manufacturing

www.sfimanufacturing.no

Newsletter #7

Date: 28th of March 2019
Research Area 1: Multi-Material Products and Processes

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 centre. This issue of the newsletter focuses on research area 1: High structural efficiency products based on multi-materials with robust and adaptive manufacturing processes.

In this issue:

- About the research area
- Update on RA1
- Introduction to the HYB process
- Short update on RA3

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

Multi-Material Products and Processes

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.

Update on RA1

WP1.1 – Additive Manufacturing

Multi-material additive manufacturing

Additive manufacturing (AM) has attracted extensive attention in the SFI Manufacturing consortium. AM is regarded as one of the "game-changing" technologies for future production of multi-material products, due to its great potential to achieve flexibility and design freedom. However, the development of large thermal gradients during the building process results in AM parts with significant residual stresses, which will have potential impact on the mechanical performance, localized deformation and structural integrity of the parts. The list of process parameters is long and complex. Residual stresses build up is affected by many process parameters, e.g., part geometry and size, build strategy, thermal characteristic of feedstock, melt pool size etc.

The growing importance of AM technologies in industry calls for a concentrated, systematic effort to understand the effect of AM process parameters on residual stress development and eventually control or even mitigate residual stresses in AM parts. Hence, the most relevant parameters must be established and utilized for modelling. The consortium is therefore planning to start a PhD-thesis called: "Residual stresses in additive manufacturing of multi-material metallic components". Furthermore, the consortium is planning to get a Postdoc with the work title: "Interface physics in metal additive manufacturing of multi-material products". Both these candidates will be important to develop new knowledge on this topic. *Researchers Vegard Brøtan and Xiaobo Ren would like to call out for industrial wishes when it comes to material combinations and applications. We believe the industry is best at finding the proper material-direction for the studies.*

Aluminium

The first parts made by the powder bed machine in Trondheim were made in AlSi10Mg. The material quality was low with a density around 97,5% and low ductility at approximately 2% elongation to break. Since then, several students have done their master thesis on AlSi10Mg production in that specific Laser Powder Bed Fusion machine In Trondheim. This period has shown that an Argon atmosphere is preferable compared to Nitrogen. It has also been shown that heating of the build platform is crucial to the quality of the parts, as the parts have much less inherent stress and porosity.

Furthermore, through an international study, we have learned and tested that a pre-scan of each layer with 50W laser heating reduces the amount of hydrogen and moisture. In addition, other studies have shown that special scan strategies can be of further improvement. A recent publication on these local tests, displays a relative density of 99,68% and more than 10% elongation to break. This is a good result on an international scale. However, we believe that it can be done even better. The last publication does not fully conclude on an optimal build strategy, as the optimal value in the study was at the outer region of the test parameters. Figure 1 displays two different test samples from the study. The consortium has also started to look into nano-particle doping of aluminium powders to achieve even better results.

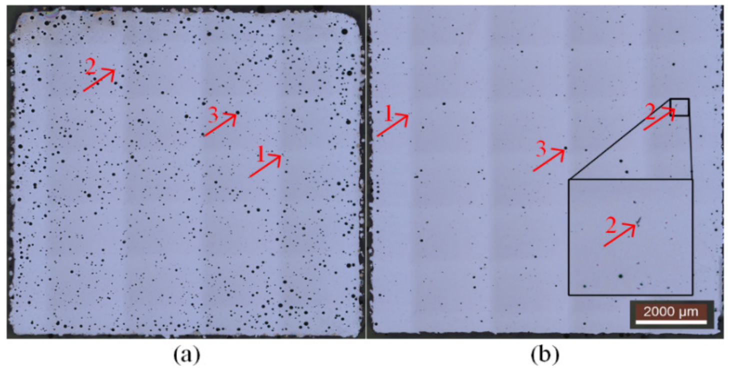


Figure 1. Optical microscopy of two test specimens. The arrows indicate pore categories: 1) metallurgical pores, 2) disrupted oxides, 3) large pores. Inset in (b) is an enlarged view of a disrupted oxide.

Directed Energy Deposition

PhD student Linn Danielsen Evjemo is contributing to WP1.1 with her work on robotic control for complex DED-parts. First, she has mastered smooth transitions as seen in Figure 2. Secondly, she has been working on parts with intersections and overlapping sections. In transitional sections and thin features, one is often required to change the shape of the part to enable building the part in DED. This is a matter of route planning and process understanding. However, unwanted effects may occur mid-build, which can cause defects or even crashes. It will therefore be important to have real time monitoring of the build process. The next steps should be to take advantage of the freedom in orientation introduced by the robot in order to build structures with overhang, as well as designing control algorithms to correct for geometrical deviations during production.

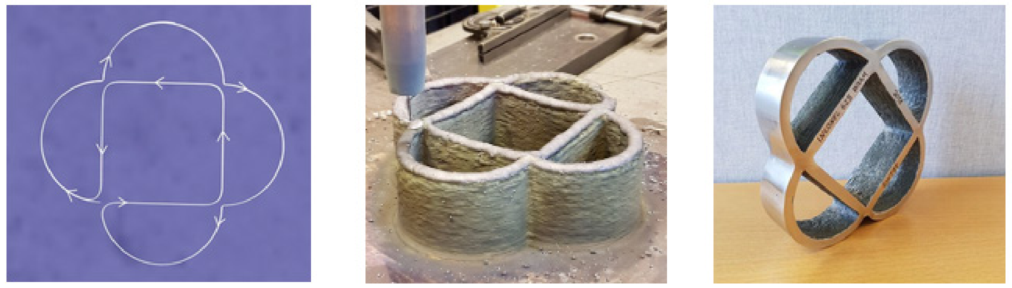


Figure 2. Here we can see the path for the weld in order to avoid actual crossings within each layer, and the final metal structure before and after processing. The dimensions are approximately 16 x 16 cm2.

WP1.2 – Multi-Material Products of Dissimilar Metallic Materials

For MMP's of dissimilar metallic materials, joining is a key enabling technology for achieving high-performance products. In SFI Manufacturing, joining aluminium to steel has been a focus area due to great scientific and industrial interest. Several joining methods have been investigated, and we have identified three methods for deep study: Cold Roll Bonding (CRB), Hybrid Metal Extrusion & Bonding (HYB) and Cold Metal Transfer (CMT) welding. CRB and HYB are solid-state joining processes, while CMT is a fusion-based method. For all these joining methods, the formation of brittle intermetallic compounds (IMC) is a key challenge.

Our research aims to better understand the mechanisms of IMC at macro-, meso- and micro-scale, as well as nano-scale. The link between different length scales needs to be established to obtain a full picture of the phenomenon (link to WP1.4). Three PhD students are involved in the research of joining aluminium to steel, each with a different focus. 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 Muhammad 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 "hand-shaking region" to bridge the knowledge generated at different scales using advanced material characterization tools. Under a multiscale framework, the information and knowledge flow between different scales will help us to solve the key challenge in joining aluminium to steel.

