REVIEW OF ACTIVITIES

2018-2019

Cocasd

Cover: Electron Backscatter Diffraction (EBSD) image of Nb alloyed carbon steel grade.

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3 DURABILITY & LIFETIME PREDICTION

4 MATERIALS FOR THE FUTURE

5 NANO MATTERS

6 WORKING WITH OCAS

Realising our vision in the midst of change

“In 2025, OCAS wants to be a top-of-mind R&D centre for ArcelorMittal and metal-based industries worldwide, by offering its customers highly effective alloy and coating development services and related application testing, accelerating their R&D output using OCAS’s unique testing, processing infrastructure and competencies.”

In 2018 and 2019, OCAS has pursued its vision with further developments and innovations in all areas, even within an industrial and economic environment marked by turbulence. As we embark upon 2020, we take pride in reviewing for you the highlights of these past two years.

ENERGY TRANSITION

In the context of increasing effects of global warming and greenhouse gas emissions, the primary goal of the so-called ‘Energy Transition’ is to decarbonise our energy systems. Which is an enormous challenge. For the time being, the core of the Energy Transition effort is the generation of electricity using renewable energy resources, like wind, solar and hydro power. For the renewal of gas pipelines in today’s changing environmental conditions, an area closely associated with the energy transition, we’re investigating the assessment of current and future infrastructure for the storage and transport

of hydrogen. We've been building competence in hydrogen as a clean energy carrier for over 15 years now – and today that expertise is coming into its own.
Electrical steels are more important than ever, with the rapid rise of the e-car industry. One of our key activities is the development of electrical steel alloys and related coatings, along with electromagnetic application testing.
In this regard, the development of alloys and coatings – OCAS's core business – remains a key strategic objective. In the last few years, we have supported – and differentiated – these developments with advanced combinatorial, digital and nano-characterisation tools.
As our knowledge grows deeper in developing and deploying new steel grades, metal alloys and associated coatings or surface technologies, we must now control the microstructure and surface conditions down to the (sub)nanometre. This 2018-2019 Activity Review includes some metallurgical examples that show how our high-end microscopic techniques lead to further understanding of material behaviour.

Another focus these last two years has been the non-standard testing and modelling of materials and components to elucidate everything that triggers damage: fatigue, wear, corrosion, hydrogen, and combinations of these factors. The strengthening with the expert services of Endures in the field of offshore and marine corrosion as well as the industrial spin-off Guaranteed contributing to material repair and extended lifetime is fully in line with this strategy.
Industrial assets reliability increase, using all this know-how, thus is a logical key working axis for the upcoming years.

TWO IMPORTANT EXPANSIONS OF EXPERTISE

In the summer of 2019, we acquired a controlling stake in – Endures, experts in maritime corrosion and we partnered with Finindus and ArcelorMittal Belgium in Guaranteed, a new spin-off, providing a specialised industrial welding repair activity. Both companies are long-term additions to OCAS's know-how, reinforcing our areas of focus and creating new synergies through our collaborations.

Endures, based in Den Helder, The Netherlands, is a contract research company specialising in applied research on marine corrosion and antifouling.
By joining forces with OCAS's advanced research activities in metallurgy, coating and steel application development, the two companies combine expertise in the field of corrosion and materials science.
This synergy extends our offshore service offer and provides custom-made solutions, adding value, reducing costs and preventing metal structure damage for our customers.

The spin-off company, Guaranteed, operating in a synergic way with and within the central maintenance department of the ArcelorMittal Gent plant, was created by OCAS, Finindus and ArcelorMittal Belgium to add value for its customers by repairing, refurbishing and producing large metal parts using Wire Arc Additive Manufacturing (WAAM). Using state-of-the-art advanced simulation tools to guarantee 'right first time' production, Guaranteed works to reduce downtime and lengthen the lifetime of industrial equipment.

Finindus, being a sister company of OCAS, is the investment firm of the Finocas group. The Finindus portfolio is showing a strong momentum, and OCAS is very well-placed to also support these companies as they grow and mature thereby capitalising and adding value to our competencies and infrastructure. One example is Borit, which is contributing significantly to the energy transition. Borit has successfully completed its investment program including a.o. a second, optimised Hydrogate® press and has positioned itself as a leading independent supplier of bipolar plate assemblies for fuel cells. Borit delivers its products worldwide to Tier 1 and OEM customers.
Keystone Tower Systems (KTS) is another example of a portfolio company that has successfully entered a new stage in its development. KTS is now building the first industrial scale production facility for wind turbine towers using a patented automated spiral welding technology. This is a first step towards the final goal: operating mobile units capable of producing tall wind turbine towers on site, thereby overcoming transport restrictions. KTS can rely on OCAS's competencies in steel grade selection, coating, welding and large-scale fatigue testing.

EXTREME, BUT SAFE, TESTING

With regard to the OCAS operations, the most prominent aspect in the last two years has been our ambitious investment plan, whereby we continued to make substantial investments in state-of-the-art equipment. During this time, OCAS has reaped benefits from its OCAS XT (Extreme Testing) facility in Zwijnaarde, with its testing capabilities for large components.
Our "Jacket Connection" project financed by the major operators of offshore windmill infrastructure in Europe led to international recognition in this booming market. In this project our patented test infrastructure for accelerated fatigue testing of real-size components proved to fulfil the expectations of our customers and led to a 20 times faster result compared to classical hydraulic testing. Several spin-off projects for other applications are now discussed with a number of industrial partners.

PROGRESSIVE DIGITALISATION

From the very beginning, OCAS has been a digital lab – and now, with the era of digitalisation sweeping all of industry, we are forging further ahead in this important area. In the last two years, we have extended our operational backbone systems for managing our R&D laboratory to ArcelorMittal Global R&D labs and to partners on the Technology campus in Zwijnaarde.
An example of our advanced digitalisation initiatives is our image recognition tool, whereby we convert steel microstructure images into digits, enabling classification and objective analysis of ever more complex microstructural products we develop. Digital is never an end in itself but always a tool

complementing and supporting all of our other tools and technologies.

CONTINUING TO REALISE OUR VISION

All of these activities were conducted against the background of difficult economic times for the steel industry, compounded by the accelerating changes in all areas of industry and society.
In light of this, we decided to review our vision statement, which we announced in our 2016-2017 Annual Review, to see if it was still on target, or perhaps in need of adjustment. We were gratified to find that our vision out to 2025 still holds true: our assets, unique equipment and competencies are all still very much relevant to the strategic choices that we have made. The various energy transition fields, for example, are all growing markets. In fact, our vision is becoming more sharply focused with the new evolving market conditions, and we continue to invest with confidence.

Serge Claessens,
Chief Technology Officer

Sven Vandeputte,
Managing Director

1 DIGITALISATION

As an industrial R&D centre, our primary mission is to develop new products and solutions for our customers and assist them with our technical competences to help them achieve their goals. And it is our ambition to do this in the most efficient way and with the highest quality standards. In this context, our secondary objective is to continuously improve our operations – and digitalisation is a key factor in realising this. During the past two years, digitalisation of our operations has risen exponentially, allowing us to achieve another level of performance. This ongoing digital transformation is largely due to the increased computational power that OCAS has access to today, and to the enhanced performance of modern artificial intelligence (AI) tools.

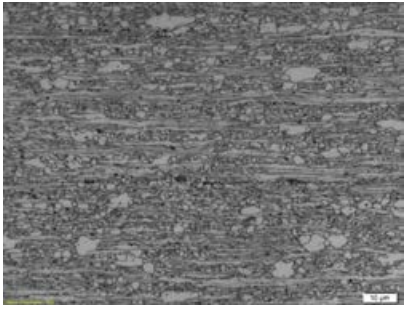
For this, a Digital Cell has been created in our organisational structure to gather all engineers active in this domain. This cell is in charge of piloting, consolidating and

disseminating all digitalisation activity in our lab with (amongst other initiatives) multi-disciplinary cross-fertilisation as a particular target.
A first digital pillar – which has accelerated enormously – is everything related to (big) data, which concerns all stages of data management in our R&D biotope.

— The first stage is ***data generation***, where our small-scale combinatorial experimentation has been expanded from rapid sample synthesis to further property screening and microstructural analysis. As such, quantities of data are generated more quickly, and the necessary tools have been constructed to handle all these data efficiently.
— For such a structured ***data capture and storage***, our existing Lab Integrated Management System (LIMS), called JobManager, has been upscaled to a modern 4.0 tool that enables standardisation of activities, storage of data with a uniform ontology, and visualisation via state-of-the-art big-data analysis packages.
— In particular, huge steps have been taken on (pre)***treatment of high complexity data*** such as time series and images, including 'face-recognition' of microstructural images using Artificial Intelligence.
— The next step is profound exploration of Process-Structure-Property correlations in these extended data sets by means of the most recent ***machine learning techniques*** (e.g. artificial neural network models).
— All these tools are also being increasingly applied to data sets directly originating from an industrial production context. As such, several successful cases of technical support to customers have been realised.

Next to the big data axis, our classical modelling activities have advanced significantly thanks to higher computational power and better algorithms and models. These models cover the final application part – e.g. simulation of electric motors allowing a reduction of the number of trial prototypes at our customers, prediction of geometrical and metallurgical evolutions in welding and wire arc additive manufacturing, modelling of the mechanics during forming processes or the mechanical behaviour of final components – as well as the steel processing part – e.g. simulations of metallurgical evolutions during hot rolling. All of these capabilities enable us to further reduce expensive experimentations and, ideally, they produce 'first time right' results.

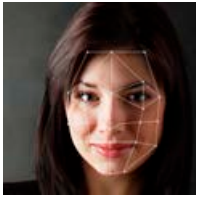
— *Serge Claessens & Lode Duprez*

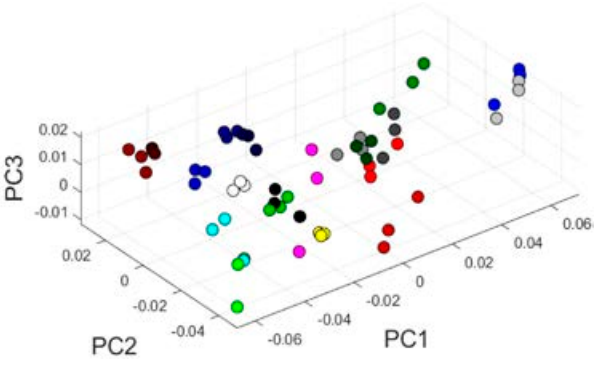


Digital steel microstructure image

+

Deep learning (“google face recognition”)





Machine based distinguishing of 20 HSLA microstructures by reducing a microscopy image to a 3-dimensional vector

Applying the Google ‘face’ recognition algorithm to a microstructural ‘phase’ is fascinating and looks highly promising for tomorrow’s product development.

Jan Rens & Arunim Ray

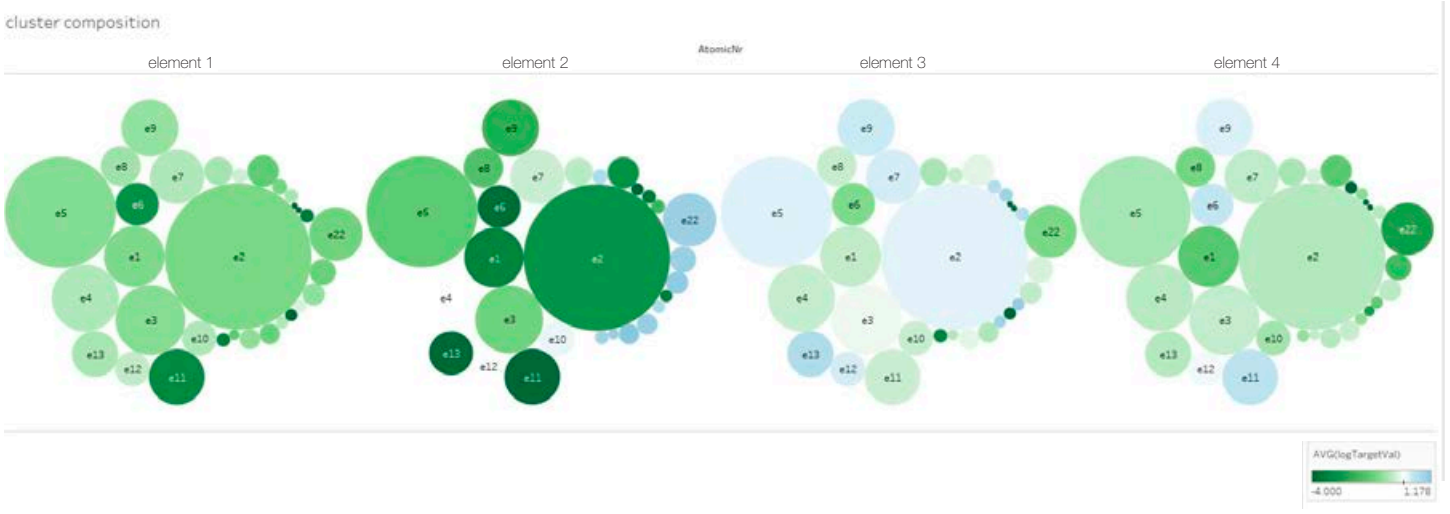
Man versus machine challenge

The use of artificial intelligence in materials science is highly valuable in identifying Process-microStructure-Property (P-S-P) links in steel research. Finding and understanding these P-S-P links has always been of key importance for new steel product development. And modern digital tools can bring this understanding to another level.

Since 2018, OCAS has made considerable progress in describing the microstructure of steel. To obtain a compact representation of microstructural images using deep learning techniques, an image needs to be reduced to a series of values. Basically, this means applying the 'Google face recognition' algorithm to digital microstructural images of different steels. An example of the principle is shown in the image on the left page, which clearly illustrates a machine's capability to distinguish microstructures. Indeed, in the 3D representation, each set of three coloured dots – representing one microstructure – is grouped together and similar materials are found close to each other, whereas different materials are well separated.

DIGITAL PRODUCT DEVELOPMENT

The OCAS team organised a man versus machine challenge to compare the human eye with artificial intelligence. The results illustrated that a machine performs better in microstructure classification than a person, i.e. the machine can see features that a human no longer detects. Based on these encouraging results, the machine learning was applied to much more complex martensitic microstructures. First outcomes confirmed that the machine is extremely powerful in feature extraction and in differentiating microstructures, and first attempts to make the link with final properties were highly promising. The machine learning provided us with first indications of properties solely based on the microstructure – i.e. without any input of chemical composition or process information, but purely based on the microstructural image.



Data mining and artificial intelligence have allowed us to take the first steps towards virtual metallurgy: i.e. materials design based primarily on historical data and modelling without the need for physical experiments.

Kurt Lejaeghere

Harnessing the power of data

OCAS's activities cover a broad spectrum, ranging from metal casting and rolling to chemical, mechanical and surface testing. Data on these activities are sometimes correlated and form a rich source of information. However, access to consolidated, high-quality data is essential. We have developed a comprehensive Laboratory Integrated Management System (LIMS) to manage all activities at the lab, allowing us to control and log all process parameters.

Thanks to JobManager, our in-house developed LIMS, OCAS has entered the digitalisation era. Historical and new data produced in the lab are stored in a standardised way, laying the foundations for big data analyses and artificial intelligence.

DATA-DRIVEN QUALITY

Many activities, such as vacuum casting and various types of chemical analysis, are available in JobManager via standardised procedures, ensuring the highest level of quality control. The system enforces a rigorous validation flow, supported by permission management and controlled documentation. Moreover, human error is avoided as much as possible by extracting data from equipment automatically and performing data consistency checks.
Based on repeated experiments, statistical process control provides a view on expected uncertainties and flags anomalies. This approach has enabled us to successfully obtain ISO17025 accreditation for several chemical analysis techniques.
Because efficiency and quality are key, in addition to dealing with operational activities, JobManager contains tools for project follow-up, knowledge management and quality control. The system also manages a comprehensive inventory, coupled to an intelligent scanner-based tagging system for warehousing.

