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Newsletter #5 RA1

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This newsletter is published prior to each workshop of SFI Manufacturing. The aim is to keep the community up to date with the current research that is being carried out within and related to the SFI. This issue of the newsletter is focused on the research and achievements from the area RA1 - High structural efficiency products based on multi-materials with robust and adaptive manufacturing processes.

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sfi Centre for Research-based Innovation
The Research Council of Norway

SFI Manufacturing
A cross-disciplinary centre
for research based innovation
for competitive high value
manufacturing in Norway

About the research area

New advances on sustainable, lightweight and high performance products can be achieved by combining the best properties of different materials, such as the impact toughness of aluminium and weight/strength ratio of carbon composites. This is a major trend for demanding markets such as the automotive, aerospace and maritime industries. **In the first three years of SFI Manufacturing we have focused on selected topics related to design and manufacturing processes of multi-material products. The two main scientific focus areas have been to study different processes of joining dissimilar materials and on topics related to additive manufacturing of metals and polymers.** However, the global trend towards circular economical thinking will have a strong influence on product design including choice of materials. Sustainability in material selection and production processes, including high recyclability of materials in multi-material solutions will therefore become a focus area in SFI Manufacturing in the coming years.

Much of the research work in SFI Manufacturing is competence building activities on a rather fundamental or low TRL level performed by PhD students. However, in SFI Manufacturing we also have a focus on bringing this competence to a higher TRL level and closer to innovation. This is done in industrial spin-off projects which we call "border zone" projects. In these projects, one or more of the industrial partners in the SFI and some of the R&D partners also work together with companies who are not partners in the SFI. What we learn in these border zone projects is then brought back into the work within the SFI. This is why, in this newsletter, we also report ongoing status and results from some of these border zone projects.

News from workpackages WP1.2 and WP1.4

Among various dissimilar material combinations, joining of aluminium to steel has been given extensive attention both scientifically and among industry due to the increasing relevance in lightweight solutions. Within SFI Manufacturing, we have worked on this topic during the first three years of this centre. We have taken a multi-scale approach combining experimental process studies and advanced characterisation with numerical modelling. Three PhD-students are involved in this research. In this newsletter we give an update on the status and progress of this work. We also present information from a border zone project called Galf which is focusing on the unwanted galling process in aluminium forming. This project utilizes many of the results generated in SFI Manufacturing.

News from workpackage WP1.1

In addition to more conventional processes of producing multi-material products, in SFI Manufacturing we have a special focus on additive manufacturing (AM) as an important enabling production technology alone and/or in combination with traditional production methods. This process has until now mainly been used in mono-material situations but has the potential to be an important multi-material production method. Many of the SFI Manufacturing partners, both industrial and R&D partners, are also involved in the KPN project MKRAM (Material Knowledge for Robust Additive Manufacturing), and the activities within SFI Manufacturing on AM are closely coordinated with the activities in MKRAM. Therefore, in this newsletter, we inform about some activities and results from the MKRAM project. In addition, we give a short status update on two important new infrastructure projects just being started, where AM plays a central role.

News from workpackage WP1.3

In this newsletter we also briefly present some topics related to industrial multi-material manufacturing challenges where polymeric materials are involved. The main common challenge in most of these situations are related to adhesion at the interface between the different material surfaces. One of the processes that was initially studied in SFI Manufacturing has continued in a border zone IPN project called SamKomp (Joining of composite structures). The topic of this project is joining of composite structures with either gluing or secondary lamination. We give a short update of progress from this project in the newsletter. We have also performed a fundamental numerical modelling study of the interface energy between an aluminium surface and epoxy resin in a gluing process. In addition, some investigations into a new group of materials called "vitrimers" are reported. There are many potential application areas for this group of materials, one of which is reversible glue. With so many potential application areas this is an interesting topic to study for the SFI.

Results from research and PhD-activities

Joining aluminium to steel

In SFI Manufacturing, we have chosen a multiscale approach, to both modelling and material characterization, in order to tackle the research challenges related to joining aluminium to steel. One of the biggest challenges is the formation of brittle intermetallic compounds (IMC). Our research aims to better understand the mechanisms of IMC at the macroscale, mesoscale and microscale, as well as the nanoscale. The link between different length scales needs to be established to obtain a full picture of the phenomenon.

One important feature of SFI Manufacturing is to generate spin-off projects, or so-called border zone projects. The synergy between SFI Manufacturing and spin-off projects may not only maximize the outcome of both projects, but may also establish the link between fundamental knowledge and industry case studies. A good example is the synergy between SFI Manufacturing and the IPN project Optimals, in which an aluminum-steel crash management system (CMS) is one of the industrial demonstrators. We are currently working on establishing an international EU-founded project (M-era.net project) in which we want to implement the multiscale modelling framework for galling and wear where the theory was developed in SFI Manufacturing and described in a report last year. The PhD work in SFI Manufacturing supplies the knowledge and understanding of physical phenomenon, while spin-off projects can drive the research-based innovation, a win-win situation.

Back to the multiscale approach, PhD student Siri Marthe Arbo applies a "top-down approach", using the cold roll bonding technology to study the effect of different factors on the type and quantify of Al-Fe intermetallic phases. PhD student Zeeshan Khalid uses a "bottom-up approach" to gain insight in the details of the bonding properties of Al-Fe joint through density functional theory (DFT) and atomic scale simulations. PhD student Tina Bergh tries to establish a "handshaking region" to bridge the knowledge generated at different scales using advanced material characterization tools. The information and knowledge flow between different scales of a multiscale framework, will help us to solve the key challenge in joining aluminium to steel.

PhD progress reports

Top-down approach - Siri Marthe Arbo's adventures

So far during my PhD, we have learned more about cold roll bonding of steel and aluminium and have developed a good process for our machine and available equipment, giving sound joined samples. The work performed last spring resulted in two conference papers, that I will present on ICTMP2018 (Denmark) and Metal Forming 2018 (Japan). Last fall I spent three months at the Technical University of Darmstadt in Germany, working on a collaboration project on cold pressure welding of steel and aluminium. In this collaboration project, we are joining steel with three specially designed aluminium alloys from Hydro with different wt% of silicon. The initial analysis has been performed and different tests are now being executed to test the strength of the joints.