Based upon the generic research in SFI Manufacturing, several spin-off innovation projects (IPN's) have been generated, which significantly accelerate the transfer of basic research to industrial applications through well-defined industrial case studies. There are two good examples to mention when it comes to the benefits of the synergy between SFI Manufacturing and spin-off projects. In the IPN Optimals project, the objective is to join aluminium and steel in order to produce high-performance hybrid automotive structural components, e.g. aluminium-steel crash management system. In contrast to joining aluminium to steel, galling is an un-wanted process where aluminium sticks to tool surface in a forming process. How to reduce galling through better understanding of "sticking" is the focus in IPN Galf.

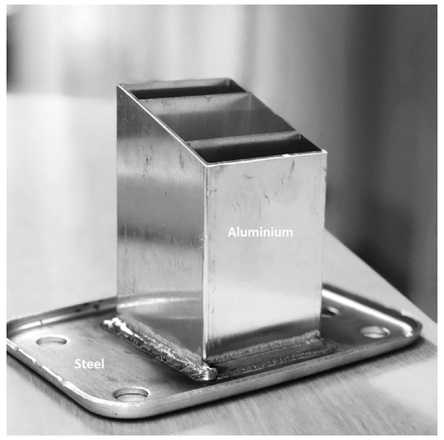


Figure 3. Aluminium crash box was joined to a steel back plate using the CMT process in the IPN Optimals project. Two aluminium-steel components were welded to an aluminium bumper beam to form a crash management system.

Finalizing my PhD, what have we learned – Siri Marthe Arbo

As I am now in the process of finishing my PhD, I thought I would use my last post in the SFI newsletter to summarize some of our work and highlight some of the challenges remaining. During my PhD work we have investigated the possibility of joining steel and aluminium by roll bonding. We established a rolling process and a post-rolling analysis routine to make sure that the composites we produced were comparable and reproducible. We have studied the effect of different process parameters and how to best combine heat treatments with the rolling process, which is of special importance when working with aluminium alloys in the 6xxx series. It is common knowledge that Fe-Al intermetallic phases will form, either during joining or during the post-joining heat treatments, along the steel and aluminium interface and that this intermetallic phase layer will have negative effects on the mechanical properties of the joints. Therefore, it is of high interest to investigate the effect of adding a metal interlayer between the steel and aluminium base metals, in an attempt to avoid the formation of the brittle and unwanted Fe-Al intermetallic phases.

Through a comprehensive study together with PhD student Tina Bergh, we showed that nickel-foil can be used as a metal interlayer when performing roll bonding of steel and aluminium. The nickel-interlayer successfully prevented the formation of the Fe-Al intermetallic phases. Through post-rolling heat treatments, a significant increase in bond strength was achieved, while an intermetallic layer formed along the aluminium-nickel interface. During bond strength measurements, the fracture occurred in the Al-Ni intermetallic phase layer, however a decrease in bond strength was not observed until the layer thickness reached 5 µm, illustrated in Figure 4. These findings encourage further studies on the use of nickel as an interlayer during joining of other steel-aluminium combinations.

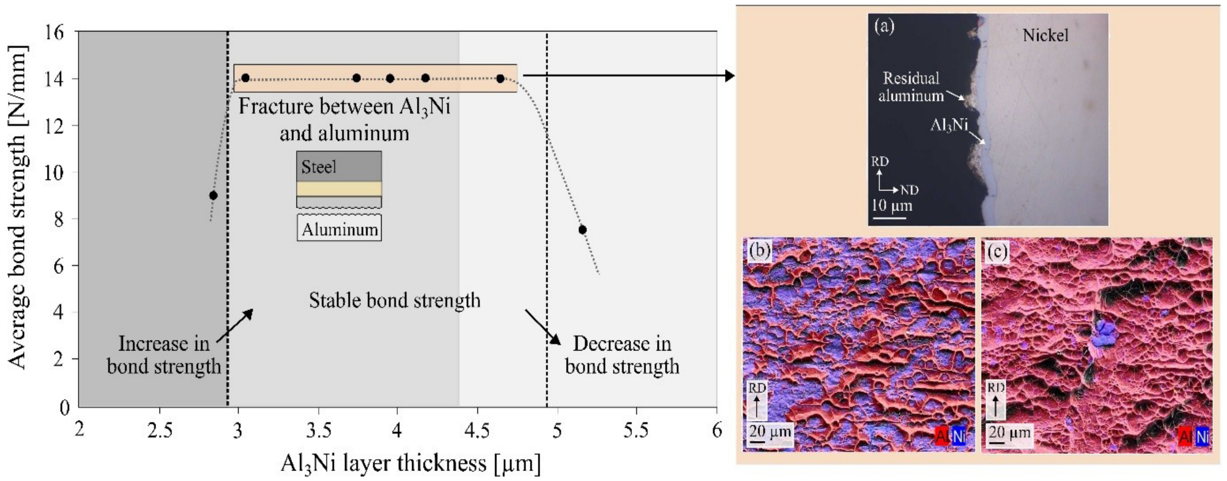


Figure 4. Showing the relationship between the thickness of the Al-Ni intermetallic phase layer and the achieved bond strength after post-rolling heat treatment at 450°C for one and two hours. A ductile fracture in the aluminium layer was observed in the joints with highest strength as showed in the images on top.

There are several different types of steels and aluminium alloys that are used in various industrial applications. Therefore, it is important to understand how the different alloying elements influence the formation and growth of the Fe-Al intermetallic phases. A good amount of literature is already found on the effect of different alloying elements on the intermetallic phase layer growth. However, the findings have not been structured and thoroughly compared. Therefore, I have dedicated the final part of my thesis to investigate the formation and growth of Fe-Al intermetallic phases in several different material combinations.

The different material combinations are joined, and heat treated under the same conditions, thus direct comparisons can be made between them, clearly showing the effect of the alloying elements on the intermetallic phase formation. The interface between the different steel and aluminium alloys after heat treatment at 500°C are shown in the Figure 5, where already clear differences in thickness and characteristics can be observed. I hope that this thorough and structured investigation on the intermetallic phase formation and growth can in the future be used as a tool, to help identify process windows where dissimilar metal joints with a high bond strength can be produced, and where the Fe-Al intermetallic phase layer thickness is kept to a minimum.

