mentioned equipment plus the nano-indenter, which will be used in the future, while also instructed in the safety procedures of the laboratory. I also helped Eng. Guilherme M. Volpato from Federal University of Santa Catarina (UFSC) to arrange his Master Thesis topic, which came to be included in the project just described. His research, therefore, will be performed here at THI, he will take classes at UFSC, and his supervision will be done by Prof. Tetzlaff, Prof. Fredel, and myself.

The two last paragraphs show that this project is indeed in expansion and hopefully will continue on this path in the upcoming years. The research topic itself is relevant, up to date, and is being explored by many institutes, albeit not with the alloy being worked here nor high volumes of light reinforcement particles added (15 per cent in the volume of titanium carbide, that is). We also plan to explore more alloys and work with different reinforcement particles, while also continue optimizing the heat treatment of such materials. Only with the whole production line in mind can efficient additively manufactured components be produced, and this is why cooperation between academy and industry is so important. More students may be included in this project in due time, and be they from Brazil or Germany, they will indeed meet plenty of tasks, as there is much to be done. Publications are also being written by myself and colleagues in order to make our findings available to other research groups. These documents are also necessary to show this technology's capacities and to prove our competence to the selection boards of other funding institutions such as the *Deutsche Forschungsgemeinschaft*. Throughout the last months, I also have been writing three scientific papers that are related to the topic, while Dr.-Ing. Lemos and Eng. Volpato are also writing another two. With this, we hope that we can reinforce all the connections established and make new ones.