We know a lot about the fundamentals regarding steel and aluminium joining, so this spring I have shifted the focus towards new material combinations and different metallic interlayers when performing cold roll bonding. We have been focusing on joining stainless steel and commercially pure aluminium, to better understand the influence of alloying elements in steel. To avoid the brittle Fe_xAl_y intermetallic phases when joining steel and aluminium, the use of metallic interlayers is of high interest. So far, we have successfully produced samples with nickel and silver as metallic interlayers and these samples are now being analysed.

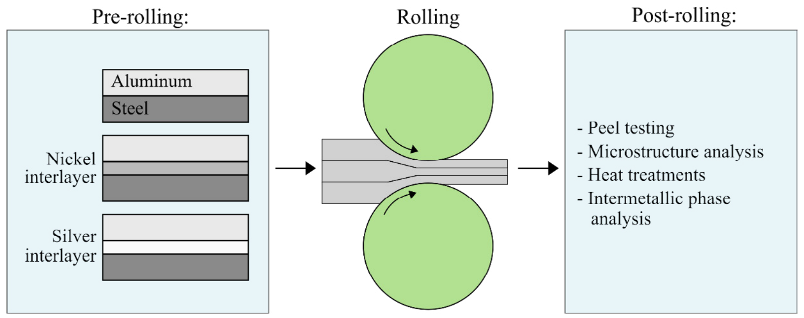

Figure 1. Illustration of the methodology in PhD work of Siri Marthe Arbo.

Handshaking - Tina Bergh's "toys"

Transmission electron microscopy (TEM) is my tool for characterising the interfaces in joints of aluminium and steel using different joining processes, i.e. cold metal transfer, hybrid metal extrusion and bonding and cold roll bonding. The crystal structure and composition of the joints, down to atomic scale, is the focus of my study. There are different intermetallic phases at the interfaces, that control the mechanical properties of joints. It is thus important to obtain a thorough understanding of different intermetallic phases, e.g. type and thickness. From a multiscale investigation point of view, my work is a "hand-shaking" method, bridging the atomistic modelling (by Zeeshan Khalid) and macroscopic investigation (by Siri Marthe Arbo).

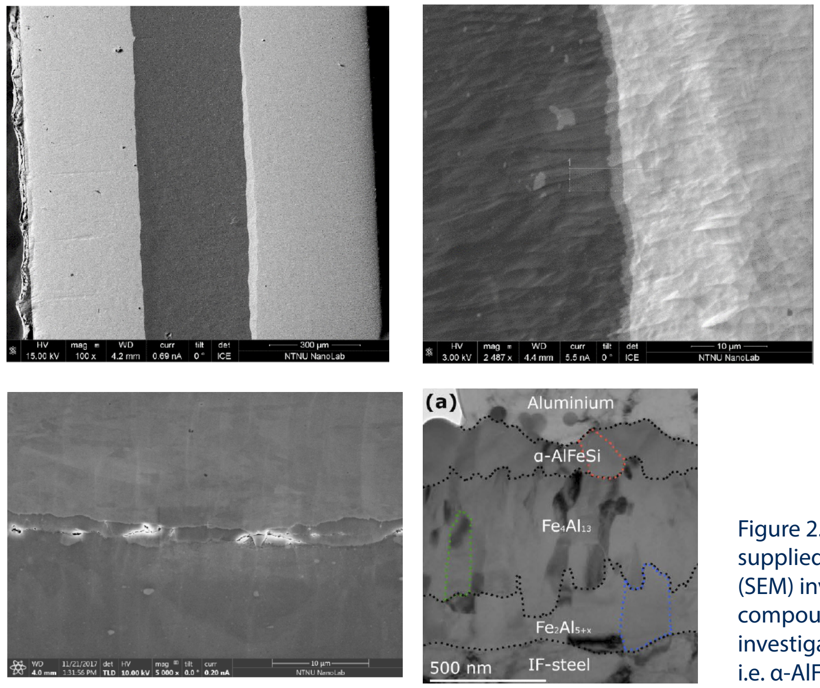

Figure 2. Characterization of cold roll bonding (CRB) specimen supplied by Siri Marthe Arbo. Scanning electron microscope (SEM) investigation found discontinuous intermetalic compound (IMC) layers up to ~3 μm. Through TEM investigation, it is found that the ICM consist of 3 distinct IMCs, i.e. α-AlFeSi, Fe_4Al_{13} and Fe_2Al_5.

Multi-scale modelling - From the atomistic world of Zeeshan Khalid to welded component

In the previous RA1 newsletter we described a welding experiment joining of aluminium to steel by cold metal transfer and advanced TEM characterisation of the intermetallic phases that forms at the aluminium/steel interface by PhD student Tina Bergh. We then briefly described the atomistic models of the intermetallic phases and the interfaces between them that PhD student Zeeshan Khalid is working on. We are now taking this work one step further by setting up a multiscale model of the welded structure. We consider three different scales that we refer to as the macroscopic, microscopic and atomistic scale (see Figure 3). The numerical modeling at each scale was carefully chosen to take in account the most important mechanisms that are affecting the welding resistance, including the detailed structure of the intermetallic phases at the aluminium/steel interface. The scales were connected by a well-defined work flow. The macroscopic scale benefits from the continuum structure mechanics models, which are solved with standard finite element (FE) techniques using SIMLAB Toolbox (developed in SFI CASA) and LS-DYNA. The mechanical properties of the intermetallic interface layer are calibrated using microscopic models. Currently the softening at the heat affected zone is not considered, but a similar multiscale approach could be used for that.