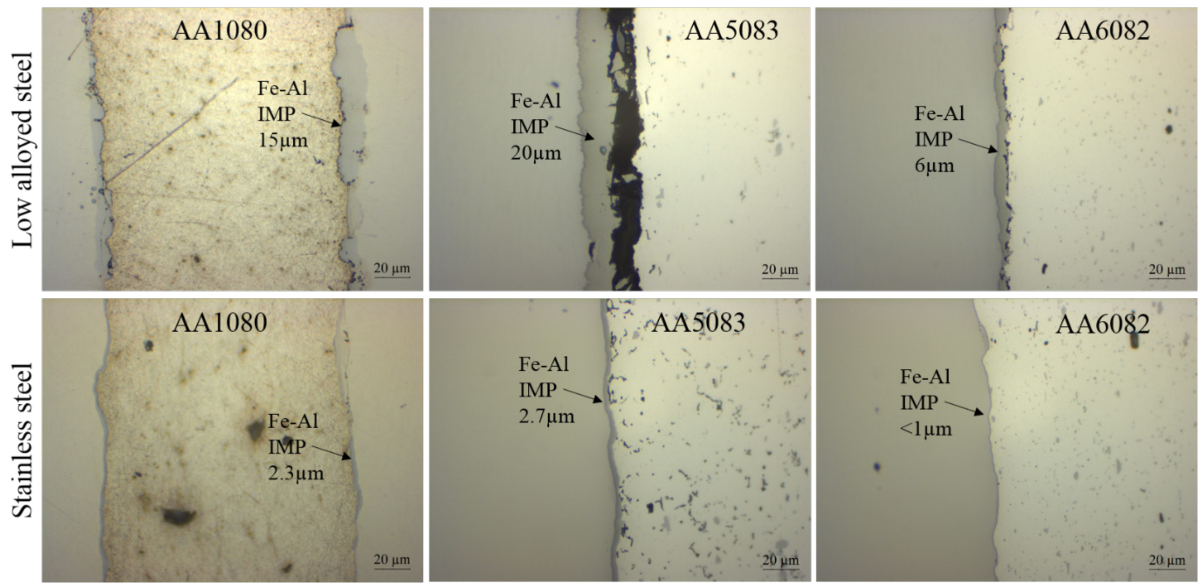


Figure 5. Images showing the cross-sections of the different material combinations after heat treatment at 500°C for one hour. The average intermetallic layer thickness is stated in the images, clearly showing how the different alloying elements influences the intermetallic layer growth rate.

Intermetallic compounds in aluminium-steel joints characterised by Transmission Electron Microscopy – Tina Bergh

The focus of my project is to use advanced electron microscopy techniques, primarily transmission electron microscopy (TEM) techniques, to characterise aluminium-steel joints from the micrometre scale to atomic scale. Such characterisation is important for understanding how the joining parameters influence the joints and to explain the mechanical properties of these joints. Intermetallic compounds typically form at the aluminium-steel interface, and first and foremost, we are interested in characterising these phases. For this, I mainly use spectroscopy techniques to determine the elemental compositions, together with different electron diffraction techniques to identify the crystal structures.

Recently, I have looked at aluminium-steel laminated roll bonded composites in collaboration with Siri Marthe Arbo. In this study, nickel interlayers were placed between the aluminium and steel sheets, so that the brittle Al-Fe(-Si) phases were avoided entirely. At the nickel-aluminium interface, a layer of mainly Al_3Ni formed after heat treatment at 450°C. Interestingly, this layer developed into a layer of Al_3Ni and Al_3Ni_2 after heat treatment at 500°C and 550°C. The microstructure of these phases can be seen in Figure 6. We are planning further TEM studies to better understand the Al-Ni phase formation upon heating.

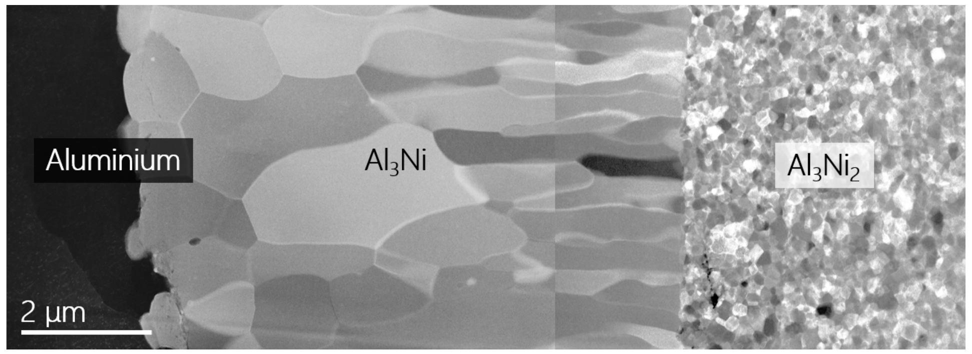
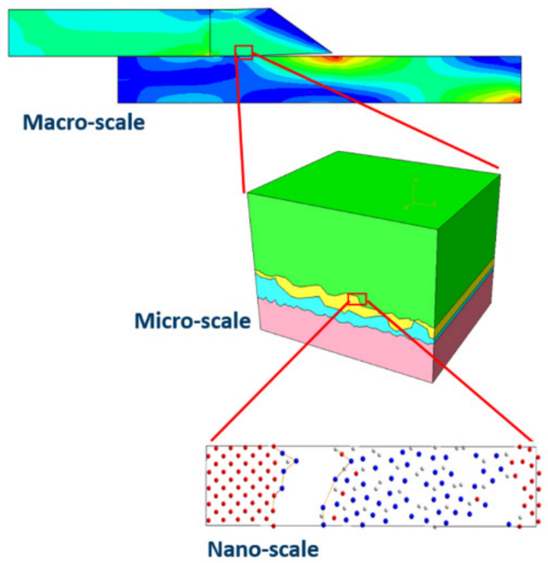


Figure 6. Bright field scanning TEM image showing the microstructure of Al_3Ni and Al_3Ni_2 that have formed at the Al-Ni interface in a cold roll bonded aluminium-steel laminated composite with nickel interlayers after post-rolling heat treatment at 550°C for one hour.

A main goal this year is to characterise an aluminium-steel joint produced by hybrid metal extrusion and bonding (HYB), which is a promising joining method patented by HyBond, a partner in SFI Manufacturing. The TEM results so far show that there is only a thin intermetallic compound layer at the interface that consists of Al-Fe-Si nanocrystals that are typically 20-40 nm thick. Ongoing studies focus on further characterising the phases at the interface, and also the different phases present in the aluminium alloy prior to joining. Electron diffraction is crucial in this work, and I am also working on methods to analyse big electron diffraction datasets automatically with different python functionalities. In addition, I am characterising an aluminium-steel joint made by cold metal transfer where three inter-metallic compounds α-Al-Si-Fe-Mn, Fe_4Al_{13} and Fe_2Al_5 have formed at the aluminium-steel interface. The focus for this study is now to investigate crystal orientations, since this is important for modelling work, e.g. to set up realistic interface models for the density functional theory (DFT) studies that is Muhammad Zeeshan Khalid working on.



Multi-scale modelling

In SFI Manufacturing, we aim to establish a multi-scale modelling framework to better understand the boning mechanisms of aluminium-steel joints. The effect of the intermetallic layer (thickness, composition and geo-metrical distribution) on the boning strength has been a focus area.

Figure 7. Illustration of multi-scale modelling framework. At the macro-scale, the intermetallic layer is represented by a cohesive zone model implemented in finite element model. At the micro-scale, the local response of the interface including the thickness, composition and geometrical distribution of different phases are models using a finite element. At the nano-scale, elastic properties of each inter-metallic compound is determined by density functional theory (DFT) calculations This work is part of the PhD-work of Muhammad Zeeshan Khalid.