DATA-DRIVEN KNOWLEDGE

JobManager deposits all data into a SQL database, which includes processing and testing parameters as well as metadata, such as the parent material, the scheduling of the activity, the operator and the project. Cross correlating entries on different materials or tests may reveal hidden

JobManager contains tools for project follow-up, knowledge management and quality control. The system also manages a comprehensive inventory, coupled to an intelligent scanner-based tagging system for warehousing.

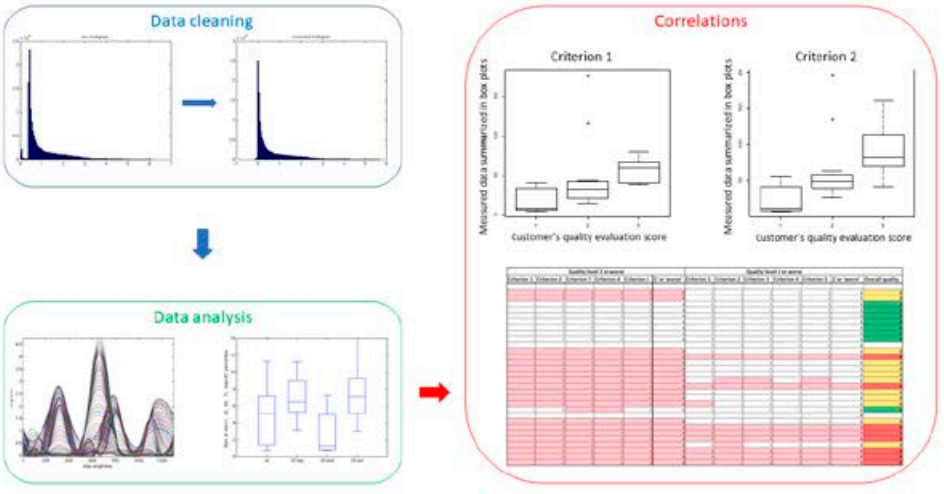
Roger Hubert

trends and identify optimal composition or processing conditions.
The amount of information reaches staggering proportions: 300,000 samples are currently registered in JobManager. To extract insights from such ‘big data’, we use state-of-the-art analysis techniques. Data mining and artificial intelligence have allowed us to take the first steps towards virtual metallurgy: i.e. materials design based primarily on historical data and modelling without the need for physical experiments.

A DATA-DRIVEN FUTURE

With JobManager, OCAS is decisively playing the digitalisation card. We plan to continue to develop tools for controlling our processes and harvesting data from them. On-the-fly monitoring and visualisation capabilities will be added too, and more advanced database queries will be made accessible through the JobManager interface for data mining and machine learning. Over the longer term, the software will become web-based and accessible through a smartphone app.

These developments are being added to JobManager in a modular fashion, which makes the software extremely customisable. Thanks to this flexibility, JobManager is now being deployed at several other metallurgical labs around the world.



In our digital approach, modelling goes hand-in-hand with physical experiments in the lab. Managing large quantities of data and comparing these with the customer's quality rating is a good example of how digitisation leads to knowledge that creates better products as well as better customer experiences.

Steven Cooreman and Patrick Goes

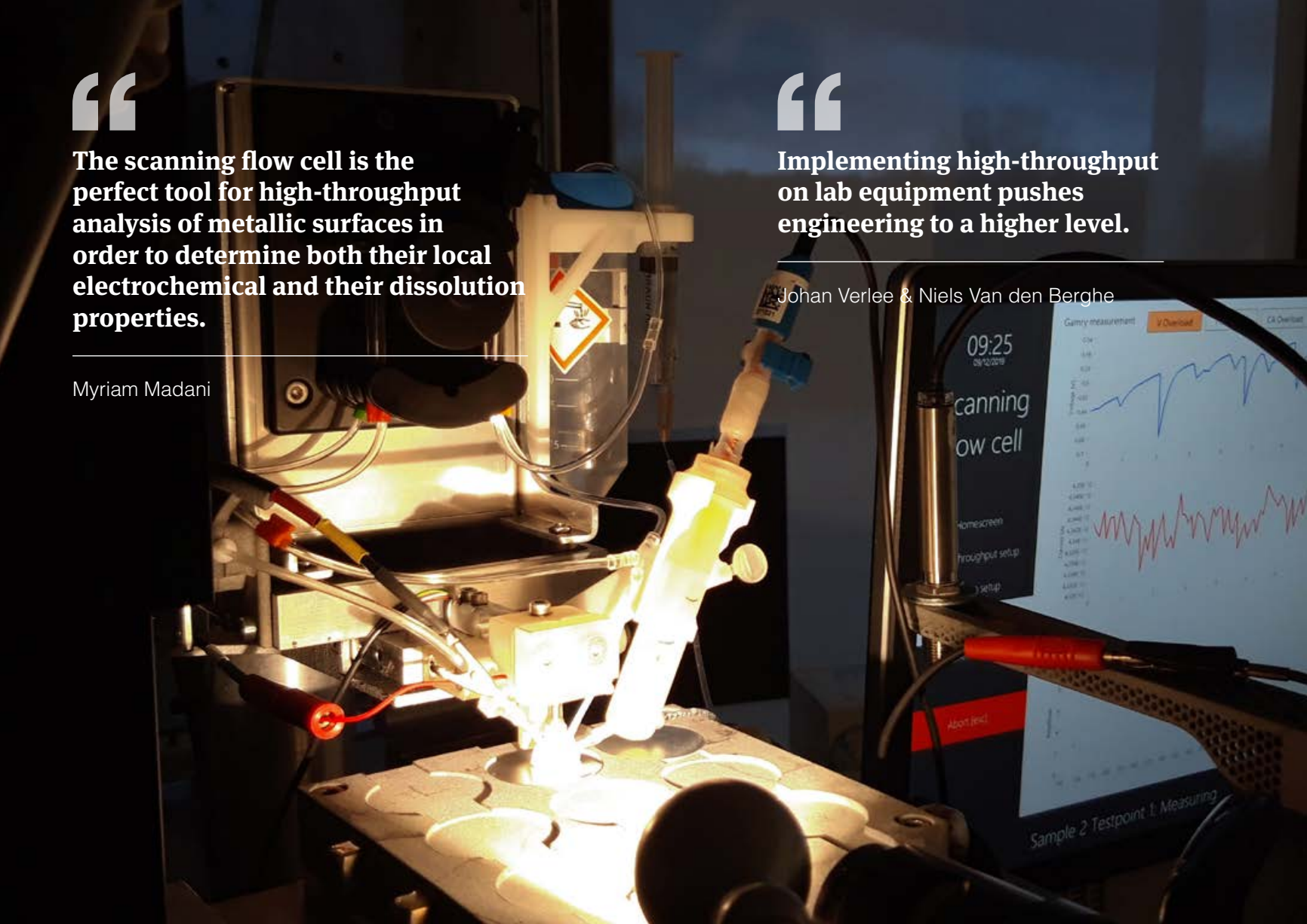
Big data analysis identifies product issues

One of our customers experienced quality issues on their final product. As the customer's production process is rather complex, it was difficult to identify the cause of the problem. It could have been anything: from the quality of the incoming supply of raw material to some processing issues.

In a first approach, a numerical model of the customer's production process was set up to investigate the influence of the different parameters on the final product. However, due to the complexity of the production process, it was hard to reproduce the actual boundary and loading conditions. In addition, it was quite a complicated matter to capture the different quality aspects of the incoming material. Consequently, it was virtually impossible to discover the causes of the observed problems by means of a numerical model.

DIGGING THROUGH DATA DIGITALLY

Therefore, OCAS suggested tackling the problem through statistical analysis of a sufficiently large set of experimental data. Measurements were conducted on the material at different stages of the production process. The data obtained was analysed and 'translated' into a set of quantities expressing the quality of the incoming material.
Statistical analysis revealed a clear correlation between those quantities and the customer's evaluation score. With this information at hand, the material supplier was convinced of the necessity to improve the quality of the raw material. Our customer and the supplier discussed various options for resolving the issue. So far, the actions that have been taken have already resulted in a significant reduction of scrapped material, for both the supplier and our customer.
Thanks to this digital approach, a complex problem could be addressed in a limited amount of time.



The scanning flow cell is the perfect tool for high-throughput analysis of metallic surfaces in order to determine both their local electrochemical and their dissolution properties.

Myriam Madani

Implementing high-throughput on lab equipment pushes engineering to a higher level.

Johan Verlee & Niels Van den Berghe

Combinatorial metallurgy at work

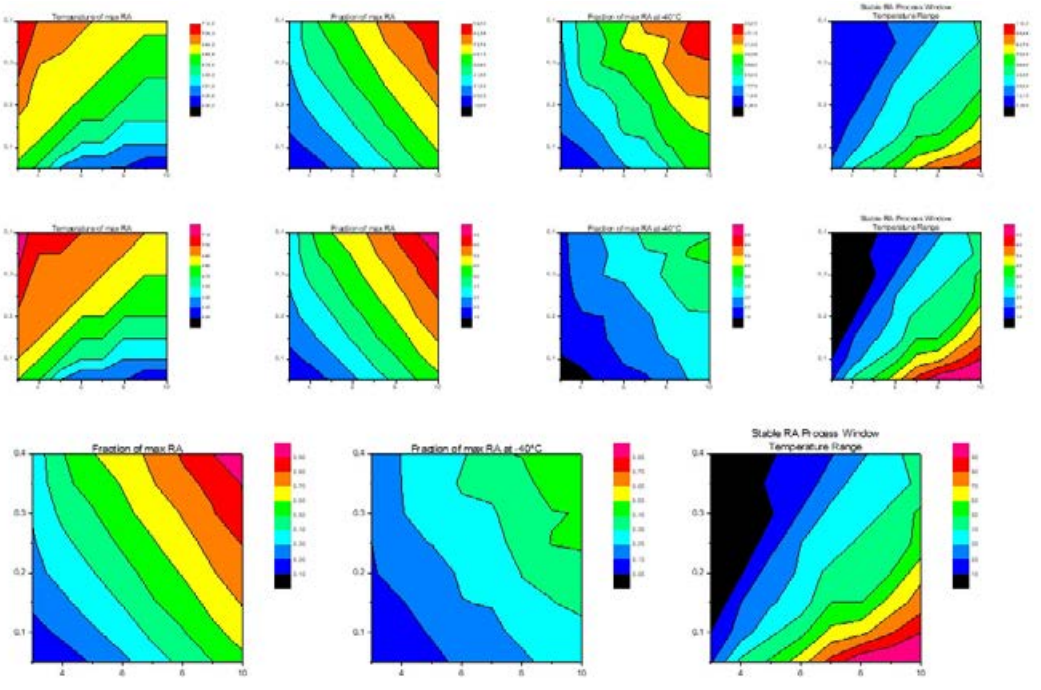
Combinatorial metallurgy allows the efficient generation of large data sets. In breakthrough or exploratory projects, decision-making becomes more effective by determining interesting hot spots or very quickly eliminating uninteresting chemistry ranges.

SMALL & FAST

Because of the large number of samples, miniaturisation and automation are key in experimental combinatorial work flow. In other words: 'small & fast'.
Today, OCAS is fully equipped for small-scale sample production: small-scale casting, accelerated rolling, processing multiple samples and thermomechanical processing in various atmospheres. Special sample holders and automated flows enable fast characterisation of properties and structure.
Several projects have already benefitted from this methodology: screening for maraging steels, lightweight steels for industry applications, fire resistant composites, new alloys for additive manufacturing, and coating development for better corrosion resistance.

QUICKLY SCREENING METAL SURFACES FOR CORROSION PROTECTION

To screen the corrosion protection of newly developed coatings, the OCAS scanning flow cell, with coupled electrochemical data collection and analytical units, is the ideal tool. Not only because of its multi-reservoir high-throughput and full automation, but also thanks to its high lateral resolution obtained by confining the measurement locally.
The OCAS scanning flow cell allows high-throughput screening of anti-corrosion properties to identify key parameters and limit the need for expensive, lengthy real-life exposure testing. The technology monitors the dissolved elements online using UV-VIS or ICP-MS – delivering quick insights into the active protection mechanism.
As a result, this scanning flow micro-cell addresses several issues, making it a highly valuable tool.

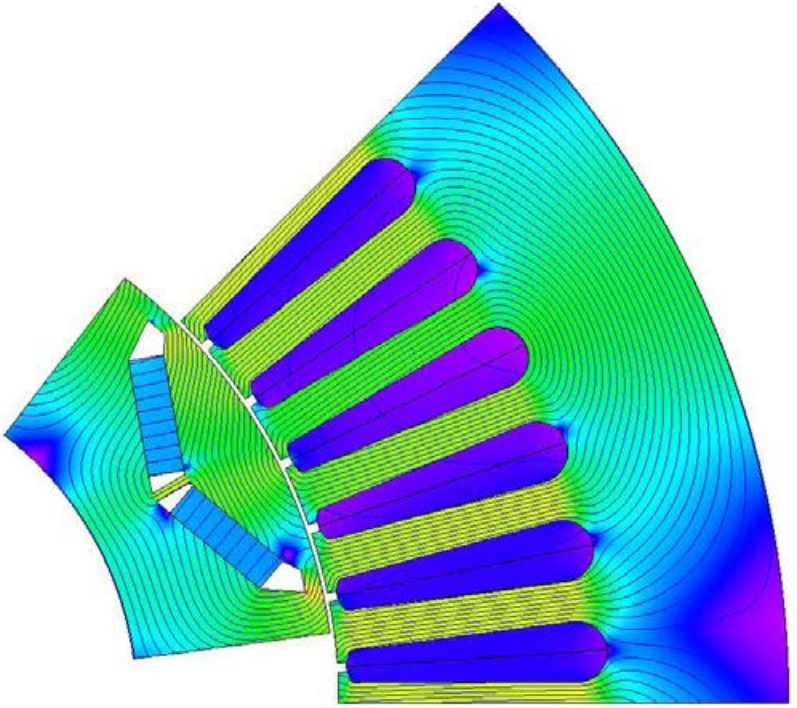


The use of artificial neural network models truly maximises the output of combinatorial research. It optimises the experimental work by easily spotting interesting combinations and simplifying the analysis of large databases.

Laura Moli Sanchez & Nele Van Steenberge

ARTIFICIAL NEURAL NETWORK MODELLING'S PREDICTIVE POWER

Artificial neural network modelling is a non-linear statistical analysis technique linking input data to output data using a particular set of non-linear functions. It is very powerful when very little (or no) prior knowledge is available concerning the physical background of the relationships between alloy composition, processing parameters and the final properties. So, it's the perfect tool for exploratory research. OCAS has developed a model to predict the mechanical properties of new nano-precipitates in order to strengthen alloys based on the artificial neural network approach. By optimising composition design and processing, this model is supporting the development of the alloys. Based on the outcomes of the neural network, new alloys with optimum compositions and process routes have been generated. From here, experimental work will be conducted to confirm the predictions.



Improved simulation capability for electric motors

One of the principal components of an electric machine is its magnetic core, which guides the magnetic flux through the machine and prevents flux from leaking out. The magnetic core is made up of stacked laminations of electrical steel, characterised by high permeability and low losses.

However, manufacturing and assembly techniques for cutting and stacking the laminations to produce the core generally result in local material degradation and somewhat weaker magnetic properties. Also, electric motors are usually operating under conditions that are very different from those in which the electrical steel was initially characterised, which exposes the material to, for example, high temperature, high mechanical stresses, or high-frequency magnetisation waveforms due to harmonics in the supply voltage.

Through numerous collaborations with customers in both automotive and industrial market segments, OCAS has developed modelling techniques – which take the effects of the various manufacturing and operating conditions into account – to predict the performance of the core in the final application.

Our unique strength comes from the combination of our in-depth material knowledge, the availability of an advanced laboratory that is well equipped for magnetic and electrical characterisation of electrical steel, and our strong modelling capability, which makes use of bespoke software modules for loss calculations.