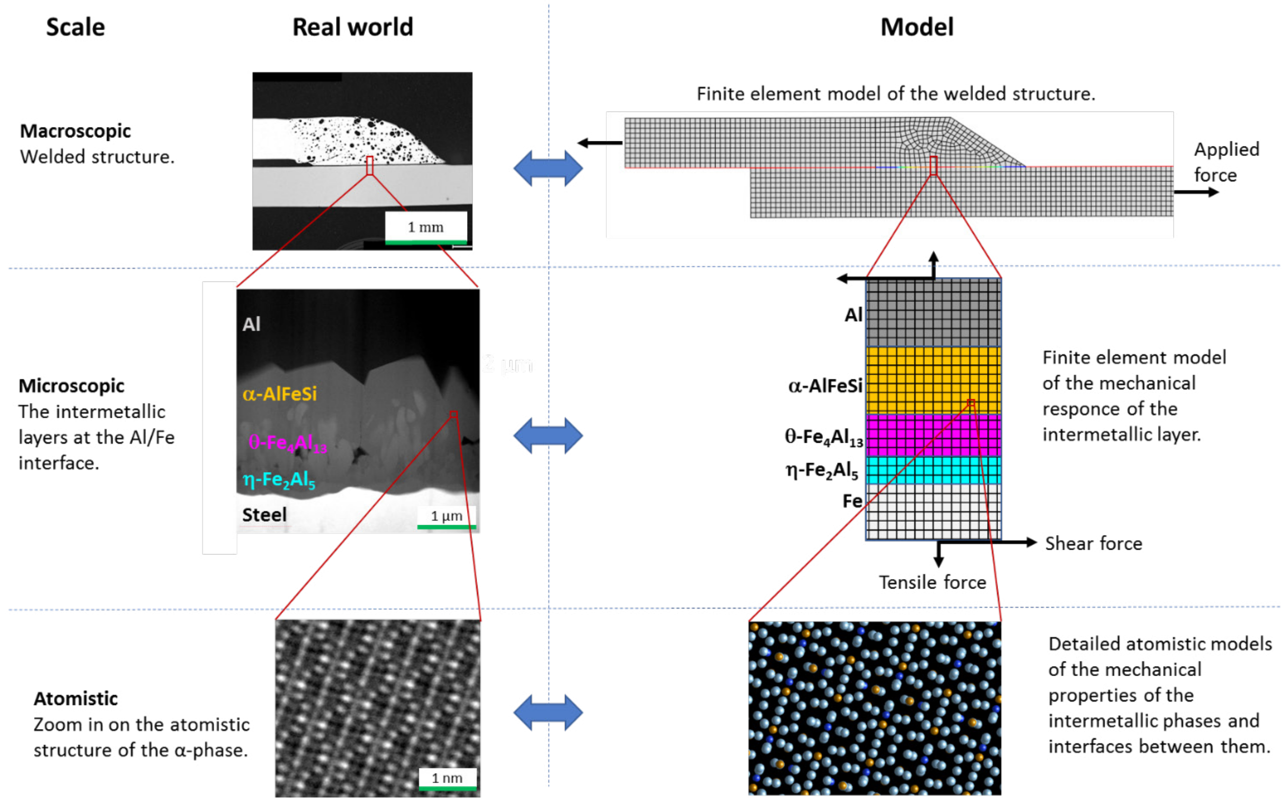

Figure 3. Conceptual illustration of the multiscale model and how it relates to the experimental observations at all scales. The experimental techniques in the left column that guide the modelling, are from the top light microscopy of the welded structure, high-angle annular dark field scanning transmission electron microscopy (HAADF-STEM) image of the intermetallic phases and an image of the α structure constructed from a large set of HAADF-STEM images combined with SmartAlign, respectively.

The microscopic model which is a continuum FE model, describes the overall mechanical properties of the aluminium/steel interface. At this scale, we start by representing the messy interface structure with a simplified layered model. However, it is possible to set up a more complex geometrical representation of the intermetallic phases if it is needed to catch the physics. The current microscopic model has a great potential to calibrate the mechanical response of the interface when it is subjected to both tensile and shear forces. It accounts for the geometrical aspects of the intermetallic phases (thickness and morphology) and their mechanical properties, (elastic constants and stress-strain behaviour) as well as the fracture properties of the interfaces between them.

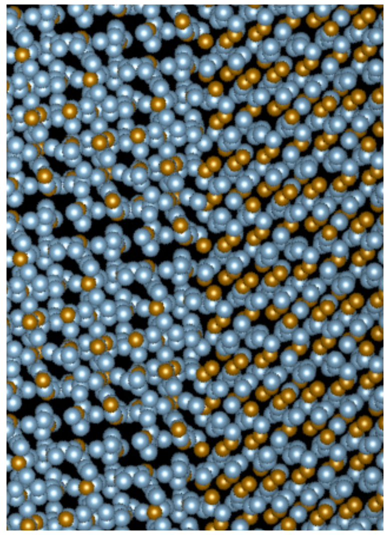

Figure 4. Atomistic interface structure between the θ and η phases.

At the atomistic scale, the elastic properties of the different intermetallic phases are calculated from first principles using density functional theory (DFT), which is a fully quantum mechanical approach. DFT is a highly accurate method, but also very computational intensive requiring access to national high-performance supercomputer facilities. Using the improved interface builder developed in SFI Manufacturing, low-strain atomistic structures of the interfaces between the intermetallic phases have been set up. From these interface structures, the work of separation and tensile properties of the interfaces can be calculated. However, since some of these interfaces are very complex, like the interface between the θ and η phases shown in Figure 4, which involves nearly one thousand atoms, we resort to molecular dynamics (MD), which is a much less computational demanding method but also less accurate. To check the accuracy of MD, it is benchmarked against DFT for some parts of the simpler interface.

Galf - Galling in aluminium forming

Galling is an unwanted process where aluminium sticks to a tool surface in a forming process. Scientifically, this process is much related to the process described above on joining different metals together. A border zone project called Galf is focusing on the galling process. The goal of this project is to "optimise coating and lubrication solutions of tool geometry and process parameters towards an innovative tool design for a more cost effective aluminium component production, allowing higher productivity by a reduction of galling". This project is currently running at a high activity level.

The innovative tool coating-lubrication solutions aimed for in Galf are expected to be of high relevance for the participating metal forming partners in SFI Manufacturing. Tribological tests are now defined, ranging from cold to hot forming, designed to mimic the most relevant conditions present at production processes. The physical tests will be linked to numerical models used in numerical simulations of the forming processes. This will result in inside information about the conditions throughout a forming operation, and enable us to define related surface contact characteristics.

The physical characterisation through advanced methods and lab instruments, such as TEM and scanning electron microscope (SEM) will become crucial in the next phase. The physical and numerical modelling activities performed in the SFI Manufacturing are of high relevance as they are linked to galling. Also, the interaction with the three PhDs working in RA1 on aluminium-steel solid state welding is important. What we aim to achieve in the SFI, we want to avoid in Galf: solid state welding of aluminium to steel surfaces. The common key is the understanding of the underlying mechanisms, and the clever utilisation of the understanding.