Mechanical joining – A novel joining concept with one-sided accessibility

Mechanical fastening is considered as a promising technique to enable joining of multi-material products. However, most of the state-of-the-art mechanical joining methods today require access to both sides of the assembly, which limit the design flexibility. Assembling methods with one-sided accessibility were invented to overcome these challenges. However, even with these joining methods, free spaces from both sides of workpieces are still required for the joining to be performed, see Figure 8. This reduces potentially design freedom, as in the configuration, for example, when a thin plate (top plate) is to be joined to a thick plate (bottom plate) with no access and no free space from the bottom surface (see Figure 8A).

To tackle these limitations with current assembling methods, SINTEF is trying to develop and demonstrate the feasibility of a joining concept with only one-sided accessibility and without any free space from the bottom workpiece. This joining concept with its simplicity and its advantages will potentially open up for new opportunities in design of light-weight structures for various applications (see Figure 8B for some potential industrial applications).

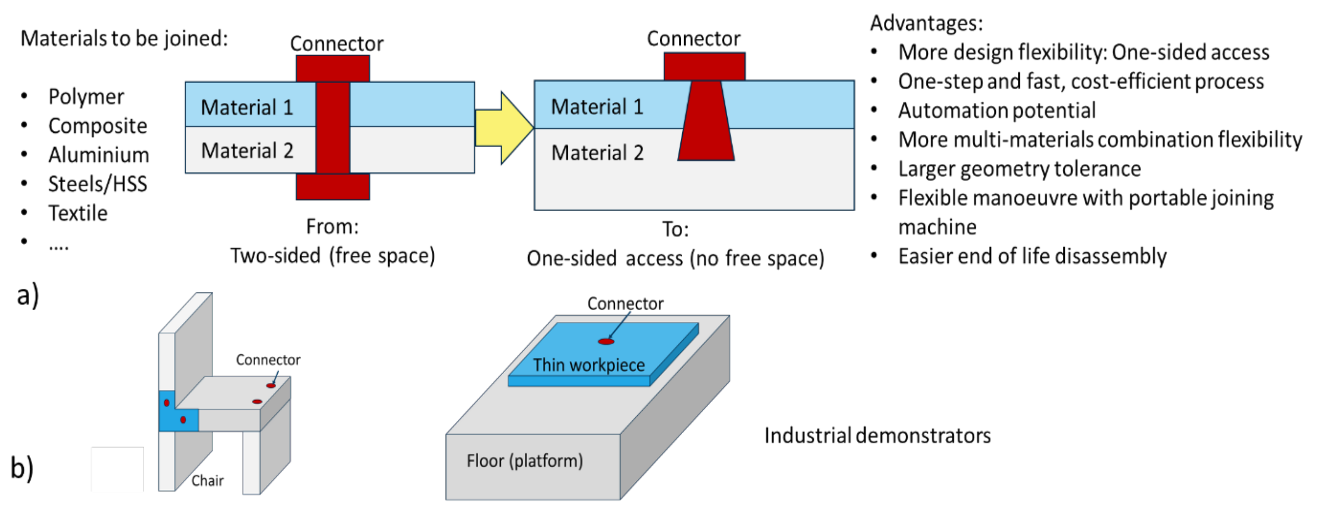


Figure 8. A: Illustration of idea, from two-sided free space joining (left figure) to fully one-sided accessible joining. B: Illustration of some potential industrial applications.

WP1.3 – Multi-Material Products containing Polymer Based Materials

New additive manufacturing capability at SINTEF Industry in Oslo

The Polymer and Composite Materials group in SINTEF Industry in Oslo has received their new Hydra additive manufacturing R&D platform from manufacturer HyRel (see Figure 9). This R&D platform combines different manufacturing techniques in one machine, and can combine up to five materials in one print job (to give a single part in one print job using multiple materials). The Hydra uses head modules which fits into any of the five positions and allows the versatility to perform several different manu. facturing operations. Examples of manufacturing processes are:

- Filament deposition: A common, easy to use and low cost additive manufacturing technique uses plastic filaments (with a typical filament diameter of 1,75 mm). The solid plastic filament is taken from a spool and melted by the head module to deposit polymer melt in a layer by layer structure to build a 3D shape. A range of filament head modules are available to enable processing different polymer filaments from low melting temperature thermoplastic elastomer to high melting temperature polymers.
- Extrusion deposition: Head modules are also available for the extrusion of liquids, pastes or slurries. The R&D platform can also accommodate multiple liquids such as two-component thermosetting polymers. The extrusion deposition system may also be used to deposit adhesives to controllably and reproducibly distribute adhesive systems prior to an adhesive bonding process.
- Post processing: Modular routers are available to perform finishing, grinding or polishing immediately following the additive manufacturing process.
- Analysis: Analytical equipment can be mounted on one of the free positions to enable in-process microscopy to continuously monitor build quality and surface finish.

While not intended for part manufacturing, this platform will enable research into a range of different AM processes in SFI Manufacturing and allow the production of prototypes and demonstrators. The build volume of 40x30x25cm is housed within a heatable chamber. The Hydra platform complements the existing polymer powder bed fusion (SLS) and various stereolithography (SLA) additive manufacturing machines in Oslo.

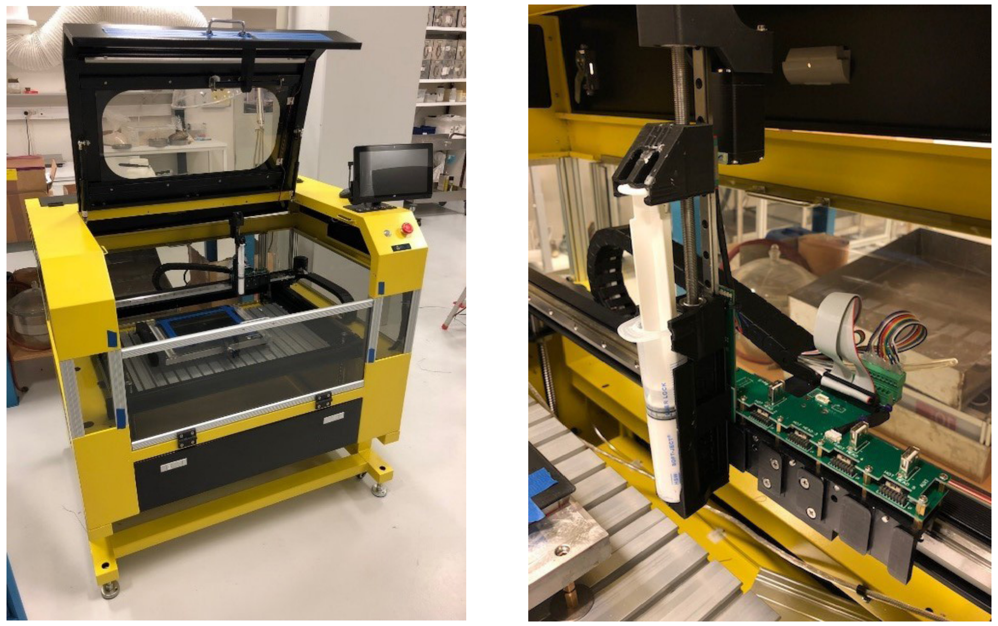


Figure 9. A: The Hydra additive manufacturing R&D platform (shown here with a white extrusion deposition module). B: Close-up of the 5 head module positions, one of which is loaded with a simple syringe dispensing head module.