ADVANCED MATERIAL CHARACTERISATION CAPABILITY

OCAS has a strong track-record in the advanced characterisation of electrical steels. Apart from the tools for magnetic and electrical measurements and the characterisation of the insulating coatings on the as-delivered sheet material as described in the international standards, on the request of our customers, we have developed methodologies to obtain specific material data. For example, the effects of various cutting techniques on the magnetic properties can be determined locally.

We can also simulate realistic operating

Our integrated methodology allows us to improve the simulation capability for electric motors for our customers.

Jan Rens & Ahmed Abdallh

conditions – including high temperatures, mechanical stresses, and high excitation frequencies – to which the electrical steel is subjected in an electric motor.

IMPROVED IRON LOSS MODELLING

Due to the factors mentioned above, the magnetic core losses that are measured on an electric machine are, in general, significantly higher than those that could be expected from the datasheet. OCAS has derived advanced formulations for the prediction of core losses in electric motors under real operating conditions, taking various production processes into account. These models are based on our advanced material characterisation capability to determine both local permeability and core losses under specific conditions.
Recently, our modelling approach has also been extended to include the effect of higher harmonics due to inverter-fed operation, which leads to the presence of minor loops and skin effects that redistribute the magnetic flux throughout the thickness of the lamination. Our integrated methodology allows us to improve the simulation capability for electric motors, which enables more accurate designs and can reduce the number of expensive prototypes at our customers.

We believe modelling will considerably reduce the number of experimental welding tests that are needed.

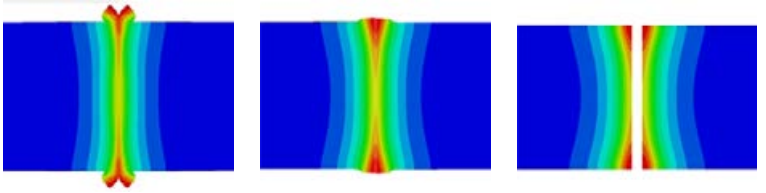
John Vande Voorde & Patrick Goes

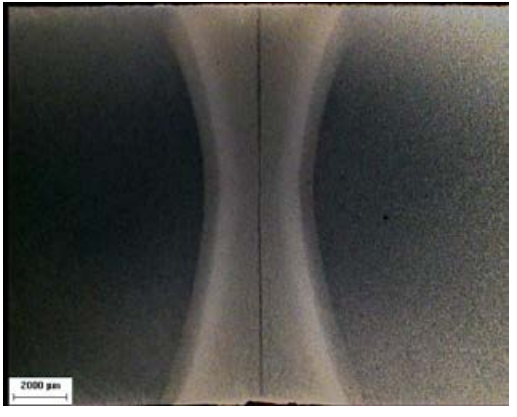
Simulation tools are critical to achieving the target first time right – which is crucial to establishing additive manufacturing as a viable industrial manufacturing process.

Joachim Antonissen

Our numerical model has the potential to improve the weld quality in existing products and speed up the introduction of new pipe materials.

Jan Rens





Metallurgical knowledge, obtained from exploring the possible causes of low weld toughness in HFI welded pipes, is now coupled with our welding process modelling efforts to implement a sophisticated forging control.

Özlem Esma Ayas Güngör

Modelling welding processes

The ability to model welding processes and to predict geometrical, metallurgical and technological process results offers many advantages. The simulations allow fast and precise handling of a great variety of testing scenarios. However, in applications such as welding, the complex physics makes it very difficult to model accurately.

SIGNIFICANTLY REDUCING THE NUMBER OF EXPERIMENTAL WELDING TESTS

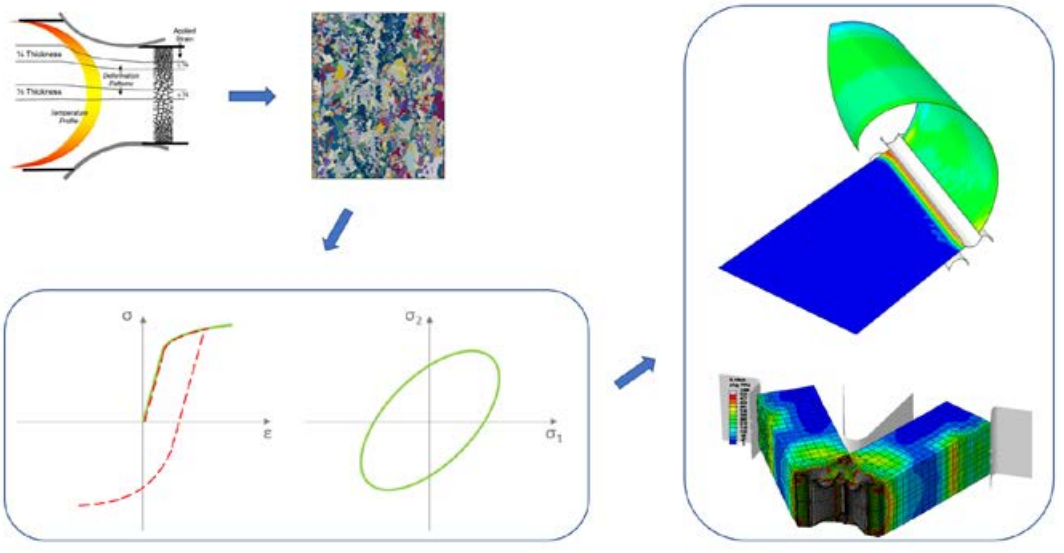
As OCAS and its customers are keen to predict and overcome the occurrence of possible welding issues – such as residual stresses due to distortion, or the metallurgy of the heat-affected zone influencing the hardness – OCAS has teamed up with different research institutions across Europe to develop the toolkit required to formulate answers to these questions.
Currently, OCAS has tools available to predict the weld bead shape and the actual welding heat input and to estimate the microstructural aspects in the weld pool and the heat-affected zone. This allows OCAS to respond to welding requests more efficiently and quickly. In the past, a large number of experimental tests was needed to adequately respond to our customers' requests. From now on, it will be possible to significantly reduce the number of experimental welding tests and still gather enough data to provide technical support for e.g. optimising welding parameters to minimise distortion due to local heat input.

RIGHT FIRST TIME

As speed is essential in many additive manufacturing related business cases, going through iterative product design cycles is not an option. Simulation tools can provide key differentiators for achieving the target first time right.
It is our goal to substantially reduce the experimental work load and number of trial & error iterations required to obtain a fully functional and large-scale component. Thereby contributing to achieving the target right first time, which is crucial for additive manufacturing to establish itself as a viable industrial manufacturing process.

NUMERICAL MODEL FOR OPTIMISING HFI WELDING

Today, High Frequency Induction (HFI) welding is considered to be the most productive line-pipe production method. However, HFI welded pipes suffer from a bad image due to inconsistent weld quality and poor low-temperature toughness of the weld when compared to submerged arc welded (SAW) pipes. Improving existing welding technology requires numerical models to better understand the underlying physical interactions, optimise process parameters, and improve weld properties. In order to enhance our understanding of High Frequency Induction welding, OCAS has developed a numerical model taking electromagnetic, thermal and mechanical effects into account. The model allows us to provide recommendations for optimising the process parameters and implementing a sophisticated forging control, which lead to substantially improving the toughness of HFI welded pipes at our customers.


¼ Thickness
½ Thickness
Deformation Patterns
Temperature Profile
σ
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σ2
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Optimisation of materials, processes and structures in a virtual lab

Finite Element Analysis (FEA) modelling is used to evaluate the performance of structures and components and to optimise their design. Over the last several decades, our understanding of the mechanical behaviour of metals has significantly improved, resulting in advanced phenomenological models and more reliable simulations. Moreover, the continuous increase of computational power and the introduction of other numerical techniques – such as DEM (Discrete Element Method) and PFEM (Particle Finite Element Method) – have led to ever more realistic simulations.

Nowadays, FEA modelling is not only used to assess the behaviour of single components, but also to investigate more complex problems – e.g. to optimise metal forming processes, such as roll forming and stamping, or to assess the structural integrity of pipelines.
Furthermore, huge effort has been exerted in the development of RVE (Representative Volume Element) modelling approaches and physics-based constitutive models – for example, crystal plasticity models. In such models, the material's texture and microstructure are explicitly considered. Hence, they enable us to investigate the relation between microstructure and macroscopic mechanical properties, thus making it possible to optimise a material's microstructure in a virtual lab. In addition, efficient multi-scale material modelling approaches are being developed, so that those physics-based models can also be applied to industrial-scale problems.

TOOLKIT PROJECT

From July 2016 to June 2019, OCAS participated in the European funded project "Toolkit for the design of damage tolerant microstructures". Within the framework of this project, a so-called ICME (Integrated Computational Materials Engineering) approach was adopted to develop steel grades with a tailored microstructure, starting from the desired component behaviour. A set of simulation tools was developed to reproduce the complete chain of material processing and testing in a virtual environment, starting from the production of the raw material up to evaluating the performance at component scale. The proposed methodology was then used in two case studies: one to improve the crack arrest capabilities of modern pipeline steels, and the other to increase the energy absorption of a car crash box.

Academics are developing and using highly advanced models and techniques. It's important to strengthen the collaboration between industry and university, so that those advanced models are employed in industrial-scale problems.

Steven Cooreman

PREDICTION OF MECHANICAL PROPERTIES OF LARGE DIAMETER WELDED PIPE

Over the past few years, OCAS has been developing efficient numerical models, which enable various pipe forming processes to be simulated, with the overall goal of predicting pipe properties from coil/plate properties. The main challenge lies in accurately describing the hardening behaviour, which can be rather complex, as pipe forming involves several strain reversals and strain path changes. Therefore, an advanced phenomenological model was implemented, which was capable of capturing the Bauschinger and cross-hardening phenomena and provides more accurate predictions than conventional models. Furthermore, in collaboration with Katholieke Universiteit Leuven, a Postdoc project was launched to implement a multi-scale material modelling approach, in which physics-based models are considered to describe the material's anisotropy and hardening behaviour.


Super Air Knife

Numerically designed heavy-gauge plate rolling

For steels, the most important mechanical properties are strength, ductility and toughness. The general trend in steel development is to improve all of these properties at the same time and increase the thickness at an affordable cost. In this regard, numerical simulation of steel processing is a very powerful tool for accelerating the time-to-market for new steel products.

THERMO-MECHANICAL ROLLING … RIGHT FIRST TIME

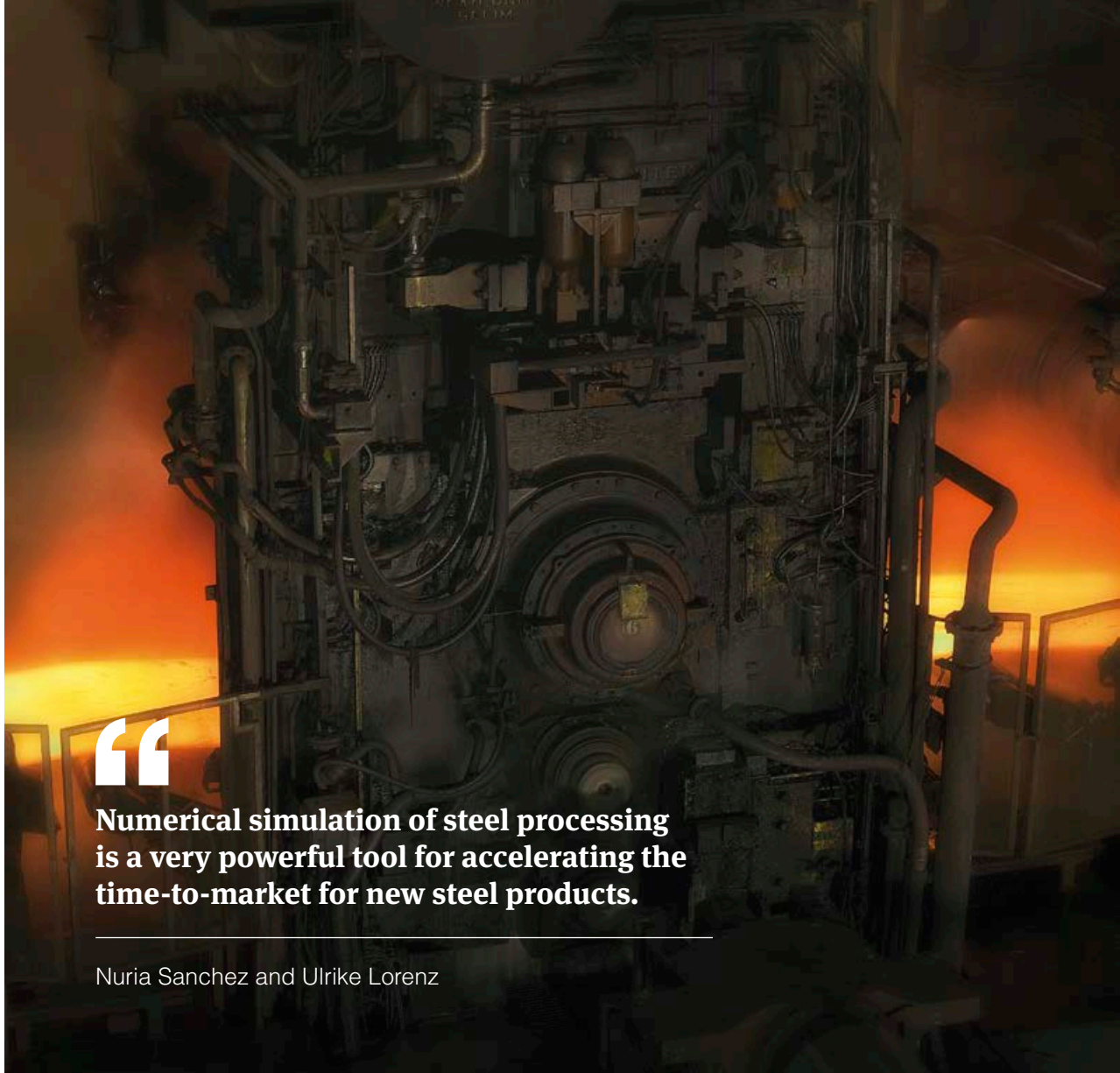
Once the tailored steel microstructure is designed at pilot scale to fulfil product specifications, the industrialisation phase is launched. In this step, the numerical simulation of the industrial processing allows us to define the processing window within the industrial production constraints to achieve the target microstructure, and hence the material's specified properties. Let's visualise this with an example: the thermo-mechanical processing of steel is a processing route that provides the steel properties after hot rolling. This means that the designed microstructure needs to be generated at the end of the process.

Numerical tools allow us to follow up the metallurgical mechanisms occurring during processing as a result of the temperature variations in air or water cooling and deformations applied to the steel during rolling. Thus, the optimised processing conditions can be numerically derived to attain the specific properties.

The main advantage of using numerical tools is that the number of trials needed for industrialisation of a new steel grade drops dramatically. In most cases, numerically designed trials provide successful 'right first time' results, while incremental approaches require iterations based on experience and trial-and-error.

INTERCRITICAL ROLLING

High strength heavy gauge structural steel grades are most often rolled thermo-mechanically (TM). TM-rolling of heavy-gauge steel plates is often performed intentionally in the intercritical austenite-ferrite phase region for three reasons: (1) to increase yield strength, (2) to avoid the deformation gradient across the plate thickness from surface to core, and (3) to minimise thermal gradient due to the high thickness. However, intercritical rolling, followed by air cooling, produces a bimodal distribution of ferrite grain size, which is known for its detrimental effect on toughness.



Numerical simulation of steel processing is a very powerful tool for accelerating the time-to-market for new steel products.