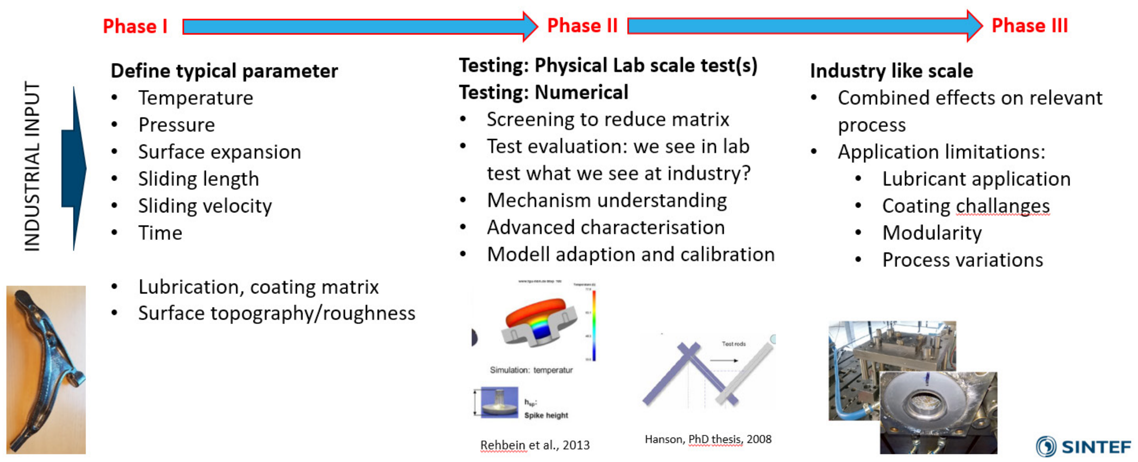

Figure 5. Test Strategy in IPN Galf illustrated in phases.

Additive manufacturing

In the last newsletter the growth of Additive Manufacturing (AM) in Norway was presented. During the last months a lot has happened in this field, and we feel it is important to summarize the news.

Wire and arc additive manufacturing (WAAM)

The WAAM technology adopts an electric arc as heat source and wire as feedstock in the AM process. WAAM is well suited to the manufacturing of medium to large scale metal components of moderate complexity as well as repair of components with high requirements of material integrity, quality and cost of manufacture. The advantages of using WAAM system instead of existing AM systems include higher deposition rates (up to 2500 cm^3/h), potentially unlimited build volume, low capital and feedstock costs, good structural integrity and a strong supply chain capability in industry. WAAM has been used to produce components in e.g. titanium, aluminium and steel. In SFI Manufacturing, the WAAM technology has been demonstrated through the PhD work of Linn Danielsen Evjemo and SINTEF, by combining cold metal transfer (CMT) welding equipment and industrial robot arms. This demonstrator is also a showpiece of cross-disciplinary research between RA1 and 2.

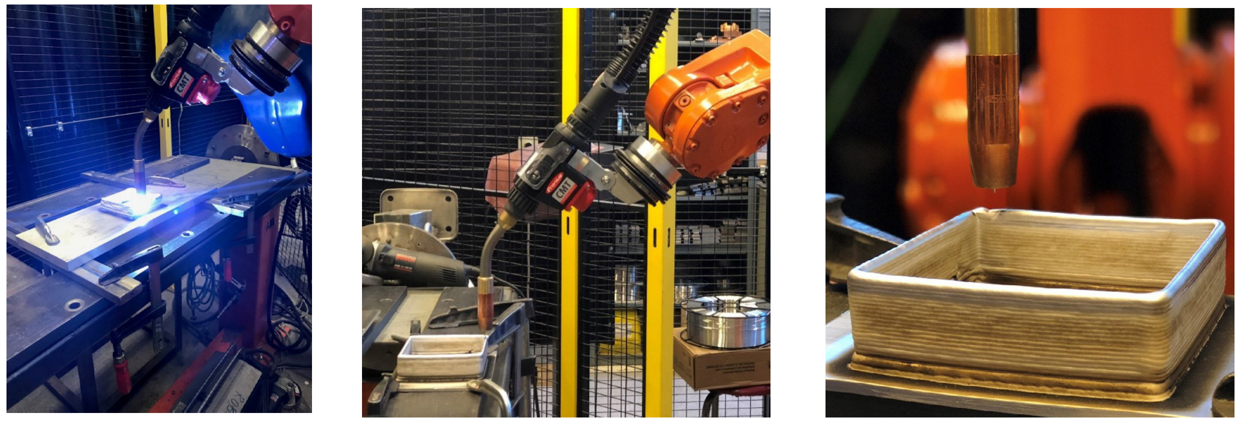

Figure 6. Wire Arc Additive Manufacturing of aluminium - making a "pet food bowl".

Infrastructure update on catapult centres and MANULAB research infrastructure

The catapult centre Manufacturing Technology at Raufoss will build up three different mini-factories. The first one will focus on the industrial use of AM, and is planned to be up and running by the end of this year (2018). The catapult centre Future Materials, managed by Elkem in Southern Norway, will focus on powder production for AM, and has ordered an atomizing unit that can produce 50-150 kg batches of spherical powder.

The infrastructure funding, MANULAB, managed by NTNU, has decided to purchase an SLM 280 with several extra packages. The most important packages include a build chamber heat package, where the chamber can be continuously heated to 550°C. Furthermore, the 250x250x300 mm machine will be able to use much smaller build platforms for testing small batches of powder and hence reducing development cost. The machine will come with a 700W Yb:YAG fiber laser system, which makes it the strongest laser based-powder bed fusion (LB-PBF) mounted laser system in Norway.

Grain structure in laser based powder bed fusion metals

The characteristics of the LB-PBF-produced microstructures are influenced by many factors, e.g. the heat input rate, material properties, cooling rate, and laser scan strategy. With advances in computing capabilities, numerical simulations that allow for extensive parametric studies incurring moderate costs become an effective tool for analysis and prediction of the microstructural evolution caused by additive manufacturing. To investigate the grain structure in metals we use electron backscatter diffraction (EBSD). EBSD is a microstructural-crystallographic characterization technique to study any crystalline or polycrystalline material. The technique involves understanding the structure, crystal orientation and phase of materials applying a SEM.