New PhD position in WP1.3: "Lifetime prediction and structural degradation of polymer and polymer composite components" based at NTNU Gjøvik

Assessing the lifetime of multi-material products based on polymer materials is challenging for many reasons. The structure and properties of polymers change over time, and therefore real plastic products are sensitive to the environment they experience during use. Products may be exposed to mechanical factors such repeated mechanical loading, impacts, or abrasion, or environmental factors such as direct sunlight, extreme temperatures, aggressive chemicals or a combinations of these. Even long durations in the natural environment can eventually lead to part failure if the combination of mechanical factors and environmental factors combine. Therefore understanding how the material are affected by their environment and mapping their degradation is key to predicting the lifetime of plastic parts.

The 4 year PhD project will include research work to contribute to the development of new models and knowledge on degradation mechanisms of thermoplastic polymers as well as fiber reinforced polymer composites both of thermoplastic and thermoset polymer matrices. In addition, the candidate will develop models for changes of structural integrity and prediction of lifetime of polymer and polymer composite based components, with priorities on case studies relevant to the partners of SFI Manufacturing. Industrial partners are invited to suggest case studies that could be investigated during this PhD project.

The PhD candidate will be supervised by Professor Sotirios Grammatikos (NTNU Gjøvik), and co-supervised by Professor Are Strandlie (NTNU Gjøvik) and Ben Alcock (SINTEF Industry). The PhD candidate will be well positioned to take full advantage of the combined facilities of NTNU and SINTEF. Interviews have been conducted and the candidate will begin in mid 2019, with an expected completion in mid 2023.

Figure 10. NTNU Gjøvik (photo: Kenneth Kalsnes)

Multi-Material Polymer Components: Overmoulding one polymer on another – Anna-Maria Persson

Overmoulding is a manufacturing process in which one polymer (often a soft, thermoplastic elastomer) is moulded over a solid substrate which may be metal or another polymer or polymer composite. The successful performance of the part is dependent on the quality of the interface between the two materials. Material factors such as surface cleanliness, chemical pretreatment and roughness, and over-moulding process parameters such as melt injection temperature, pressure and injection speed all affect the quality of the interface. If the substrate is also a polymer or polymer composite, the compatibility of the mating polymers is also key. Recent research by Anna-Maria has looked at factors relevant to the adhesion of thermoplastic elastomers (TPEs) overmoulded on glass fibre reinforced thermoplastic substrates, with a focus on the relating the material chemistry on the surface to the mechanical bond strength in bonded parts.

White light interferometry (WLI) is a technique to measure the roughness of a part by reflecting light off the surface. WLI has been applied here to characterize the surface roughness on the surface which will be subsequently overmoulded with TPE. Figure 11 shows a typical surface topography of a thermoplastic composite. This surface topography originated from the sandblasted mould surface, and the adhesion is affected by the roughness value. In this case, the roughness did not show a significant dependence on the glass fibre content in the thermoplastic composite substrate.

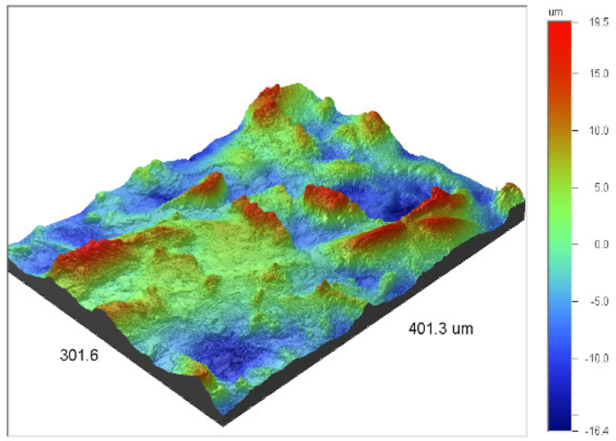


Figure 11. Surface topography of a glass reinforced thermoplastic substrate that will be used for overmoulding with a TPE. Height scale: -16 to 19 µm.

Since the thermoplastic substrate is reinforced by glass fibres, optical microscopy of cross sections of overmoulded parts was used to assess how the glass fibres where distributed in vicinity of the interface, and in the bulk. Figure 12A shows how the matrix material covered nearly all of the interface and the minimum thickness between a glass fibre and the TPE was of the same length scale as a glass fibre diameter.

Understanding the local chemistry on a surface is also critical to achieve the best possible interfacial bond between two materials. Fourier transform infrared (FTIR) spectroscopy is a technique which can differentiate between different chemical groups on the surface of a material. The detection of these different bond types can then be used to identify the polymer types present on a surface. The use of a new FTIR-spectrometer microscope at SINTEF Industry in Oslo allows scanning of sample surfaces to map out the chemical variations over the area. TPEs are typically combinations of different polymer types and the ways these two polymers are distributed on the surface influences the bond performance in an overmoulding process, and therefore FTIR was used here to study the phase separated morphology of these TPE materials. Figure 12B shows that the surface of one of the TPE materials comprised islands of one component in a matrix of a second component.

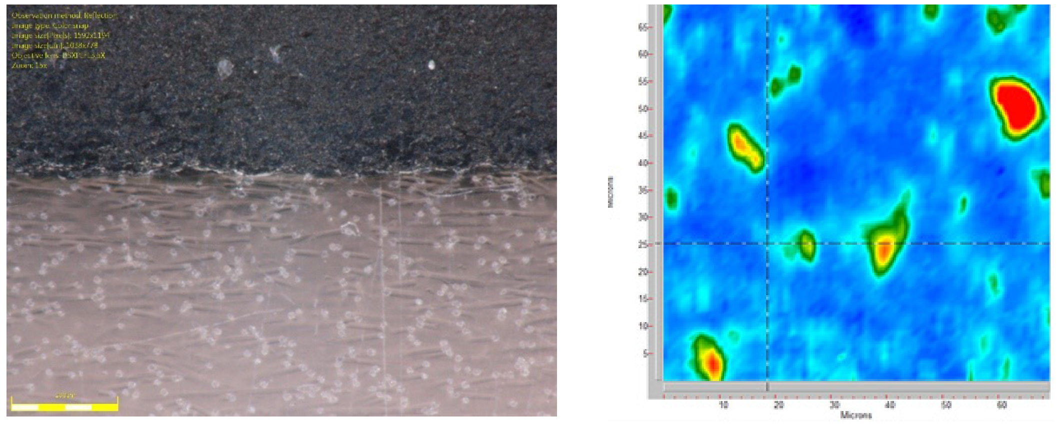


Figure 12. A: Polished cross-section of a layered sample showing a TPE component (top) on a glass fibre reinforced thermoplastic composite substrate. The flow direction (in the moulding process) is out of the plane of the paper and it is clearly visible that most of the glass fibres near the interface are oriented perpendicular to the flow direction. B: Infrared spectroscopy/microscopy scans of the surfaces (ca. 70 µm x 70 µm) of a TPE material. The colours indicate an inhomogenous distribution of chemical groups, revealing non-uniform material distribution on the material surface, which would be expected to influence bond performance on this surface.