Nuria Sanchez and Ulrike Lorenz

Together with the partners of the European-funded INCROHSS project, OCAS studied the impact of two-phase rolling on the microstructure and the distribution of properties in heavy-gauge steel plates. By means of improved microstructure investigation techniques and modelling, we studied the relation between the temperature gradient, ferrite-austenite balance at high temperature, strain partitioning between phases and subsequent transformation. To predict the behaviour of materials during intercritical rolling, a micro-mechanical model has been set up. Furthermore, this research provides guidelines for a wider and more stable processing window for steels when rolling in the two-phase intercritical temperature region.

2 ENERGY TRANSITION

It's probably not necessary to reiterate that global warming can only be slowed down by a drastic reduction of greenhouse gas emissions – carbon dioxide first of all. Therefore, the general idea behind the so-called 'Energy Transition' is to decarbonise our energy systems. However, with the objective of achieving a carbon-neutral economy by 2050, as targeted in the 2015 Paris Agreement, the challenge is huge. On the one hand, we have to switch rigorously from fossil energy carriers – counting today for about 80% of the global primary energy production – to renewable resources. On the other hand, global primary energy demand is expected to increase by more than 30% by mid-century.

The fading out of fossil fuel consumption is expected to last a long time. The current point of view deems it necessary to shut down coal-fired power plants quickly and to replace them with higher efficiency gas-fired power plants. In parallel, the implementation of Carbon Capture and Sequestration (CCS) is acknowledged to be a suitable means of counterbalancing the continued CO_2 emissions, at least for some decades. Fossil-free technologies do exist – some are mature (like nuclear fission), but cause other environmental concerns. Others, like nuclear fusion, still need a number of years to develop before they can contribute to our energy mix.

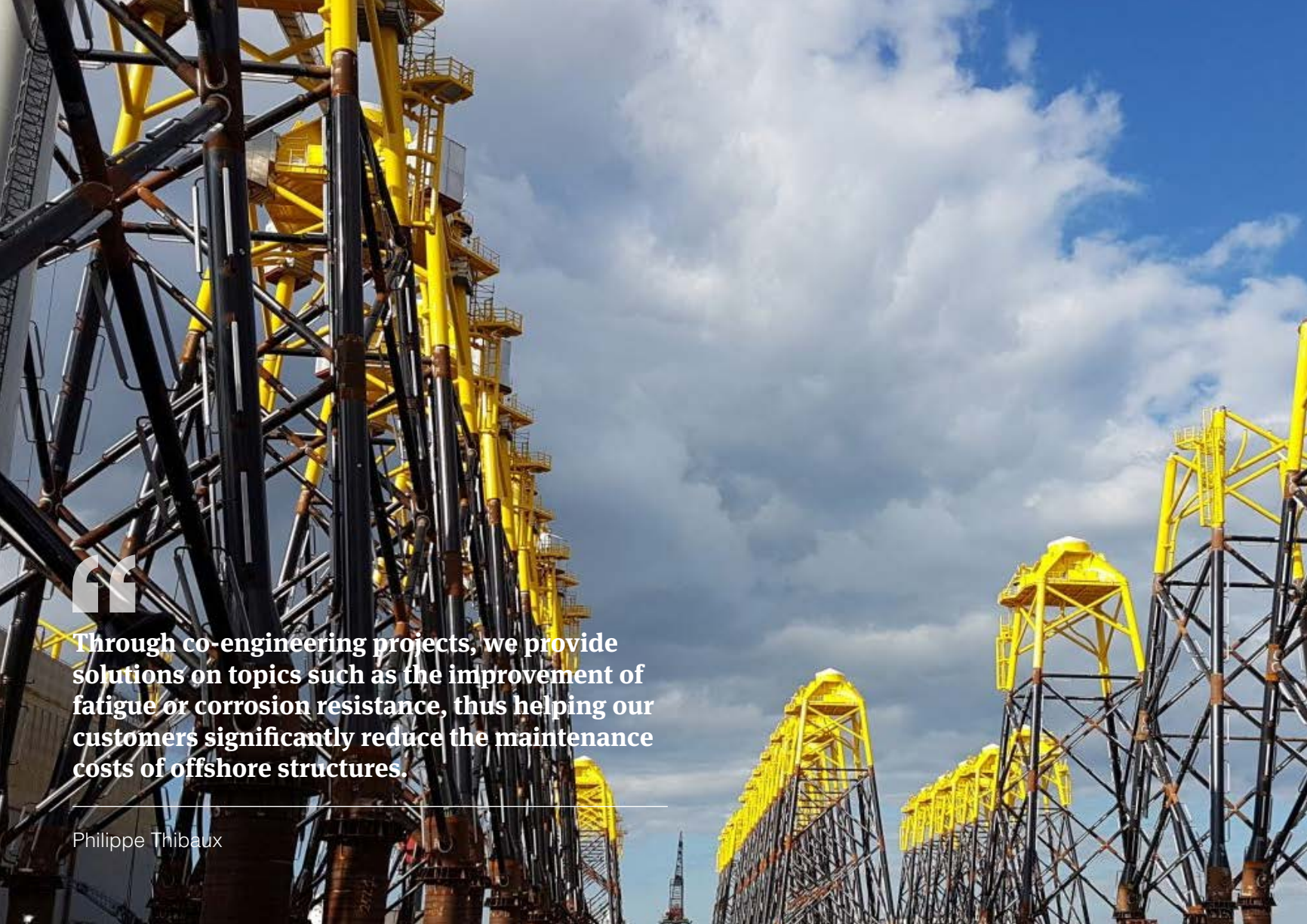
So, for the time being, the core of the Energy Transition remains the generation of electricity using renewable energy resources, like wind, solar and hydro power. By end of 2018, about 600 GW installed wind turbine capacity was reached globally, of which 23 GW are offshore. Even if the installation rate is temporarily slowing down in Europe, wind energy is expected to play the dominant role in our future energy supply. Solar energy, today also representing around 600 GW globally installed capacity, is a suitable choice, primarily in southern regions.

Steel making is strongly affected by the Low-Carbon Economy and the Energy Transition. After publishing its first Climate Action Report in May 2019, ArcelorMittal Europe has recently released its CO_2 roadmap to reduce emissions during steel production by 30% by 2030, with the further ambition to be carbon neutral by 2050.

At the same time, the Energy Transition offers new opportunities to serve a growing market. For example, already today, the ArcelorMittal group is supplying substantial amounts of heavy plate for the windtower market and Magnelis® coated sheet for the support structures of photovoltaic solar power plants. The overall market outlook is promising, given that installations like

concentrated solar power plants or offshore wind parks are constructed with several hundred tonnes of steel per MW installed capacity.
As the research centre supporting ArcelorMittal in the energy market for many years now, OCAS has been playing a leading role in providing information concerning technology trends and market data related to the Energy Transition. We have also identified some of the technological challenges and research topics that need to be addressed to speed up the clean energy economy, and we are keen to work on it.
Our confidence that we can deliver is based on our experience and the expertise we've built up in the past. Some examples are mentioned in this chapter. To begin with, the market success of Magnelis® has its roots at OCAS. We continue to support its application at our customers. And we've already launched the development of an even improved version. Thanks to our network in the offshore wind industry, we are familiar with the concerns of the different stakeholders and are closely collaborating with them in the field of fatigue and corrosion protection. Here, as in many other cases, the aim is to help customers identify the most cost-effective solutions for their installations – which means, in this specific case, reducing the total cost of electricity production and, eventually, accelerating the Energy Transition. Likewise, we are seeking cheaper cryogenic steel solutions for the storage of liquefied natural gas (LNG), a market that is expected to grow considerably in the near future.
OCAS has a long track record in the development of electrical steels for motors and generators. New steels, together with our support for the design of motors, will help to make optimum use of electrical power, in particular in the transportation sector. It goes without saying that the automotive industry is currently in the middle of a steep transition to electrification, with the prospect of a booming market for OCAS.
We consider our expertise developed in our hydrogen lab to be one of our strongest assets for future steel solutions. Hydrogen is a clean energy carrier and will be increasingly used for energy storage of renewable power or fuel-cell powered cars and trucks. However, under service conditions during hydrolysis or redox reactions, the surrounding material, usually steel, may be stressed by highly corrosive conditions. Here again, the challenge is to develop cost-effective solutions for lowering the barrier to the implementation of clean energy. In collaboration with our spin-off company Borit – which has direct access to the markets as a component provider – we believe we are perfectly positioned to facilitate this task.
On many occasions, OCAS has proven its ability to provide comprehensive steel solutions, comprising the choice – if not the development – of steels, their corrosion protection, processability, weldability and in-use performance, often in combination with structural design support. We are sure we can assist the energy market in making the right choices for the future.
We want to contribute our part to solving the most important challenge facing humankind in the 21st century.

— *Martin Liebeherr*



Through co-engineering projects, we provide solutions on topics such as the improvement of fatigue or corrosion resistance, thus helping our customers significantly reduce the maintenance costs of offshore structures.

Philippe Thibaux

Solutions for wind power

Wind energy is one of the most important sources of renewable energy. Offshore wind turbines consist of steel structures that are submitted to large and variable loads in harsh environments, such as low temperatures in the North of Europe or corrosive conditions in the sea.

Over the years, OCAS has built in-house expertise to help companies develop the most efficient structures under the safest conditions. Our knowledge of physical metallurgy is of particular importance for the development of steel grades with adequate properties – strength, toughness, corrosion-resistance and weldability – for the production of wind turbine towers or offshore foundations.

Welding is the method of choice for many parts of the construction. The industry can count on OCAS's submerged arc welding system to produce representative components and evaluate their behaviour in small- or large-scale tests.

Applications for use at low temperature require knowledge of fracture toughness (for selecting material, for example). OCAS has a wide variety of experimental and modelling tools for investigating the behaviour of the material and defining safe conditions.

Variable loads due to turbulences, rotation of the rotor, or waves make fatigue the critical load case in the design of wind turbine support structures. OCAS has investigated ways to optimise steel foundations in order to increase their fatigue resistance. Today, OCAS has unique large-scale fatigue testing capabilities, operating more than 20 times faster than alternative test benches in industry. OCAS also works in close collaboration with many actors in the wind industry – through Joint Industry Projects (JaCo, Crown), subsidised projects (JaBaCo, Fatcor, ...), and direct contacts.

Thanks to the recent collaboration with Endures, OCAS has enlarged its services in the field of corrosion protection and testing facilities for the offshore and marine environment.

OFFSHORE PRE-QUALIFICATION FOR ARCELORMITTAL'S OFFSHORE PLATE OFFER

One of the key features of ArcelorMittal's offshore plate offer is its enhanced weldability, which ensures the steel can be welded without deteriorating its high strength or excellent toughness. This is proven by performing so-called pre-production qualification (pre-qualification, in short), which demonstrates the steel's inherent suitability for component assembly using welding. The most common standards for offshore pre-qualification are EN10225, NORSOK M-120 and API RP2Z, and they outline in great detail the requirements that the steel has to meet, including third-party oversight during all aspects of the pre-qualification campaign. OCAS has successfully performed multiple pre-qualifications for a number of ArcelorMittal

Our submerged arc welder, heavy-duty fatigue set-ups, and unique metal processing equipment enable us to support new product development for the most demanding offshore applications in the energy sector.

Ulrike Lorenz & Christoph Gerritsen

plants and products. This has allowed us to hone and optimise the approach, fulfilling the challenging requirements.
In addition, OCAS is involved in other welding-related projects, such as the investigation of high-productivity plate welding techniques, to expand the plate weights that can be delivered. In this light, OCAS also organised an international seminar together with the Belgian Welding Institute in October 2019. The seminar, on the topic of high-productivity welding processes for thick section steels, brought many international speakers and participants together, including important ArcelorMittal plate customers.

SALINE WEATHERING RESISTANT GRADE DEVELOPMENT

Weathering steels have grown in importance in the market, as they show a significantly higher resistance to atmospheric corrosion than regular carbon steels. The enhanced corrosion resistance of weathering steel is attributed to the formation of a dense and well-adhering patina, which effectively inhibits damage to steel structures, prolonging their lifetime and repainting cycle.
In the revision of standard EN10025-5, describing weathering structural steels, a high-strength variant is introduced with yield strength up to 460 MPa and a toughness requirement at low temperatures. These structural steels are applied primarily in the construction of bridges, wind turbines, aesthetic constructions, and containers. Together with the ArcelorMittal Gijon steel plant, OCAS is developing a thermo-mechanically rolled steel grade that incorporates these new high-strength requirements.
Current standards for offshore grades (EN 10225 and API 2W) focus on toughness and weldability, while weathering resistance is not addressed. In a multidisciplinary approach, OCAS is developing an offshore steel grade with enhanced saline corrosion properties that still retains good toughness and weldability.

For 15 years OCAS has been expanding its capabilities for H-related research. As such we believe we are well armed to thoroughly tackle the technological challenges in multiple applications. The response to our "SteelyHydrogen Conference" confirms that our international recognition in this field remains top of mind.

Lode Duprez

How hydrogen research fuels the future

The most abundant element in the universe, hydrogen is also a promising source of 'clean' fuel. However, some issues still remain to be resolved first of all.

For more than 15 years, OCAS has been developing tools, methodologies and techniques to address the various aspects related to the presence of hydrogen in steel and metals in general. This has resulted in a large international network and the related recognition. In that context, OCAS organised its 3rd international 'SteelyHydrogen' conference in May 2018 – following two successful SteelyHydrogen conferences in 2011 and 2014, both of which were attended by more than 100 participants. For this third edition, the scope was enlarged to other metals, such as Al, Ni and Ti.

AN OVERALL SUCCESS

'SteelyHydrogen' – the International Conference on Metals and Hydrogen – allowed us to obtain a global view on today's international research on hydrogen in metals. With an attendance exceeding 170 participants, more than 100 scientific contributions on a variety of metals and applications were displayed and presented. This 3rd conference was very well received, as evidenced by the feedback from the attendees. A selection of papers has furthermore been published in a special edition of the scientific journal "Corrosion" (August 2019, Vol. 75, Issue 8 879). Taking all these factors into consideration, the conference was a real success from the organisational, scientific and networking points of view.

OCAS's most recent hydrogen-related activities focus on four domains:

- The launching of dedicated activities in relation to the energy transition that is required to solve global warming, where we focus on the assessment of actual and future infrastructure for the storage and transport of hydrogen.
- Continued competence building – tools, methodologies and techniques – to address hydrogen embrittlement issues that new metal products may encounter in their in-use applications.
- A clear effort in terms of on-line sampling, detection, measuring and monitoring of hydrogen during the various steel production steps. OCAS's activities in quality control testing of the industrial production of advanced high-strength steels have enabled us to validate an in-house model for predicting the hydrogen evolution during the steel process.
- Using deuterium as hydrogen tracer is a powerful technique for assessing hydrogen pick-up during industrial processes. The combination of the existing metallurgical lab simulation capabilities and the use of deuterium allows OCAS to simulate multiple treatments in which deuterium (instead of hydrogen) is introduced into the material. This methodology has been implemented on several product studies to first analyse and then suggest production optimisations that reduce hydrogen pick-up on industrial process lines.

Now, with great anticipation, OCAS has started preparing for the 4th edition of SteelyHydrogen, scheduled in 2021.

In collaboration with ArcelorMittal, OCAS has developed Magnelis®-coated HyPer® steel grades to meet the solar market's needs for even stronger and more ductile steel grades that are also lighter, thinner and more corrosion-resistant.

Ansbert De Cleene & Arunim Ray

Magnelis® protects solar structures

With excellent in-use properties and a wide range of feasibility, Magnelis® is one of the best-in-class and most cost-effective solutions for photovoltaic solar structures. Since its launch, Magnelis® has been selected by many manufacturers around the world to provide superior protection for long-lasting solar mounting structures, even in the harshest environments.

Solar photovoltaic plants are designed to last at least 20 to 25 years. They are built in various climate types (tropical, industrial, ...), in different locations (deserts, sea shores, islands, ...) having a variety of geological soils, including the most aggressive. The supporting structures of these solar panels must withstand these conditions while generating minimal maintenance costs.