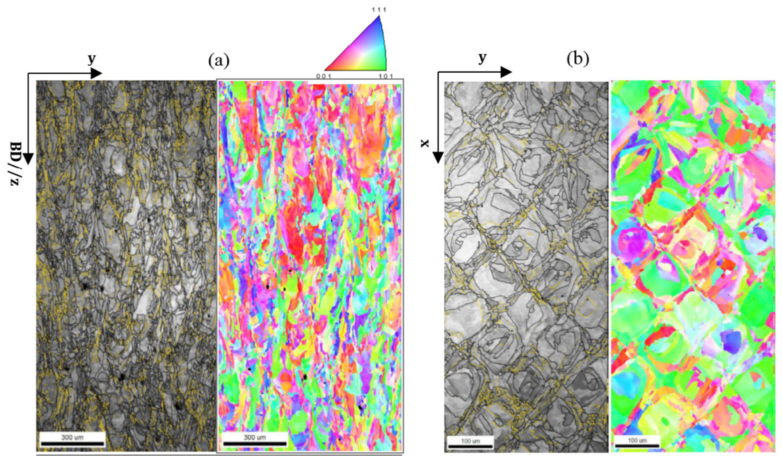

Figure 7. Grain structure in a typical laser based powder bed fusion. a) Display the build direction and b) display the build plane.

The structures shown in Figure 7 display a common grain structure in laser based powder bed fusion parts. These samples are made in 316L stainless steel and investigated in a SINTEF laboratory at Raufoss. In the build direction (BD) we can observe elongated grains due to the shape of the melt pool. This variation in microstructure illustrates the reason for anisotropic behaviour gained from the production process.

In the XY-plane, parallel to the build platform, we can clearly observe the square pattern given by the laser cross hatching, whereas the hatching distance is 105 µm. It has been concluded in recent studies that the elongated grains display an improved elongation to break along the build direction, however, the perpendicular samples often display improved tensile properties.

MKRAM activities on polymers and metals

The aim of the KPN project MKRAM (Material Knowledge for Robust Additive Manufacturing) is, in short, to understand the effective mechanical properties of parts made by powder bed fusion. This includes mapping and understanding the variation in properties related to the parts' build orientation and position in the chamber, as well as the repeatability, i.e. the variation in properties from one "build" (one processed chamber) to the next, and from machine to machine.

Based on trials with the most common polymer material for PBF, polyamide 12, we see that, with good control of the reused powder, the repeatability is good from build to build. However, the variation due to build orientation and position in the chamber may be large (see figure 8), and this information must be used when defining the layout of parts in the chamber. Furthermore, for critical parts this variation must be included as input for the FE analysis based design of new parts.

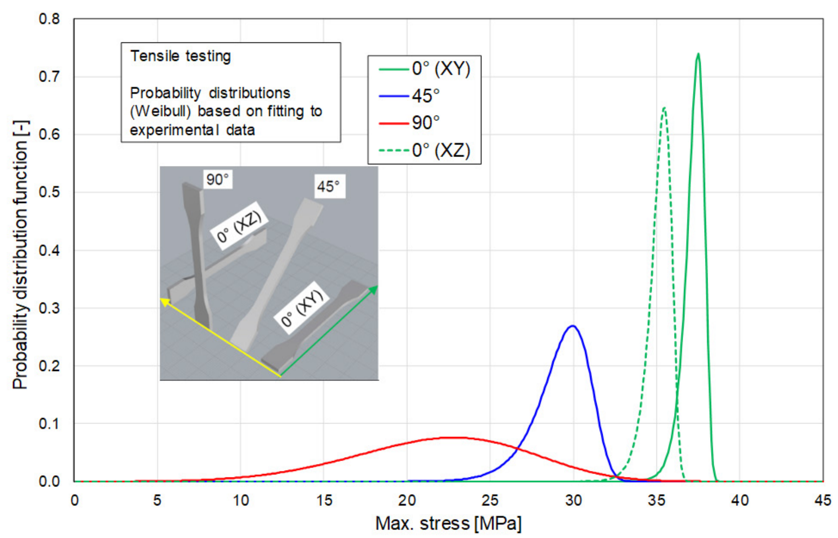

Figure 8. Probability distributions of maxiumum stress for four build orientations for polyamide 12 (90°C is perpendicular to the powder bed). The distribution for a given build orientation reflects positions in the chamber, and the weakest parts originate from certain positions near the walls of the chamber.

An upcoming activity in MKRAM will be to compare the conventional polymer PBF process (with a laser scanning over the powder bed and melting powder locally) with HP's multi jet fusion process (which "jets" an ink pattern that absorb infrared radiation, thereby selectively melting powder). Results so far indicate that the latter process induces less anisotropy.

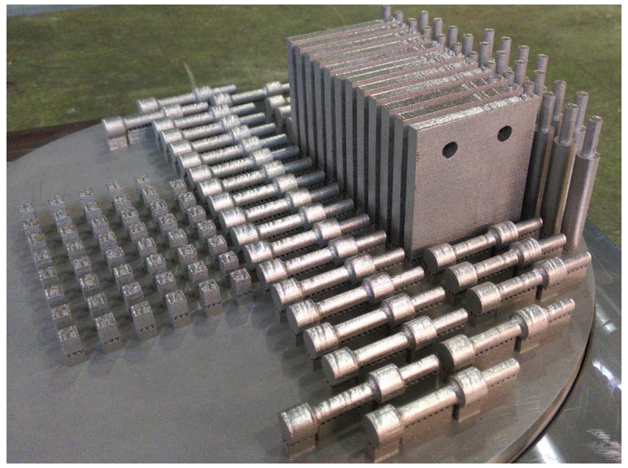

Figure 9. Haynes 282 test specimens after production. The parts are now removed from the build plate and then heat treated at 1135°C for 2 hours, 1010°C for 2 hours and 788°C at 8 hours.

In the MKRAM project we are working on robustness in AM through material knowledge and testing. MKRAM has looked at nickel-based alloys, maraging steels and aluminum alloys. For nickel-based alloys Inconel 718 is the industry standard in additive manufacturing. Together with GKN, we found that there was no AM literature on Haynes 282, a material used in several aircraft engine parts. Therefore, the project started to investigate the possibility of getting the material in powder form. After some intense searching, a supplier cooperating with Haynes was found and powder was ordered. Some months later 42 small cubes with different production parameters were produced in Trondheim.