WP1.4 – Multi-Scale Modelling Ontologies for Manufacturing and Materials

Ontology has gained a lot of attention the last years as a tool for structuring and organising knowledge and data. Within biotechnology, onotologies have been used for decades to classify and integrate drug discovery data. Large Norwegian engineering companies like Aker Solution and Aibel have also started to use ontologies for improved information management to improve quality, increase efficiency and reduce risks. This article is motivated by the feedback the SFI got from the International Scientific Advisory Board, to look into a knowledge framework for manufacturing and materials science. It describes what an ontology is, and mentions the Industrial Ontology Foundry, which is an umbrella initiative containing several existing ontologies for manufacturing. Finally it describes a European initiative to create a new ontology for applied sciences.

What is an ontology? An ontology can be said to be a specification of a conceptualization. With this we mean that an ontology defines a set of concepts and the relations between them representing our knowledge of the domain for which the ontology covers. Using a logical framework, like descriptive logic, one can derive new knowledge from an ontology.

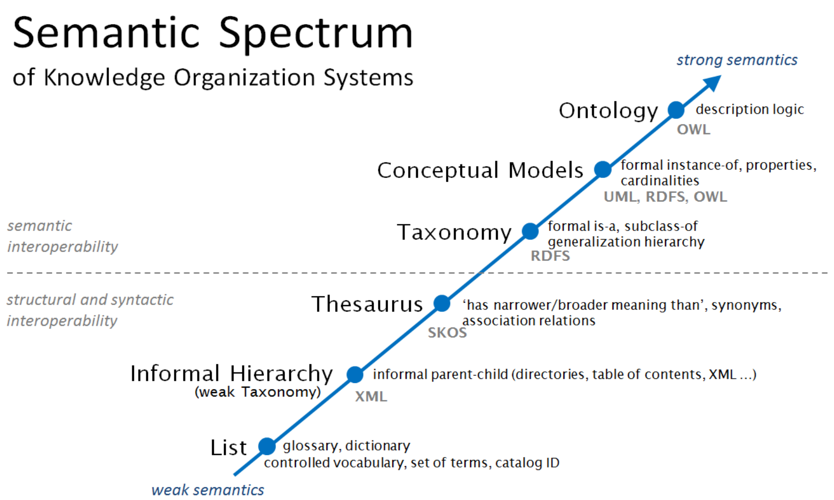


Figure 13. Levels of semantic systems (source: Geoff Gross).

Figure 13 shows the semantic spectrum by Geoff Groff. Here he compares some common ways to organise knowledge according to their level of semantics. The more semantic a knowledge system is, the less a priori information is needed in order to be able to understand and make use of it. The term interoperability means the ability of a system to work and exchange information with other systems. For flexible and robust exchange of information, one needs a high level of semantic interoperability, it is here ontologies play a key role.

A historical sidenote. The word ontology has a long history in philosophy, in which it refers to the subject of existence. The so-called ontological argument for the existence of God was proposed by Anselm of Canterbury in 1078. He defined God as "that than which nothing greater can be thought", and argued that "if the greatest possible being exists in the mind, it must also exist in reality. If it only exists in the mind, then an even greater being must be possible, one which exists both in the mind and in reality".

Even though this example has little to do with todays use of ontologies in computer science, it illustrates the basic idea: the ontology defines some basic concepts and premises from which it is possible to derive new knowledge. Because of its simplicity, the ontological argument may serve as a good illustration of what an ontology is and how it can be used. Figure 14A illustrates the three concepts in Anselm's ontology: existing, the greatest being (that nothing greater can be thought) and God. In addition he includes two premises or relations that represent his a priori knowledge of the system. The first relation is that the class the greatest being only can be populated with one individual, namely God, that is God is the greatest being. His second premise or relation is that the greatest being is existing. By accepting these premises and from the transitive property of the relation is, one logically arrives at Anselm's conclusion: that God is existing.

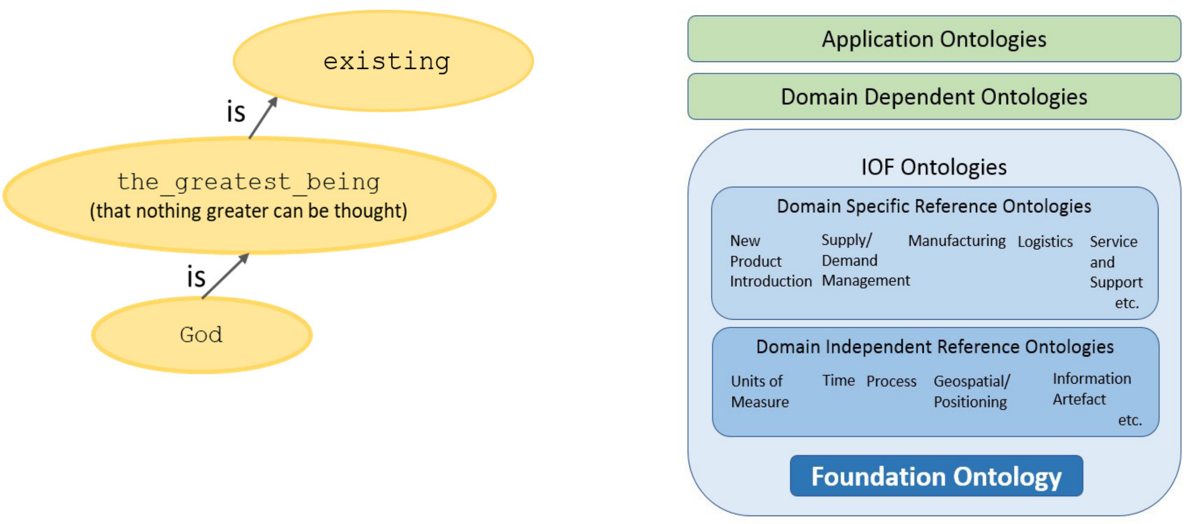


Figure 14. A: Graphical illustration of Anselm's ontological argument. The ovals represent concepts while arrows represent relations that connect two concepts. B: Hierarchy of ontologies in the IOF architecture (source: Industrial Ontologies).

The Industrial Ontology Foundry (IOF) is a new international initiative lead by Barry Smith from the US, to create an open, robust global ontology foundry. In Norway DNV GL is a central player within IOF. This initiative tries to facilitate and make it easier to combine ontologies by encouraging uniformity in terminology and vocabulary. There is a need for definitions in both human-readable and computer-readable languages. IOF will aim to develop granular ontologies and software applications across large and small enterprises. Their ultimate objective is to go towards standards in a similar way to what is happening in e.g. the biological sector. It will provide common terms and relational expressions provide starting point for software developers.