Models are needed to predict the lifetime of the structures resisting harsh environments for decades at a time. Therefore, in 2016, OCAS started field exposure in its new excavated pits at its Zelzate site. These pits have different soil compositions and are large enough for experiments with varying geometries, such as poles, profiles, flat samples and wires. The corrosion rates are monitored by weight loss, coating thickness and corrosion product analysis.

Our outdoor soil exposure site enables OCAS to compare the performance of coatings, such as Magnelis®, with other hot dip galvanised or batch galvanised products. To date, Magnelis® is outperforming batch galvanised steel in different soils. In addition, accelerated soil corrosion lab tests are also being conducted. Conducting these experiments in parallel gives us a deeper understanding of the soil corrosion mechanisms and enables us to make more accurate metallic coating lifetime predictions in different soil environments.

SHIFT TOWARDS HIGH-PERFORMANCE 'HyPer®' GRADES

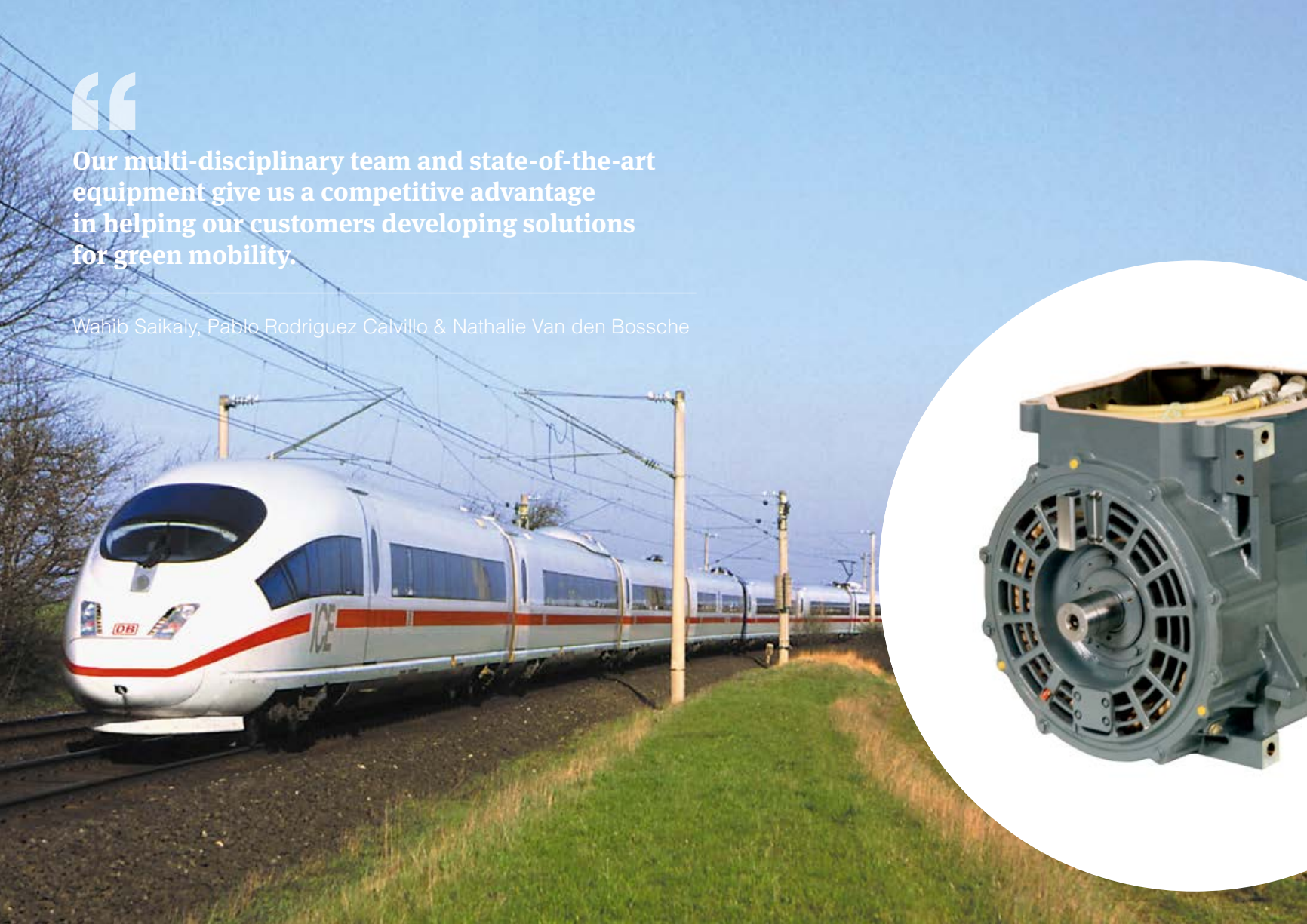
The current interest in metallic-coated structural steel grades for solar markets is shifting towards increasingly stronger – yet lighter, thinner, more ductile and corrosion-resistant – steels in order to build structures that are more reliable, strong and durable, long-lasting and affordable. In collaboration with various ArcelorMittal plants across Europe, OCAS is currently developing an extended family of Magnelis®-coated high-performance steel grades (under the 'HyPer®' brand) to meet the manufacturers' ever-increasing demand.

Starting from small lab-scale experiments, OCAS has developed robust and flexible metallurgical concepts using tightly controlled chemical compositions and strengthened fine-scaled microstructure. In recent months, successful industrialisation of the metallurgical concepts at different ArcelorMittal plants has led to the first commercial Magnelis®-coated high-strength steel, with more than 700 MPa yield strength and showing excellent ductility and in-use properties.

OCAS is currently optimising the metallurgical routes to extend the ArcelorMittal 'HyPer' offer for the various strength levels at different thicknesses, combined with a range of coating weights for multiple ArcelorMittal galvanising lines.

Our multi-disciplinary team and state-of-the-art equipment give us a competitive advantage in helping our customers developing solutions for green mobility.

Wahib Saikaly, Pablo Rodriguez Calvillo & Nathalie Van den Bossche



Green solutions for tomorrow's mobility

The family of electrical steels produced by ArcelorMittal and conceptualised by OCAS is a perfect example of the innovative solutions that are essential for the preservation and well-being of our environment. These electrical steels are the back-bone of the increasingly indispensable electric vehicles that are strongly on the rise worldwide.

In electric vehicles, electrical energy is transformed into mechanical energy to drive the vehicle. Electric machines are composed of several components, such as copper windings, insulation and magnets. Acting as an excellent magnetic path to produce the required torque, electrical steel is the heart of electric machines.

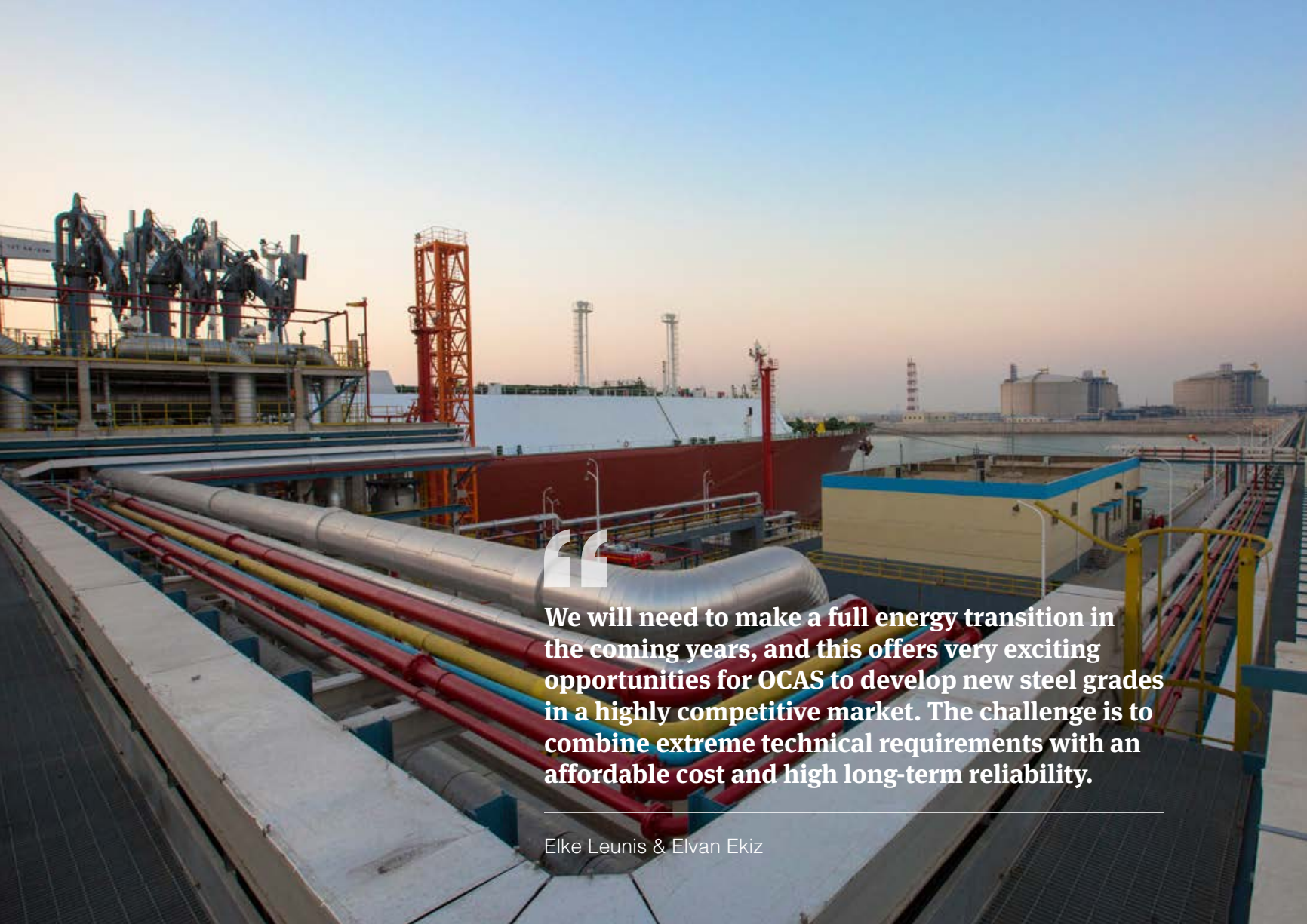
iCARe® ELECTRICAL STEEL GRADES

Market requirements increasingly need traction motors that deliver high torque in a wide speed range at the highest efficiency level. In addition, low iron-loss is crucial for high-efficiency electric machines. Furthermore, high-speed traction motors require electrical steel grades with high mechanical strength. Finally, traction motors need to be compact in order to reduce weight and volume.

Thanks to concepts developed by OCAS, ArcelorMittal offers a wide range of electrical steel grades, which are now ramping up strongly under the name iCARe®. iCARe® Save grades provide minimal iron loss, resulting in significant motor weight reduction. They are especially useful for reducing iron losses in high-speed hybrid and electric traction machines, and generators which extend the driving range of electric vehicles while keeping the same battery cell size. iCARe® Torque grades provide a high polarisation capability, allowing the motor to develop more mechanical output and thus ensuring fast acceleration. iCARe® Speed grades, to be used in the rotor, provide an excellent compromise between mechanical properties and losses. ArcelorMittal offers all these grades with a thin lamination to meet the increasing frequency levels from power electronic converters.

OCAS'S UNIQUE AND LONG-STANDING EXPERTISE

OCAS's expertise in the field of modelling electrical steel motors is unique – combining our in-depth material knowledge, the availability of an advanced lab that is well equipped for magnetic and electrical characterisation, and our strong modelling capabilities. Such expertise enables more accurate designs and reduces the number of prototypes required to industrialise a motor.
Coating is another field in which OCAS has long-standing expertise. The coating is essential to isolate the thin stacked electrical steel lamella. Control of the composition, thickness, roughness and other aspects of such a coating is of crucial importance for good motor assembly, and thus it's final performance.



We will need to make a full energy transition in the coming years, and this offers very exciting opportunities for OCAS to develop new steel grades in a highly competitive market. The challenge is to combine extreme technical requirements with an affordable cost and high long-term reliability.

Elke Leunis & Elvan Ekiz

Cryogenic steels as short- and long-term energy solutions

The global use of gas will increase significantly, mainly driven by higher use of liquefied natural gas (LNG). LNG needs to be produced, stored and transported in liquid state, below -163°C. This imposes the use of special materials, with extremely good low-temperature toughness.

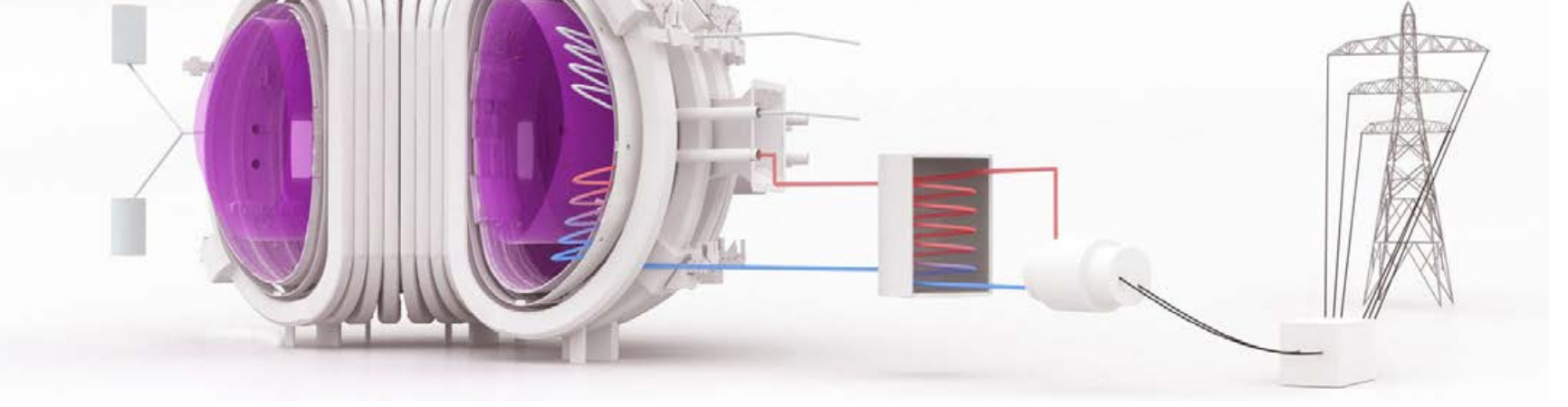
Advanced – but costly – steels are currently being used throughout the entire supply chain, from the liquefaction plant, to vast ocean tankers, to the final transportation and storage close to the end-user. So, improved cryogenic steels are ideally positioned to support new developments in energy transition. Gas fuel sources, especially LNG, are poised to enter a 'Golden Age' – a near future in which the global use of gas will increase significantly.

GETTING READY FOR THE 'GOLDEN AGE OF GAS' IN THE SHORT-TERM

ArcelorMittal has already built a strong reputation in delivering heavy plates in the cryogenic industry, such as for the construction of large-scale LNG storage tanks and large cryogenic pipes. However, a large part of the equipment in the LNG supply chain does not require such high thicknesses. Therefore, OCAS has investigated the production of cryogenic steels in thin gauges.
Production of pipes and tubes is also being considered. These studies include both metallurgical concepts with a proven track record (typically, high Ni steels) and new concepts that are expected to offer the optimum balance between cost and performance.

PREPARING FOR THE HYDROGEN ECONOMY IN THE LONG-TERM

Although the use of LNG is expected to reduce the impact of fossil fuels on the climate and the environment, significant greenhouse gas emissions will continue. A possible scenario for further reducing carbon emissions dramatically is the use of hydrogen as a fuel. Just like LNG, the production, transport and storage of hydrogen will likely be carried out in the liquid phase – at least partially. Hydrogen's extremely low liquefaction temperature (-253°C) and the sensitivity of steels to hydrogen embrittlement demand special steels to withstand such conditions. High Ni steels, which are well known for LNG applications, are not suitable for hydrogen applications. Thus, the new metallurgical concepts OCAS is developing for LNG are also being designed to be suitable for the hydrogen economy.