An additional setup with more concentrated parameters building 48 more cubes, lead the project to a parameter set where material testing could be executed. At this point more optimization of parameters are needed to get the 'perfect' parameter, however, the density of the final parts was close to 100%. It was therefore decided to do more investigation of grain structure, microscopy, yield- and tensile strength. All Haynes 282 samples (Figure 9) were heat treated according to the standard heat treatment cycle given by Haynes International. Figure 10 displays the yield strength of lying (blue) and standing (yellow) samples compared at a heat treated hot-rolled plate. We see that there are minor differences in the direction of the build. Fortunately, we can conclude that the yield strength of the AM part outperforms the traditional material. However, moving to Figure 11 this is not the case. The elongation properties of the material is highly influenced by the direction of the build. The main contributor to this anisotropy is given by the grain structure in the parts. The ultimate tensile strength is also affected and is increased in the laying structures where the elongation is low.

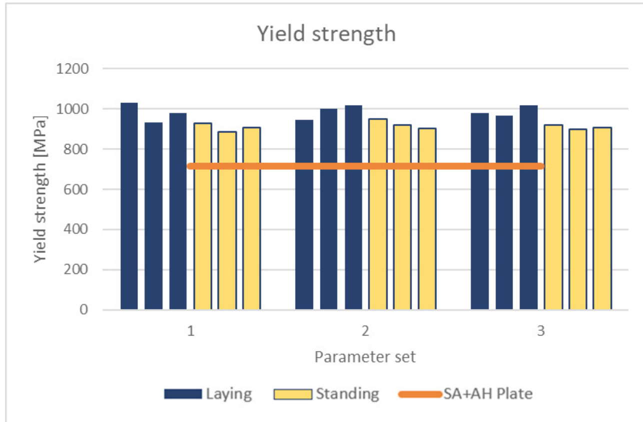

Figure 10. Laser Based Powder Bed Fusion of Ni-based alloys, so called "Superalloys". The yield strength of the additive manufactured Haynes 282 compared to a heat treated hot-rolled plate. Three samples with three different build parameters in two different directions are shown. The standing samples were constructed in the build direction and the laying samples lay along the build platform.

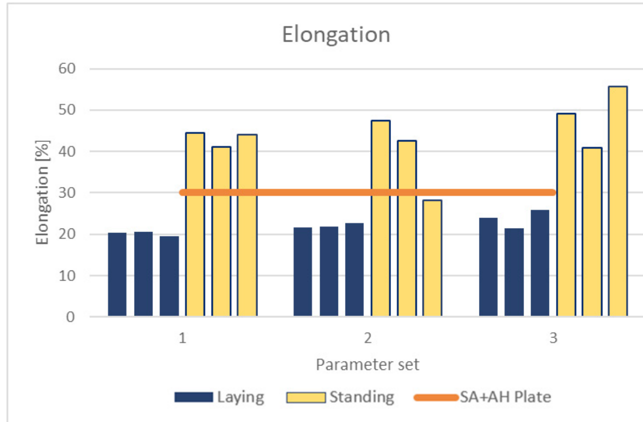

Figure 11. The elongation results from the Haynes 282 tensile tests in Figure 9. This is compared to a solution annealed and age hardened hot-rolled plate.

In conclusion, we have seen very positive results producing just a few sample sets of Haynes 282. Even though this is just scratching the surface of all the properties one should have control of in highly critical parts like In aerospace.

Industrial multi-material manufacturing challenges involving polymeric materials

The industrial partners of the SFI Manufacturing are involved in a wide range of manufacturing processes. These processes bring their own unique challenges, which may be investigated within the SFI Manufacturing in order to share the learning within the SFI platform. One challenge which is currently being investigated involves the adhesion between a metal component and a polymer component that are combined by insert moulding - injection moulding of the polymer melt onto the surface of a metal insert. Adhesion between polymers and metals is not trivial and is strongly affected by the quality of the surfaces in contact. On the metal surface, adhesive bonding typically occurs on the metal oxide surface layer, which varies from one alloy to the next.

On the polymer surface, chemical side groups can be added to the polymer molecules to make strong bonds to the opposite surface. In addition, factors such as chemical pre-treatment (primers), surface cleanliness and topography all influence performance. The process under investigation uses injection moulding of a polymer melt on the metal surface, and so the injection rate, temperature and pressure all influence the polymer morphology which in turn affects factors such as shrinkage and warping. In order to achieve a good interface between the polymer and metal components, injection parameters should be optimised to minimise shrinkage of the cooling polymer away from the surface of the metal component.

Another challenge being investigated is the optimisation of adhesion to elastomer surfaces. Many elastomers are used in applications that demand the combination of long term elastic properties with chemical and thermal resistance. These challenges are often best met with crosslinked elastomers, which have a permanent chemical network structure that resists permanent mechanical deformation and allows the elastomers to recover their original shape after loading. These elastomer parts may need to be adhesively bonded to different substrates to be held in position, but many elastomers lack suitable surface chemistry required to give strong chemical bonding to an adhesive. A range of techniques are available to change the surface chemistry of elastomers in order to improve bond strength. Examples of these techniques include high energy surface treatments (such as plasma – see Figure 12), chemical grafting highly reactive surface chemistries, or copolymerisation of the elastomer molecules to include reactive groups that can form chemical bonds with adhesives.

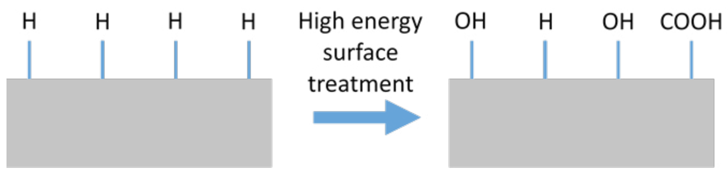

Figure 12. An example of how a high energy surface treatment such as plasma treatment in an oxygen environment may alter the surface chemistry of a polymer substrate. In this example, hydrogen atoms on the polymer surface are replaced by more reactive groups such as hydroxy- (OH) and carboxyl- (COOH) chemistries, which may lead to the formation of stronger adhesive bonds on this modified surface.

Adhesive bonding of fibre reinforced composites

Fibre reinforced composites are used in many applications due to their combination of high mechanical properties and low density. These materials typically comprise strong, stiff fibres such as carbon or glass fibre, held together and encased in a polymer matrix. Therefore, when bonding fibre reinforced composite materials to other materials, it is the surface of this polymer matrix which dictates which bonding technologies may be used and controls bond performance. In many typical high performance fibre reinforced composites, the matrix is thermosetting, which means that the matrix cannot melt and so welding processes cannot be used. Mechanical bonding methods such as riveting are not ideal since they lead to perforation of the reinforcing fibres. Therefore, fibre reinforced composites are often joined using adhesive techniques.