IOF has a governing board, a technical oversight board and top-down working groups with a focus close to manufacturing. The 4 working groups cover production and planning, maintenance, the supply chain and products/services and they will expand to other industrial activities. The IOF's mission is to have a suite of highly interoperable ontologies which should be modular and thus, easily extendable. For the top-level ontology, there is still a debate which one could be the most suitable, i.e. BFO, DOLCE, ISO5926 (a standard for data integration, sharing, exchange, and hand-over between computer systems, used in for example the gas and oil industry).

The European Materials & Modelling Ontology (EMMO) is a multidisciplinary effort lead by the European Materials Modelling Council (EMMC) to create a common representational framework for applied sciences, including materials science, chemistry, physics and engineering . The aim is to enable and support a common language between disciplines as well as semantic interoperability between systems, organisation of data, integration of database by providing a common ground for how to describe the material itself, how it can be decomposed into parts and subparts, how to describe processes and experiments, how to describe its behaviour by modelling, how to represent models by their mathematical formulation, etc. Figure 15 tries to illustrate that EMMO is a tool for describing and organising a digital representation of real-world manufacturing systems and processes.

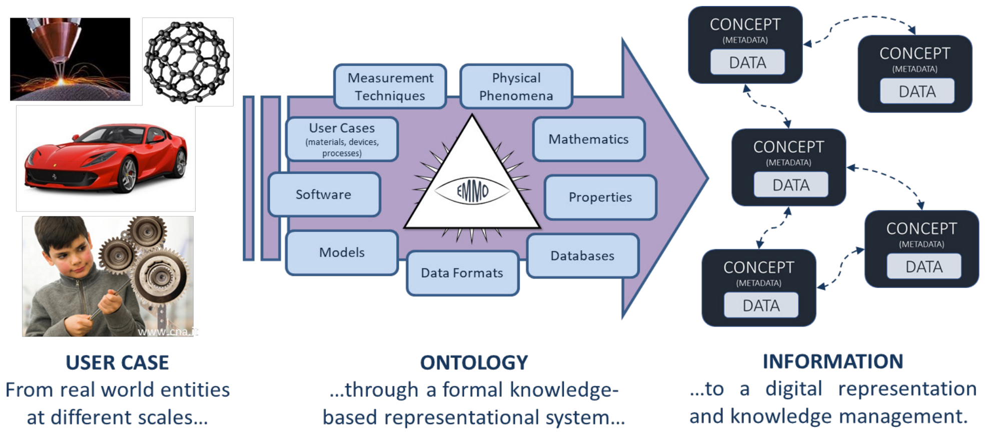


Figure 15. Illustration of how EMMO can facilitate building up a digital representation and knowledge management of real-world entities and processes (source: Ghedini & Goldbeck).

In contrast to most other ontologies has EMMO a strong theoretical foundation in not only physics and information science, but also in several disciplines within analytical philosophy, including:

- Semiotics, which is the study of how meaning is created and communicated by the use of signs that stands for something else. It provides the theory behind the representational process in EMMO, like how properties are assigned to physical objects.
- Nominalism, which is a philosophical view that denies the existence of universals and abstracts in absence of an interpreter. This view constitutes the basis for the interpretation of existence in EMMO and is behind the way sets are used to represents abstracts. The relations between signs and the real-world objects they stand for are in EMMO always subject interpretation. For instance, properties are not seen as an intrinsic quality of a physical object, but rather an abstraction of an observation process that involves an observer.
- Mereotopology, which is a combination of merology (the study of parthood) and topology (the study of space and its properties). Merology is used to create a formal way to describe how a physical object like a car or human, can be decomposed into parts in multiple well-defined steps all the way down to elementary particles. Topology is used to describes the space and time (spacetime) that all existing objects and processes unfolds in.
- Set theory, is the theory of membership. EMMO has a clear top-level separation between items that constitutes the mereotopological branch in which everything that exists in space and time reside and sets representing the abstract. This clear separation avoids Russels paradox that many other ontologies struggle with.

The multi-scale modelling case described in the previous section about WP1.2 on page 7, is currently being used as a case for demonstrating how EMMO can be used to facilitate interoperability across models operating at different scales. The key here is that the ontology provides an unambiguous definition of the physical quantities that are transferred between the scales in a both machine and human readable way.

Introduction to the HYB process

During the workshop at Raufoss next week, we will learn more about Hybond and its process for hybrid metal extrusion and bonding. A brief introduction to this process is given below.

Solid-state joining method for metals

The hybrid metal extrusion & bonding (HYB) process is a patented solid-state joining method for metals. Over the years, it has evolved into a multi-functional joining process handling a wide range of joint configurations (butt, fillet, and slot welds) and base metal combinations (Al, Fe, Ti, and Cu). At present, up to four different metals can be joined together in one pass using the HYB PinPoint extruder and AA6082 as filler wire.

Welding of aluminium

The HYB process is a patented solid-state joining method for metals, which utilises continuous extrusion as a technique to squeeze the aluminium filler material into the groove between the two plates to be joined under high pressure to achieve metallic bonding.

Figure 16 shows the experimental set-up during butt welding of two aluminium plates. The plates are separated from each other by a fixed spacing so that an I-groove forms between them. In a real welding situation, the extruder head slides along the joint line at a constant travel speed. At the same time the rotating pin with its moving dies is placed in a submerged position below. This allows the extrudate to flow downwards in the axial direction and into the groove under high pressure and mix with the base material. Metallic bonding between the filler metal (FM) and the base metal (BM) then occurs by a combination of oxide dispersion and severe plastic deformation. By proper adjustment of the wire feed rate (using the rotational speed of the drive spindle as the main process variable), the entire cross-sectional area of the groove can be filled with solid aluminium in a continuous manner.

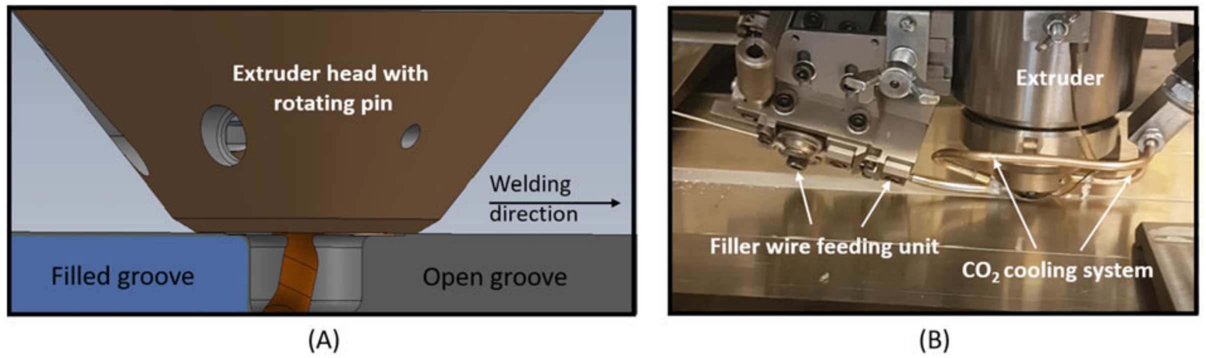


Figure 16. Illustrations of the experimental set-up during butt welding of aluminium plates. A: Close-up of the "pin-in-groove" situation. B: Snapshot of the HYB PinPoint extruder in operation.