I really appreciate the openness of the OCAS colleagues with whom we run joint projects. Also, I underline their willingness to discuss problems openly and be ready to look for flexible solutions in case of certain technical issues.

Dmitry Terentyev, Head of Expertise Group on Structural Materials and Program Manager of Fusion R&D at SCK.CEN, Belgian Institute of Nuclear Material Science

As an OCAS research engineer, it is great to be part of the nuclear fusion community, tackling technical issues first hand.

Athina Puype

Towards fusion energy

The European Climate Foundation published a study in 2010 on how to reduce greenhouse gas emissions by 2050. The study showed that the annual power demand of 29 European countries will increase by roughly 50% from 2010 to 2050. Primary sources of the world's energy mix will be fossil fuels, nuclear energy, and renewables such as solar and wind energy.

The existing power installations, which are presumed to still be operational in 2050, will only be able to provide a marginal amount of the future power demand. The power shortage should ideally be filled by carbon-free energy sources – preferably, renewable energy sources or nuclear energy – to reduce the greenhouse gas emissions resulting from energy generated by fossil fuels.

FROM FISSION TO FUSION

Currently, nuclear energy is generated by fission power plants that generate energy via a nuclear chain reaction in which uranium nuclei split into lighter nuclei by absorbing neutrons. The disadvantages of this fission reaction are that it produces nuclear waste and nuclear accidents can occur if process control is insufficient.

In contrast, a nuclear fusion reaction is an inherently safe reaction, as any deviation from the optimal reaction conditions stops the fusion reaction. The additional attractive prospects of fusion energy are underlined by this quote from Stephen Hawking: "I would like nuclear fusion to become a practical power source. It would provide an inexhaustible supply of energy, without pollution or global warming."

DESIGNING STRUCTURAL MATERIALS FOR FUSION REACTORS

The realisation of the first fusion reactor to be linked to the energy grid – called DEMO – will be enabled by, among many other things, the appropriate choice of structural materials to be used in the reactor. Fusion reactor materials are expected to face high neutron doses, high temperature and/or corrosive attacks simultaneously. Therefore, new materials need to be developed, or current structural materials need to be adapted, for adequate performance in these severe, and largely unprecedented, working conditions.

For several years now, together with institutes in the nuclear sector working towards the realisation of fusion energy, OCAS has been working on the production or optimisation of several types of structural materials for fusion reactors.

We are now part of the community in which all key players are represented.

3 DURABILITY & LIFETIME PREDICTION

The industrialised world is facing huge challenges in the coming decades – whereby the scarcity of resources and global warming are driving us towards better implementation of the circular economy principles. Steel turns out to be an excellent candidate on this quest, as it is almost 100% recyclable and always ranks high against competitive materials in a full Life Cycle Assessment.

Furthermore, in-use steel performance is expected to reach outstanding new highs for many future application fields – whether it be wear performance, improved fatigue behaviour, corrosion performance, high temperature or fire resistance, or a complex combination of these qualities. In this way, steel innovation not only contributes positively to resource scarcity, but also to extending the lifetime of the current ageing infrastructure.

OCAS continues to contribute to the search for improved durability in multiple ways. First of all, by developing brand-new steel grades, microstructures and coating solutions, outperforming current solutions by more than a factor of 10 in the most extreme cases. Secondly, by optimising the design of applications and by developing lifetime prediction tools and models that allow us to extend the lifetime of critical structures substantially.

In recent years, OCAS has developed an impressive set of unique extreme test condition set-ups that allow us not only to test critical designs close to real load conditions, but most importantly, to validate developed lifetime prediction models and tools for their reliability in real applications in real conditions.

In the domain of wear and abrasion, OCAS has continued to develop and improve relevant test methodologies and link them to real wear behaviour for certain applications. These tests allow us to rank a whole series of new metallurgies and identify key domains for optimised use. This approach could be applied to cases of offshore wear performance in jack-up legs.

In the same spirit, we continue to develop unique semi-component – and even large-scale – test set-ups to investigate fatigue performance. These initiatives are enabling us to refine our fundamental

metallurgical know-how regarding fatigue and to apply it to improving offshore structures and components. Furthermore, along with new metallurgical developments towards stronger and thicker steels, OCAS has invested in a new powerful press to investigate the bendability of these new steel grades.

In the context of the development of gas-tight pipeline connections and downhole casing and tubing lines, OCAS has developed, together with the ArcelorMittal team in Houston, a state-of-the-art premium threaded pipe connection, branded AM-BLADE.

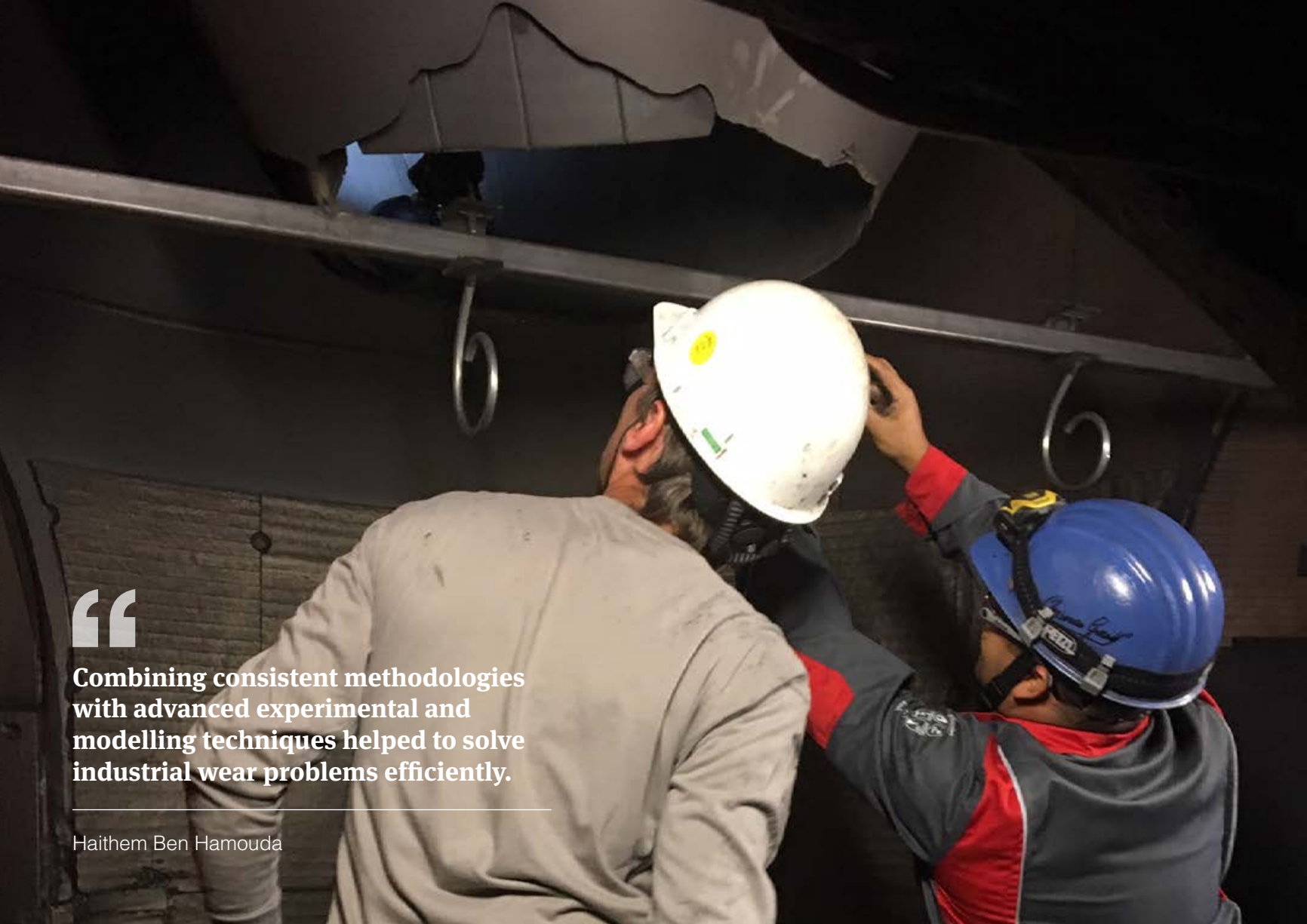
Increased energy demand has compelled the oil and gas sector to shift activities to harsher environments, leading to increasing issues with sour corrosion. OCAS has continued to extend its capabilities in terms of assessing sour corrosion behaviour, from an experimental as well as from a modelling perspective. This enables OCAS to provide effective support to customers dealing with sour corrosion.

Our corrosion work is inspired by the very successful industrialisation and ramp-up of our Zinc-Aluminium-Magnesium coating Magnelis®. We continue to answer customer requests and develop demonstrators to highlight the coating's outstanding performance in a variety of domains – such as solar farms, buried soil applications, farms, safety barriers, lighting poles, and many more – which require accurate and relevant accelerated corrosion test methods.

On top of that, we are exploring exciting new candidates for the next-generation of metallic coatings with even stronger protection, better appearance and/or reduced cost.

With Endures as a sister company, we have fortified our experience in the field of maritime corrosion, a domain that's growing in importance, because improving maritime corrosion protection is an absolute must for many energy generation systems. Our newly developed saline weathering grade shows more and more potential for being the next big thing for steel solutions in maritime environments.

— *Tom Waterschoot & Sofie Vanrostenberghe*



Combining consistent methodologies with advanced experimental and modelling techniques helped to solve industrial wear problems efficiently.

Haithem Ben Hamouda

Testing methodology boosts new material development

Wear occurs in almost every application where contact and friction define the main interaction mode. Lab testing methodologies generally try to isolate the tribological system from the industrial application by projecting the contact mode to smaller scale, making it easier to control.

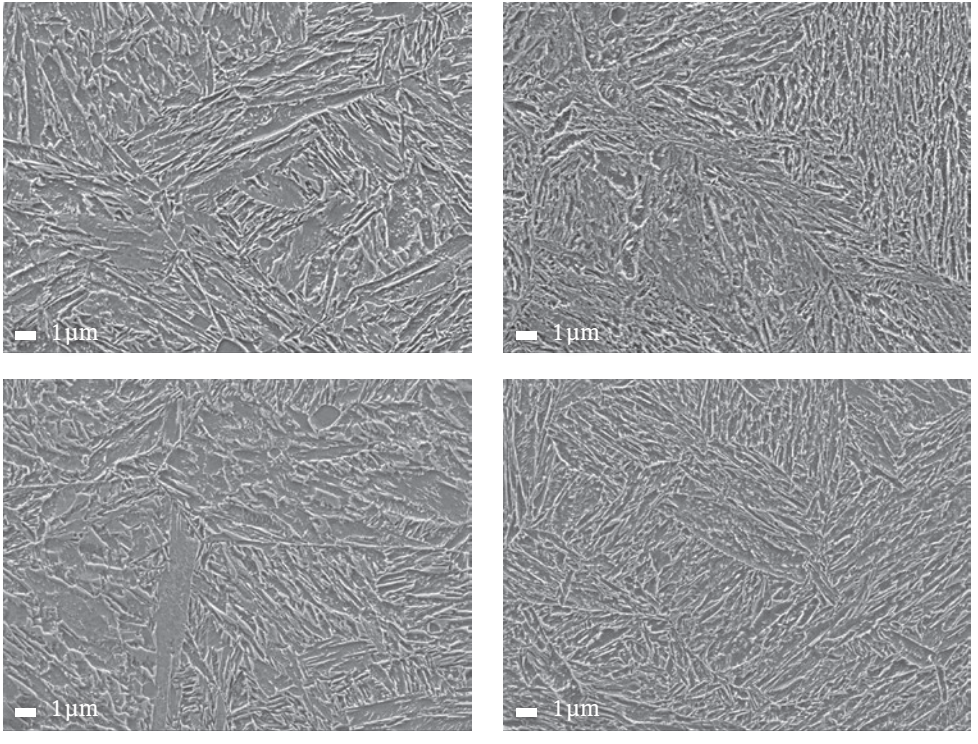
WHEN TESTING METHODOLOGY AND MATERIAL SCOPE MEET

Sliding abrasion, as observed in agricultural equipment (e.g. tiller tines and ploughing discs), is the main contact mode affecting tool lifetime. OCAS provides reliable lab testing methodologies to simulate this abrasion mode under controlled parameters such as normal load, sliding speed and lubrication level. Accelerated sliding abrasion tests performed at OCAS generate valuable data to assist the user in selecting the best material considering the in-use properties (e.g. weldability and bendability). When the contact mode is impact rather than sliding, as observed in mining applications, the abrasive wear failure and the material's ranking are different from sliding. To illustrate: precipitate-hardened steels are grades that rely on hard precipitates (e.g. carbides) to resist the scratching action of the sliding abrasives. However, the same precipitates, when impacted by the abrasive particles, are brittle and easily pulled out, causing more material to be removed.

Understanding these differences in wear performance for the same material requires a consistent post-analysis of the wear mechanism and a full understanding of the material microstructural features. For this purpose, OCAS provides advanced characterisation techniques, such as Scanning and Transmission Electron Microscopy (SEM and TEM), as well as microhardness and nano-indentation, helpful tools for qualifying wear mechanisms. Additionally, OCAS can also perform in-line monitoring of the abrasive wear using techniques such as Acoustic Emission (AE), light microscopy and friction sensors. These techniques have proven to be effective in detecting the threshold forces corresponding to a change in the wear mechanism from plastic deformation to cracking or delamination.

PORTABLE TECHNOLOGIES READY FOR IN-FIELD WEAR INSPECTION

In-field wear inspection is used to study the origin of component failure or to demonstrate material performance. In both cases, OCAS has numerous portable technologies (e.g. portable hardness,



OCAS has played a key role in the industrialisation of wear-resistant steels and the development work continues, striving for ever-increasing component lifetime.

Koenraad Theuwissen

ultrasonic thickness measurement tool, etc.) for monitoring the wear process. This approach combines valuable answers concerning possible wear failure time and origin with other factors such as corrosion and temperature. Based on this input, material selection and design recommendations are given to the customer and validated by a test-case demonstration. For the development of wear-resistant grades, these test methodologies are key in identifying the wear mechanisms active in different abrasion conditions and, thereby, in selecting the most suitable metallurgical concepts for a given application.

The output of the advanced wear characterisation helps OCAS's product developers design next-generation wear-resistant steels. They typically combine specific chemical compositions and elaborate manufacturing processes. The resulting multiphase materials show special microstructural features that provide tailored combinations of wear resistance and in-use properties.

SMART VIRTUAL TOOLS FOR NEW MATERIALS DESIGN

Advanced micro-mechanical modelling techniques allow us to deal with wear in a virtual approach. These techniques, although phenomenological, differ from traditional constitutive mechanical material models as knowledge of the materials' microstructural heterogeneity (such as grain size, shape, crystallographic orientation, etc.) is also included. This information is needed to predict where fracture will occur.

The new grades combine outstanding wear performances, such as very high hardness and strain hardening capacity, with good formability. This is beneficial for customers producing components that are subjected to heavy abrasion – such as tipping wagons, excavators and conveyors – as well as the end-users of the machines.

Despite the tight time frame, we were able to resolve the wear issue successfully.

Philippe Thibaux

Wear on the leg of a jack-up vessel

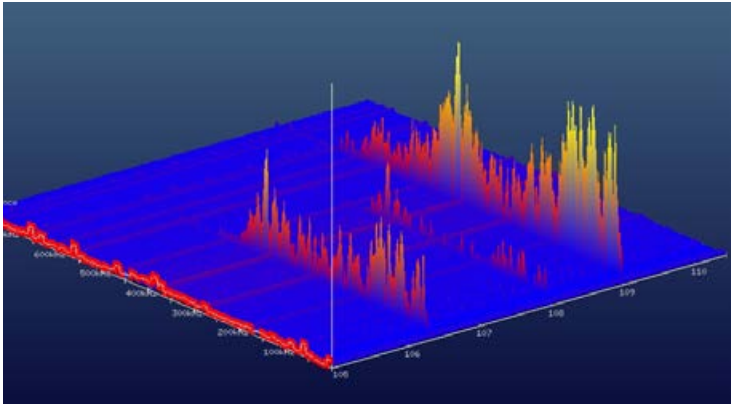
Jack-up vessels are self-elevating units with movable legs providing a mobile platform over the surface of the sea. These are typically used for offshore and wind farm installation and service platforms.