The analysis and optimisation of adhesive bonding of fibre reinforced composites is a main research focus of IPN project SamKomp - Joining of Composite Structures (with Brødrene Aa as responsible company). In this project, the performance of various adhesively bonded composite laminates is being assessed by stressing adhesive joints to failure and analysing the location of failure within the bond. Figure 13 shows a typical test set-up used to test adhesively bonded composite laminates, together with two different failure modes. In the middle image of Figure 13, failure has occurred at the interface between the adhesive and surface of the composite substrate, suggesting suboptimal bond performance. In the right image of Figure 13, failure has occurred by delamination (separation) within the composite substrate. Therefore in this case, the adhesive bond was strong enough that the composite failed before the adhesive bond, indicating a very good bond performance.

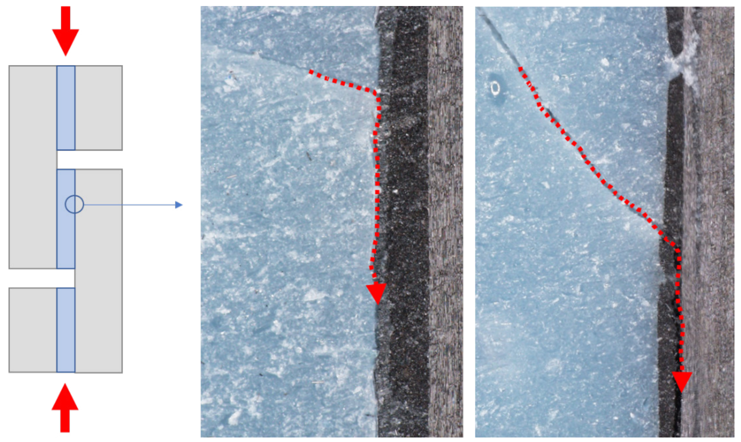

Figure 13. Mechanical testing of an adhesively bonded interface using a compression shear test. Left Image: Schematic of the compression shear test specimen, which is loaded in compression. Middle Image: Optical microscope image of an interfacial failure mode - the red arrow shows the path of a crack formed during mechanical loading. The crack travels through the adhesive layer to the interface between the adhesive (blue) and the substrate (black), this is an adhesive failure on the surface of the substrate. Right Image: Optical microscope image of an alternative failure mode - the red arrow shows the path of a crack formed during mechanical loading, but in this failure mode, the crack travels past the adhesive layer into the top layers of the substrate.

PhD progress report on 2K injection moulding of TPE

In her PhD project, Anna-Maria Persson investigates the mechanical properties of thermoplastic elastomers for injection moulding. It specifically explores the properties relevant for overmoulded parts in sealing applications. (The overmoulding process is also called two-component injection moulding.) The sealing application makes certain aspects of the mechanical properties more important than others, notably the long-term evolution of elastic properties and the variation of properties with temperature. The project aims to answer questions such as: How well will a thermoplastic material/part perform over time and how do we work with the material's strong temperature dependence. Moreover, what are the confidence levels for prediction of part performance under a certain set of conditions? It is also important to analyse which property dependencies that are essential to consider in this application, and how the test methods should be refined to gather the most knowledge out of the input resources. Sealing performance is a rather complicated sum of the material, process and design that interact with a part's projected environment and physical loading. This is especially relevant in material replacement scenarios, in which one benefits from being conscious about the inherent fundamental differences

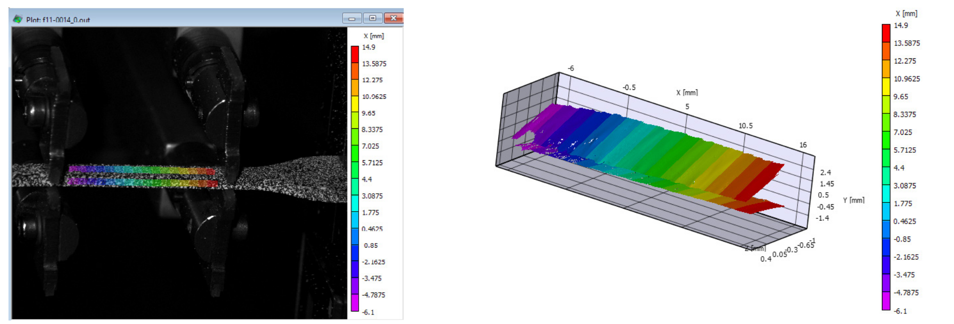

Figure 14. Mapping of longitudinal displacement on tensile specimen. a) Result plot on one of the stereo images, overlaid on a photo of the specimen during testing. Red colours indicate larger displacement. b) The use of three-dimensional displacement mapping allows the displacements to be captured on two sides of the specimen, giving an indirect volume displacement map. c) Anna-Maria Persson in front of the universal testing machine from Zwick, equipped with a temperate chamber.

Our approach began with methodical measurements of stress and strain in tensile and compression, and it will continue to other stress conditions. Accuracy is sought by employing optical measurements methods, which map deformations over a surface and indirectly over a volume. Upon this foundation, the understanding of the nature of the mechanical response of thermoplastic elastomers is characterized and improved. These data, together with data from additional experiments that characterize the development of properties with time and temperature, fuel the computerized prediction regarding material performance. There is also need for control and understanding of the interface inside the overmoulded part. Amongst other activities, customized testing methods to validate numerical models are explored. These will include to test application-like demo specimens and submitting material samples to coupled thermo-mechanical loading. The second major ongoing activity is planning two-component sample production in another facility together with the enthusiastic R&D engineers at Kongsberg Automotive Raufoss.

Other adhesion challenges

Vitrimers - One possible road to reversible glue

So called vitrimers are a recently developed group of polymer materials containing reactive chemical groups that bridge neighbouring molecules to form crosslinked networks at low temperatures. This crosslinking means that the materials are typically glassy and stiff at low temperatures. However, unlike conventional chemically crosslinked polymers (thermosets), the crosslinks in vitrimers can temporarily separate when heated, allowing the polymer to flow like a liquid. Upon re-cooling, the crosslinking networks form again in new locations, locking the material in a new shape. This thermally induced switching behaviour makes vitrimers interesting for different applications such as thermally reversible adhesives and self repairing materials. Research is underway at SINTEF to explore new chemistries and develop application areas.