Originally, the idea was to use the HYB process for simple butt joining of aluminium plates and profiles. However, over the years, the method has evolved into a multi-functional joining process handling different joint configurations and groove geometries as well as base metal combinations, as illustrated in Figure 17.

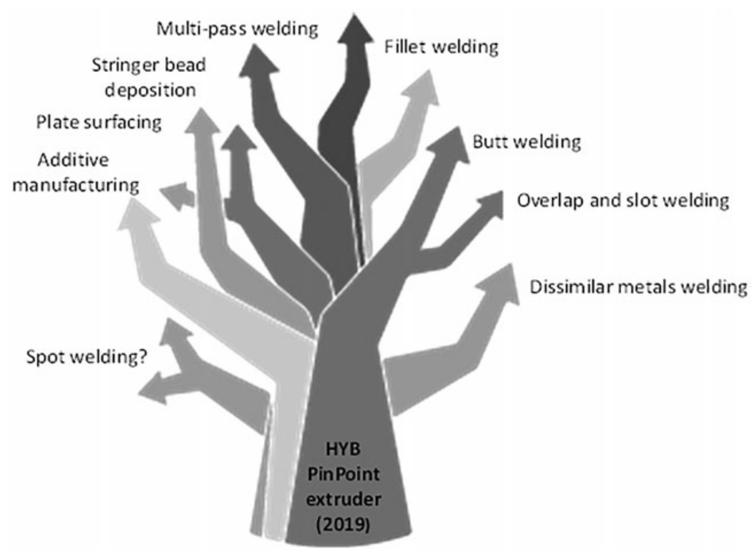


Figure 17. Possible applications of the HYB PinPoint extruder.

How the HYB PinPoint extruder works

As shown in Figure 18, the HYB PinPoint extruder is built around a 10 mm diameter rotating pin provided with an extrusion head with a set of moving dies through which the aluminium is allowed to flow. When the pin being attached to the drive spindle is rotating at a constant speed Ns, the inner extrusion chamber with its three moving walls will drag the filler wire both into and through the extruder due to the imposed friction grip.

At the same time, it is kept in place inside the chamber by the stationary housing constituting the fourth wall. The aluminium is then forced to flow against the abutment blocking the extrusion chamber and subsequently (owing to the pressure build-up) continuously extruded through the moving dies in the pin head. They are, in turn, helicoid-shaped, thereby preventing the pressure from dropping on further extrusion of the FM in the axial direction of the pin and downwards into the groove. Furthermore, if the stationary housing also is equipped with a separate die at the rear, a weld face can be formed by controlling the flow of aluminium in the radial direction.

More information on the HYB process can be found in the scientific article called "A Status Report on the Hybrid Metal Extrusion Bonding HYB Process and Its Applications", which can be found on Research Gate.

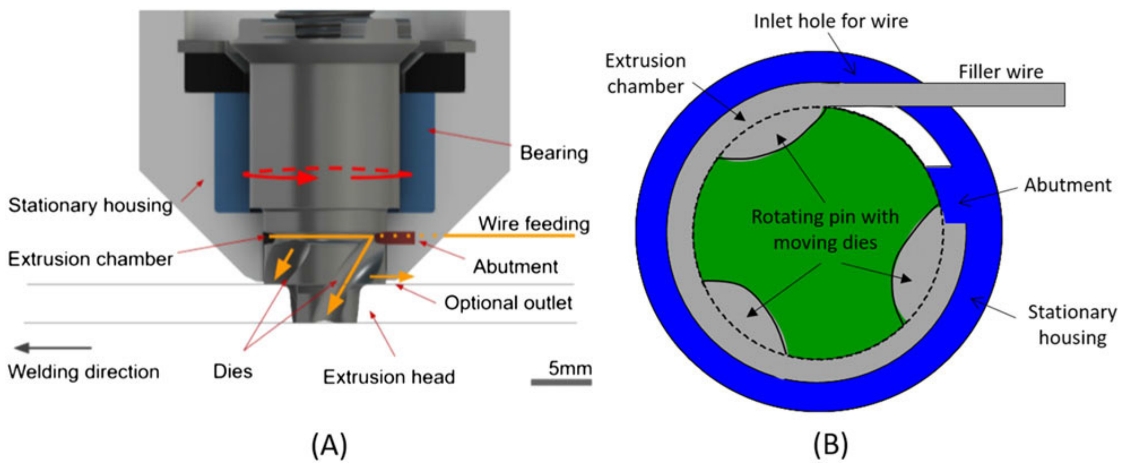


Figure 18. The working principles of the HYB PinPoint extruder. A: Section through the extruder head. B: Section through the extrusion chamber.

Short update on RA3

Two overall trends in society are digitalization and sustainability. Industry 4.0 is considered to be an enabler and condition for economic viable manufacturing in Europa. A transition towards Industry 4.0 technology will imply radical changes in organization models, processes and the work-system and the every-day life of co-workers and managers in manufacturing companies.

Sustainability is commonly understood as containing three dimensions: social, environmental and economical. With respect to environmental aspects, the Norwegian government has stated a national goal of minimum 40 % reduction in greenhouse gases emissions in 2030, compared to 1990 level. As a result, both external drivers and motivation for a more sustainable development might be stronger in the near future. Demands for a more sustainable business development will affect the entire organization: work-systems, innovation, leadership and learning systems.

One of the main objectives of RA3 this year is to develop scenarios for "Future modern organizations and sustainable business model development". These days we are scanning reports and literature to ensure that we are updated on the last results. These insights will be used to create a platform and a frame of reference for developing the scenarios within SFI Manufacturing. *At the moment, we are into reading whitepapers and reports from among others World Economic Forum and OECD. A status on this work will be presented during the workshop at Raufoss.*

At last, during I3E2019, a conference in Trondheim addressing digital transformation in a sustainable society, the 18th to 20th of September, RA3 will organize a workshop. The title of the workshop will be: "Digitalization for a sustainable manufacturing industry in the modern society", and Halvor Holtskog will chair this session on behalf of RA3, together with Hans Torvatn, Sigurd Sagen Vildåsen and Eli Fyhn Ullern.

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

Centre manager SFI Manufacturing
Sverre Gulbrandsen-Dahl, SINTEF Manufacturing
E-mail: sverre.gulbrandsen-dahl@sintef.no
Phone: +47 916 01 205

Leader of Multi-Material Products and Processes
Einar Louis Hinrichsen, SINTEF Industry
E-mail: Einar.L.Hinrichsen@sintef.no
Phone: +47 982 83 932

Stay updated! Visit the website, or follow SFI Manufacturing on Twitter, for updates and information about the program and research areas.

http://www.sfimanufacturing.no/

@SFI_Manufact

BENTELER, PLASTO, NEUMAN ALUMINIUM, KONGSBERG AUTOMOTIVE, Hydro, HEXAGON RAGASCO, KONGSBERG, EKORNES, Nammo, SANDVIK Coromant, HyBond, BRØDRENE AA, NTNU, GKN AEROSPACE, Rolls-Royce, MJØS, Forskningsrådet, SINTEF