OCAS was contacted to investigate how to mitigate the effect of wear between a rack and a guiding plate for a jack-up vessel. The guiding plate was made of wear-resistant material. The rack, in the shape of a toothed leg, was made of a high-strength steel. The contact between the teeth and the guiding plate is characterised by a very large normal load applied on the reduced contact surface of the teeth. Under such a high contact pressure, severe plastic deformation and intensive wear are present. The investigation was meant to determine whether, during major maintenance of the jack-up vessel, a different material could be selected for the guiding plate to reduce such heavy wear on the teeth.

A SUCCESSFUL TEST CAMPAIGN UNDER TIME PRESSURE

An experimental test campaign was set up to investigate the metal-metal contact by applying lubricants and using a set of different types of materials, under various operating conditions (applied pressure). The wear on the teeth was successfully measured based on controlled tribological conditions: lubrication, surface roughness, load and sliding speed, and in-line monitoring techniques for thickness reduction. Both the material and the operating conditions proved to be of high importance in wear, with thickness reduction ranging between factors of 1 and 10^4 for a given sliding length. The lower the thickness reduction measured on the tooth material, the better the wear performance would be on the rack. On the other hand, the very high reduction factor (10^4) would mean severe wear after only a few jacking operations.

The experimental campaign was accomplished in a tight time schedule that was driven by the maintenance schedule. The experiments had to be finished on time to order and install the material before the end of the ship's repair in dry dock. The challenge was met successfully – and, today, the ship is equipped with the new guiding plates.



Acoustic emission is a powerful tool for online crack detection, thanks to the direct online availability of frequency information up to 1 MHz.

Maarten Van Poucke

The instrumented bending press not only allows us to determine the minimum guaranteed bending ratio, but also provides other useful information for our customers, such as the required bending force and the springback angle.

Steven Cooreman

The power to bend high strength heavy-gauge up to 25 mm thick

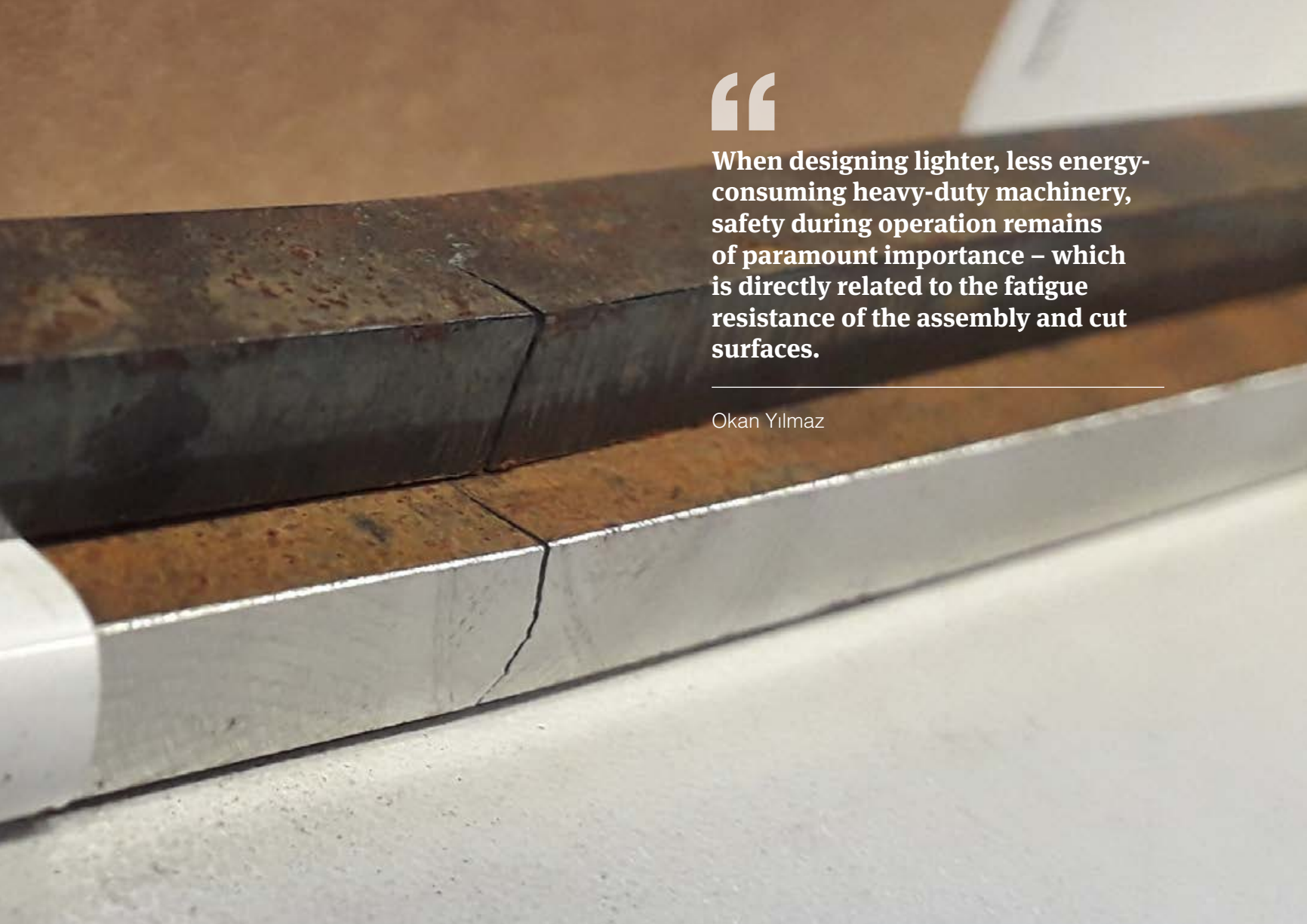
The heavy machinery market is seeking to improve the performance and efficiency of its products. To reduce the maintenance cost and to prolong the lifetime of this equipment, heavy-gauge advanced high-strength steel grades are becoming increasingly used.

A major part of the new metallurgical developments is oriented towards the production of ever stronger and thicker steel grades, such as FeMn grades, maraging steels and martensitic steels. Those grades are mainly, if not solely, deformed by bending. Therefore, their bendability must be evaluated as part of the qualification process. In general, the bendability of a material is expressed by means of the minimum guaranteed bending ratio – i.e. the smallest possible ratio of punch radius to sheet thickness for which no cracks can be observed by visual inspection.

As the required bending force strongly depends on the material's strength and thickness, ever more powerful presses are required to bend those heavy-gauge, high-strength grades. Therefore, OCAS has invested in a new servo-hydraulic press with a capacity of 1500 kN. The press is equipped with a fixture for 3-point air bending, making it possible to bend samples up to 25 mm thick. The press is instrumented to capture force, punch displacement and bending angle, providing useful information such as required bending force and springback angle.

DETECTING MICRO-CRACKS TO THE MICROSECOND

In addition, OCAS has purchased an acoustic emission monitoring system, which enables us to detect crack initiation during bending tests. So, it's possible to interrupt the test once the first crack has been detected. That way, we can identify which microstructural feature is causing crack initiation, thus improving our understanding of the relation between microstructural/metallurgical features and bendability.
This technique is also used for other in-use property performance tests.



When designing lighter, less energy-consuming heavy-duty machinery, safety during operation remains of paramount importance – which is directly related to the fatigue resistance of the assembly and cut surfaces.

Okan Yılmaz

Lighter design without compromising on in-use safety

Lately, there has been an increasing demand for ultra-high-strength steels (UHSS), as they permit weight reduction in heavy-duty applications such as trucks, trailers, cranes, and agricultural machinery, where significant fatigue resistance is important. For instance, reducing the weight allows for longer booms or more elevated loading capacity. In response, OCAS has designed the Amstrong® Ultra MCL series to meet the stringent toughness and fatigue resistance requirements for these applications.

It is commonly believed that the fatigue limit can be increased by increasing the static strength of the material, either by heat treatments or by modifying its chemical composition. However, the trend is lost at very high tensile strength values – that is, the fatigue limits attained no longer give a proportional increase with the static properties. This is generally attributed to inclusions present in these grades, which act as micro-notches that initiate cracks. Hence, the fatigue characterisation of UHSS is not a straightforward task and requires a thorough understanding of additional mechanisms, which are not relevant for milder structural steel grades. Full fatigue characterisation of UHSS grades showed us that they can live up to the constraining fatigue standards of the related applications.

HOW CUT-EDGE AND MANUFACTURING EFFECTS IMPACT FATIGUE RESISTANCE

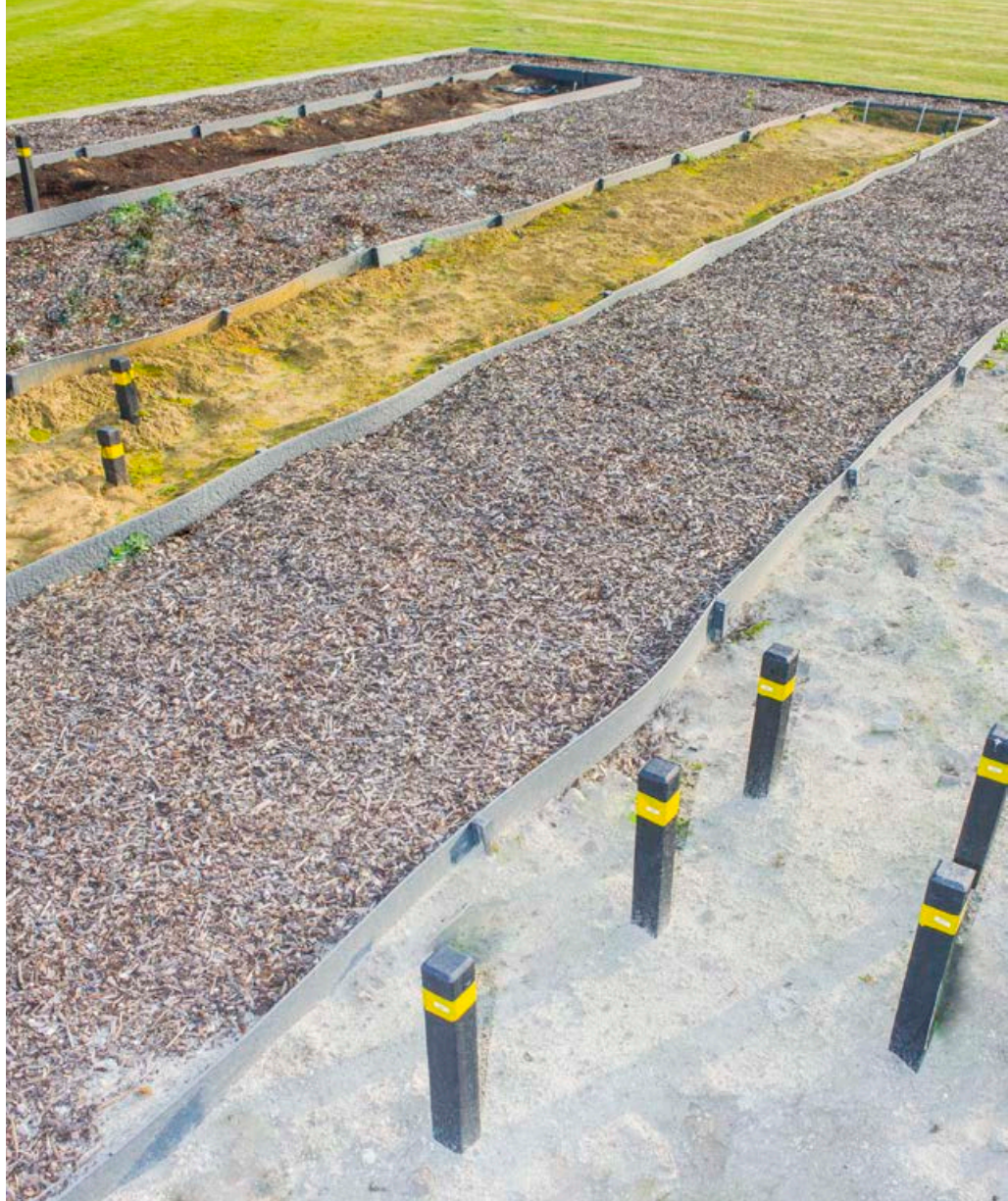
Fatigue failure typically originates at stress concentrations caused by joining (drilling a hole, in the case of a bolted joint) and cutting procedures. Indeed, fatigue cracks occur predominantly in the vicinity of joints and cuts, exhibiting a tensile residual stress pattern. The endurance limit of UHSS is extremely sensitive to its surface condition and residual stress state. Local damaged zones can be induced by common manufacturing processes such as shear or laser cutting, drilling, etc. However, in product specifications, the proper selection of the cutting process is generally overlooked. Therefore, at OCAS, we're focusing on quantifying the cut-edge and manufacturing effects on UHSS grades and how these impact endurance limits.

The major drivers for the future generation of metallic coatings are: ecology, durability and efficiency. At OCAS, we're striving to combine the best of all in a single coating.

Beril Corlu

Thanks to our dedicated soil corrosion testing site, we can support the Magnelis® commercial team with comparative data on the influence of different soil parameters, such as aggressive salt content and humidity.

Philippe Verpoort



Metallic coatings exposed

Magnelis® is a metallic coating consisting of zinc, aluminium and magnesium. Thanks to its excellent corrosion resistance in various harsh environments, Magnelis® production is still enjoying a steady increase in volume.

One of the obvious markets for this type of metallic coating is the solar panel market, where different Zn-based metallic coatings are used in the supporting structures of solar parks. These parks are typically installed in environments where conditions can be quite harsh. Supporting poles need to be buried into the soil, where different soil parameters influence soil corrosion. Another way of burying profiles in soil is by first embedding them in concrete – but this can also cause corrosion, mainly triggered during the initial drying phase after installation.

SUN AND SAND

Depending on the location, several corrosion mechanisms take place in the exposed part of the structures. In addition to atmospheric corrosion, desert areas with inherently high amounts of sunshine, making them a preferred location for installing large solar parks, also suffer from sand storms. So, sand abrasion needs to be taken into account. Similarly, the relative humidity and other weather conditions can also play an active and important role in the corrosion behaviour.

Therefore, several studies have been launched to understand and follow-up the performance of Magnelis® compared to other well-known Zn-based coatings in several of these harsh environments. These investigations are conducted via long-term exposures in various outdoor conditions in locations all over the world. Comparative studies are launched in parallel using accelerated lab tests. The influence of different soil parameters (such as aggressive salt content, humidity, etc.) are being studied in specifically designed lab tests that simulate corrosion at different depths into the soil.

Since the solar market is currently booming, an increasing number of ArcelorMittal galvanising plants have been adapted to produce Magnelis®, along with other hot-dip galvanised Zn metallic coatings. OCAS is leading and supporting these deployment actions, and we're also evaluating and validating the final product before its commercial launch.

PREPARING THE FUTURE

By applying Magnelis® to high-strength steels, several markets can reduce their CO_2 footprint due to reductions in weight. This trend is also increasing, which is reflected in the transversal validation projects within OCAS, whereby the metallurgical evaluation of these high-strength steels is performed in our lab, as well as the validation of the coatability with Magnelis® and the performance of this metallic coating.

The breakthrough R&D program 'IMpACT' (Innovative metallic coating platform) is preparing the future for metallic coatings primarily for demanding industrial applications. A next generation of metallic coatings with improved durability (atmospheric, soil & offshore), cut-edge protection, and stable appearance (among other benefits) is being targeted by this R&D program by exploring a wide range of processes and alloy compositions. The program has already produced promising lab results with good potential for upscaling.