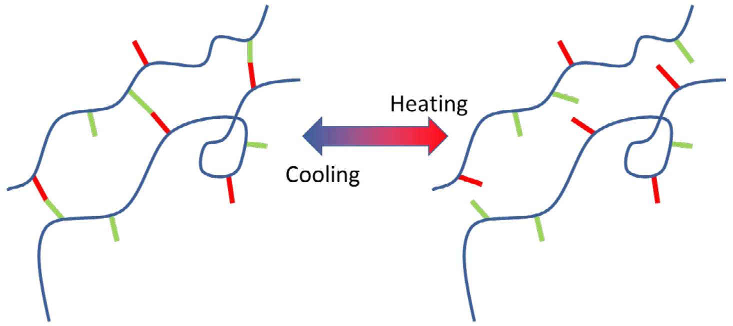

Figure 15. Neighbouring polymer molecules can be designed to contain reactive chemical groups (red and green) which combine to form chemical crosslinks. These crosslinks form a stiff network (left image), giving a glassy structure which resists large deformation. When heated (right image), these crosslinks open, and the reactive chemical groups are free to bond to new partners in other locations. This freedom to form and reform crosslinking bonds when heated makes the material flow like a liquid when hot, but rigid and load bearing when cold.

Atomistic modelling of the interface between a metal and an adhesive

Understanding the chemical reactions involved in the interface between bonded surfaces is key to predicting bond performance. Recent work at SINTEF has developed models to simulate atomic scale behaviour and estimate bonding energies between surfaces with different atomic configurations. Although atomic forces are just one of many contributing factors in adhesive bond performance, these models could be further developed in the future as a tool to screen combinations of adhesives and substrates, and predict the effects of surface contaminations such as adsorbed water layers or oxide or phosphate layers on a metal surface.

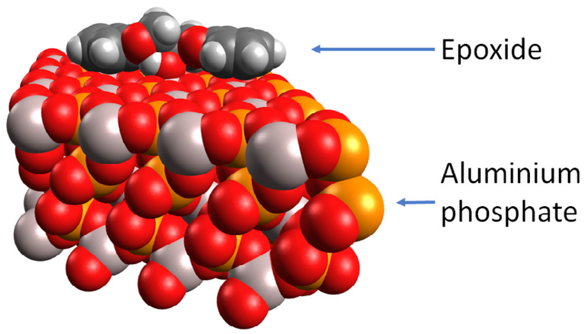

Figure 16. An atomic scale model of a representative volume element showing how an aluminium phosphate substrate and an epoxide are predicted to interact. Aluminium phosphate is typically present after the surface treatment of aluminium before adhesive bonding.

Relevant "border zone" projects

SPETT - Injection moulded solutions for primary and secondary seals in couplings

2016 - 2020

Partners: Kongsberg Automotive, Raufoss Water & Gas, HV Plast, SINTEF Industry, SINTEF Raufoss Manufacturing

The project's primary goal is to develop material and design solutions making it possible to integrate primary and secondary seals in next generation couplings using two-component injection moulding. R&D challenge: To be able to mould seals by two-component injection moulding instead of mounting o-ring seals the traditional way. It is also relevant to mould seals onto brass couplings using injection moulding.

SamKomp - Joining of composite structures

2017 - 2020

Partners: Brødrene Aa, Mundal Båt, Palfinger Marine Safety, Hydrolift, Brimer, CSUB, Polynt Composites Norway, DIAB Norge, Hans Clausen, FiReCo, Maritim Engineering, SINTEF Industry

The main goal is to establish systematized knowledge with the aim of developing new solutions for joining and fastening structures in Fiber Reinforced Composite (FRP) materials: Solutions that are safer and more reliable as well as cost-saving in relation to today's production technology. R&D challenges are e.g. related to material selection and joining method (gluing or secondary lamination), production processes of laminates and panels, and design of joints.

OPTIMALS - Optimal design and production of lightweight and high-performance aluminium-steel structural components

2017 - 2020

Partners: Benteler Automotive, Hydro Aluminium, HyBond, SINTEF Industry

The main goal of the OPTIMALS project is to enable multi-material solutions for high-performance aluminium-steel structural components with a total reduction of weight and manufacturing cost. The project will aim to achieve a measurable weight reduction (5-10%) for 2-3 automotive components while keeping or improving specific structural requirements.

GALF - Galling in aluminium forming

2017 - 2020

Partners: Raufoss Technology (owner), SINTEF Industry, SINTEF Raufos Manufacuring

The main objective of the project is to optimize coating and lubrication solutions used at aluminium forming processes to reduce galling: the adhesion of aluminium to the forming tool. The solutions will contribute to a more cost-effective production, allowing higher productivity. To reach the project goals, activities and results from the three PhDs working in the SFI Manufacturing in RA1 on aluminium-steel solid state welding are important to consider. What we aim to achieve in the SFI, we want to avoid in Galf: solid state welding of aluminium to steel surfaces. The common key is the understanding of the underlying mechanisms, and the clever utilisation of the understanding.

MKRAM - Material knowledge for robust additive manufacturing

2016 - 2019

Partners: GKN Aerospace Norway, Kongsberg Automotive, Nammo Raufoss, OM BE Plast, Sandvik Teeness, SINTEF Industry, SINTEF Raufoss Manufacturing

The aim of the MKRAM project is, in short, to understand the effective material properties of parts made by AM processes mentioned above. This includes mapping and understanding the repeatability, i.e. the variation in properties from part to part, from machine to machine, and with different materials and powders. There are several challenges related to AM of structural parts, i.e. mechanically loaded parts.

NextMoldMaker - Added value through establishing a value chain for producing mold tools with additive manufacturing

2018 - 2021 - Delivered project proposal

Partners: Skriverform, IV group, Hexagon Ragasco, Kongsberg Automotive, HV Plast, Tronrud Engineering, NAM, NTNU MTP, SINTEF Industry and SINTEF Raufoss Manufacturing

The main objective of the NMM project is to establish a working value chain in Norway for the production of optimized tools through utilizing additive manufacturing. Previous results have shown that powder bed fusion is a hot candidate for cooling and venting optimization, but there is no working value chain in place to produce the tools. Furthermore, it needs to be investigated if DED has a future in repairing and improving tool surfaces and in multi-material tooling.

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