Combined expertise from different OCAS teams resulted in a promising metallurgical concept that entails an excellent combination of corrosion resistance, mechanical properties and weldability.

Krista Van den Bergh

The OCAS Sampling and Mechanical Testing team takes pride in providing top quality test samples under high throughput conditions, even when dealing with heavy gauge material.

Koen Van Brussel

New saline weathering grade to reduce the maintenance costs of offshore structures

Current standards for offshore grades (EN 10225 and API 2W) focus on toughness and weldability, while weathering resistance is not mentioned. However, the offshore market is seeking such products to reduce the huge maintenance costs. A new plate steel product, with enhanced corrosion resistance to atmospheric marine/saline weathering conditions, has been developed for offshore applications. Target applications are topside painted steel structures: e.g. fixed and floating platforms, offshore wind towers, substations and water ballast tanks.

PROVING THE METALLURGICAL CONCEPT

The use of corrosion-resistant steel becomes attractive only if its cost remains below an extra 10% compared to standard offshore grades. Therefore, low-cost alloying is targeted in this project. A wide selection of chemistries has been tested before fixing the concept for an industrial trial.
Alloy selection was based on comprehensive corrosion testing campaigns, consisting of accelerated lab tests with alternating wet and dry cycles to simulate offshore conditions. The results showed an improved corrosion resistance of up to 60%, compared to the conventional S355G10 grade. The development of our metallurgical concept resulted in steel compositions with a good combination of corrosion-resistance, mechanical properties and weldability.
The rolling schedules have been further improved, the chemical compositions have been fine-tuned, and refined compositions have been produced and tested.
Industrial trials at an ArcelorMittal heavy plate mill have proven the feasibility and robustness of the concept. The results of mechanical characterisation showed that an S420 strength level is comfortably achieved for plates of 20 mm thick, and this is within reach for plates of 50 mm thick as well. High Charpy V-notch impact values were measured at -40°C, even at mid-thickness.

FULLY COMPATIBLE FILLER WIRE DEVELOPED IN-HOUSE

To extend the excellent corrosion and mechanical properties of the base material to the weld metal, OCAS launched a project to develop a brand-new welding wire (see also the chapter ‘Materials for the future’). Five different chemistries compatible with

the saline weathering steel were selected, processed and tested in the lab. The weldability assessment of the 20 mm thick industrial plate was made through high heat input multi-pass submerged arc welding (SAW) experiments, using the lab processed welding wires. High strength values well above the minimum requirements for S355 and S420 were measured in all welds. Excellent weld metal toughness was attained using the lab welding wire developed in-house.

The industrial material will be used for a first full-scale offshore welding pre-qualification (which is necessary in order to approach end-users and certification bodies) and for long-term durability testing under real-life offshore conditions. To assess the long-term corrosion performance of the new steel grade, outdoor exposure at two locations with different environmental marine conditions is currently running. As a lot of applications use painted structural steel, painted saline weathering steel is also being subjected to corrosion testing.

In addition to the successful development of a new steel grade, development of a fully compatible filler wire on lab-scale is a breakthrough. Today, there is no welding wire commercially available that can fulfil both mechanical (in particular, low temperature toughness) and corrosion requirements simultaneously.

Özlem Esma Ayas Güngör

By combining OCAS's welding and coatings competencies with Endures's experience in marine corrosion, we were able to identify the problem so that it could be prevented in the future.

Philippe Legros

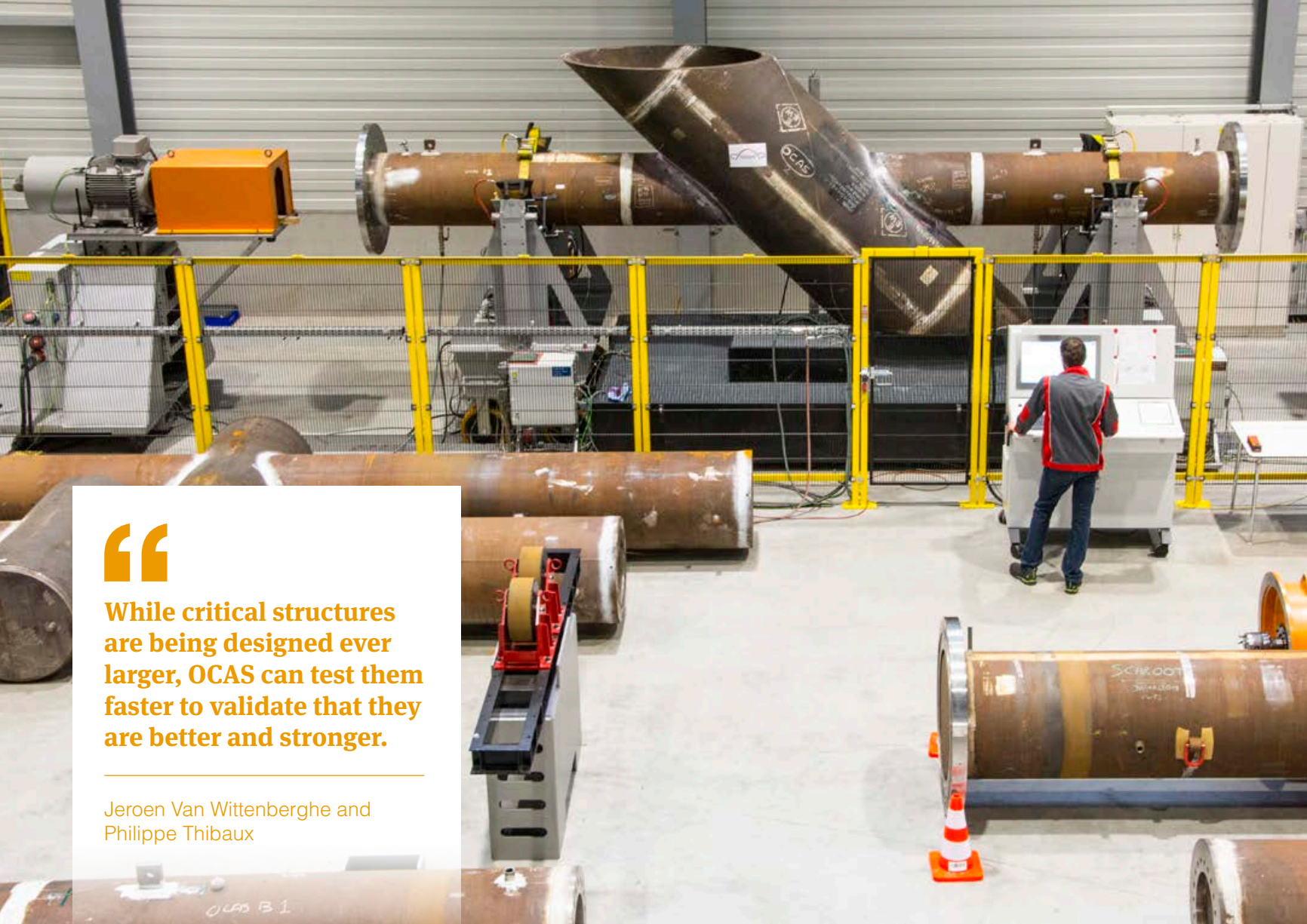
Failure analysis taken to sea

After barely six months of intensive collaboration, OCAS and Endures have already solved several customer cases by common inspections, sampling and in-depth analysis. In particular, the complementarity of our welding and corrosion expertise has proven to be especially valuable for our customers.

Marine lock gates were suffering from early and excessive corrosion. The welded and coated structure, comprised of pressurised pipes, exhibited visible corrosion. Some pipes clearly showed cracks and leaks, especially from the welds.
As the customer needed to replace some parts, he wanted to first identify the cause of the defects, and so he consulted OCAS/ Endures to analyse the problem.

MICROBIALLY INFLUENCED CORROSION (MIC)

Our joint team combined its expertise in the fields of failure analysis, marine corrosion and welding to inspect the lock gate. The quality of the welded pipes was assessed by using optical and electron microscopy. Wet corrosion products from a leaking pipe were analysed to check the potential presence of microbially influenced corrosion (MIC).
The leaking pipe clearly displayed multiple welding defects. The poor quality of the weld was the main reason for the observed leaks. Chloride corrosion residues were found inside the pipes. Furthermore, MIC-relevant micro-organisms were identified in low to moderate quantities in the corrosion products of the pipe, which might have accelerated the corrosion process.
The customer was advised to improve the welding quality. There was no need to change the type of steel or its protective coating.



While critical structures are being designed ever larger, OCAS can test them faster to validate that they are better and stronger.

Jeroen Van Wittenberghe and Philippe Thibaux

Larger, better, faster, stronger: accelerated fatigue testing of large-scale components

As several industries – such as onshore and offshore wind energy – are developing ever larger structures, materials and components are being pushed to their limits. So, conventional materials and production techniques are being replaced by stronger alternatives that should perform better.

FASTER, BETTER

In many cases, proving increased performance requires experimental validation testing. Hydraulic test equipment fit for testing large-scale components usually takes time and comes at a considerable cost. To accelerate the testing speed of such large-scale critical components, OCAS has developed a unique test rig – called CRONOS – for accelerated fatigue testing. Using our patented test technology, OCAS can offer accelerated fatigue tests on a wide range of components and structures. Typical testing speeds are between 20 to 40 Hz for test pieces weighing more than 10 tonnes – which is considerably faster than hydraulic test set-ups for large structures, which have a typical testing speed of about 1 cycle per second. Using CRONOS, a fatigue test that takes a complete month in a conventional test rig can be completed in only one day!

LARGER, STRONGER

The uniquely developed loading system allows the testing of a wide variety of components. CRONOS is suitable for accelerated fatigue testing of components and structures such as beams, rails and other profiles; pipeline sections joined by welding, bolted joints, etc. and complete welded structures such as nodes from offshore jackets.

VALIDATION OF THE METHOD

During the fatigue test programme on jacket nodes in the framework of the EU-funded JaBaCo project, OCAS demonstrated the ability to subject a complex welded structure to a wide variety of load cases in its CRONOS set-up. The set-up allows to apply linear reciprocating loads (e.g. to load a specimen in- or out-of-plane); combined 'circular' loads, where a rotating force vector equally loads the complete circumference of the tested component; and also complex multi-axial loads that allow a different load amplitude in the in- and out-of-plane loading modes.

Test samples are being thoroughly instrumented to measure overall deformation and local strain levels. Next to that, different state-of-the-art tools are being used to measure crack initiation and propagation. Hence, while structures are being designed ever larger, OCAS can test them faster to validate that they are better and stronger.

Testing metallic components at 20 to 40 Hz is widely accepted in the industry. However, some industrial companies asked us to compare the results of fatigue testing with CRONOS with a more conventional method (i.e. with hydraulic jacks).

Therefore, in the Joint Industry Project JaCo (Jacket Connections for offshore windmill infrastructure), it has been decided to include a comparison between 6 specimens tested at OCAS with 6 other specimens tested in another lab. Although the results are still confidential, we can report that they are extremely similar. They are actually closer than one would expect from traditional fatigue tests performed on a single machine!

Nice realisation showing engineering requires great team work.

Johan Verlee

The OCAS dip-dry test device is highly versatile and can quickly assess corrosion in a variety of environments.

Krista Van den Bergh

Assessing corrosion in various environments

Structures can be exposed to all kinds of environments. So, it's important to assess corrosion using accelerated tests under conditions close to reality.

To speed up its offshore product development and support activities, OCAS's Engineering team EMTEC developed a dip-dry device for accelerated corrosion tests. As corrosion performance is largely affected by environmental factors such as temperature, relative humidity, chloride concentration, time of wetness, etc., the experimental conditions of cyclic tests are of utmost importance.
That's why the new dip-dry set-up with controlled conditions was designed, built and installed. The new device provides temperature control in the different cyclic stages as well as the monitoring of O_2, pH, conductivity and relative humidity. At the same time, testing capacity has been increased. The new set-up has been validated using the corrosion performance of weathering steels at 20°C against previous results obtained with the former dip-dry set-up.

AN ACCELERATED CORROSION TEST SIMULATING NATURAL OUTDOOR CONDITIONS

The new dip-dry set-up also allows for more aggressive temperature conditions (up to 60°C) in the wet and dry stages, which are very useful for intensifying the material's ageing or simulating certain exposure environments. This new set-up is being used for testing the recently developed weathering steel grades painted with an offshore paint system certified to ISO 20340:2009 and NORSOK M-501 standards. The device allows to immerse panels in various electrolytes, whereby wet, humid and dry conditions are alternated. This has resulted in an accelerated corrosion test with conditions close to natural outdoor conditions.
Corrosion assessment uses weight loss measurements, distribution of pit diameter, and pit height from roughness measurements. Corrosion products are analysed by analytical techniques such as X-ray diffraction (XRD), Fourier transformed infra-red analysis (FT-IR), and scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM-EDX), providing elemental or molecular information.
OCAS has successfully implemented this test set-up amongst others for the development of new weathering steels.

The customer selected OCAS for this project thanks to our combined competencies in sour testing, hydrogen concentration measurement and modelling.

Marc-Antoine Thual & Philippe Thibaux

Combatting sour corrosion in the oil & gas sector

Increased demand for energy has pushed the oil & gas sector to shift activities to deeper and harsher production environments. An increasing number of wells contain considerable amounts of hydrogen sulphide H_2S. Sour corrosion is a serious issue that can cause material failure at stress levels well below the yield strength.

OCAS has a fully equipped sour corrosion laboratory that allows to test materials according to the latest standards (NACE TM0316, NACE TM0198, NACE TM0284, NACE TM0177, EFC16, etc.). In addition, OCAS also provides advanced proprietary test set-ups to its customers. Permeation testing under H_2S environment gives greater insight into the amount of hydrogen going through a material, whereas fast extraction tests allow to study the amount of hydrogen trapped in a material as a function of the exposure time. Our instrumented double cantilever beam device can follow up real-time crack propagation. Combining these techniques allows OCAS to model hydrogen distribution and transport as a function of the exposure time to the environment and the applied loads. Based on this data, the OCAS team can recommend the material that will best fit the customer's service conditions.

SLOW STRAIN RATE TESTS AS A FAST SCREENING METHOD

A major pipeline owner needed information concerning the sensitivity of different steel grades exposed to oil containing a significant amount of hydrogen sulphide. The purpose was to investigate the influence of different factors such as temperature, pH, etc. on the material's pick-up of hydrogen and to relate this to the degradation of material properties. By testing various environments, the customer will be able to define domains in which specific materials are applicable or not.
Sensitivity to hydrogen embrittlement is often investigated using constant load tests. However, this method only delivers a pass-or-fail result. In many cases, the results can be inconclusive: if all the experiments either failed or passed, no information is available to distinguish different materials. However, in the slow strain rate test, failure occurs almost always. The time or deformation moment when the failure occurs provides useful information about the severity of the testing conditions or the sensitivity of the material. Therefore, by using slow strain rate tests, the customer obtains more information while fewer experiments are needed.

OPTIMISING MATERIAL SELECTION FOR SOUR SERVICE APPLICATIONS

In a next step, different experimental results are related and the material's behaviour in the presence of hydrogen is modelled. The long-term goal is to optimise material selection for sour service applications.
As each well is unique with its own H_2S concentration, being able to provide an adequate material for a specific oil field has the advantage of reducing the CAPEX of the project without compromising the safety of the installation and its personnel.

OCAS is equipped to submit large components to extreme testing conditions without compromising on safety.

Jeroen Van Wittenberghe

Keeping connections tight

As global energy demand increases, the role of natural gas is becoming more important. To explore and produce from natural gas reserves, gas-tight pipeline connections are required. Furthermore, gas tightness for downhole casing and tubing lines will be needed for carbon capture and sequestration (CCS) projects for the ongoing energy transition.

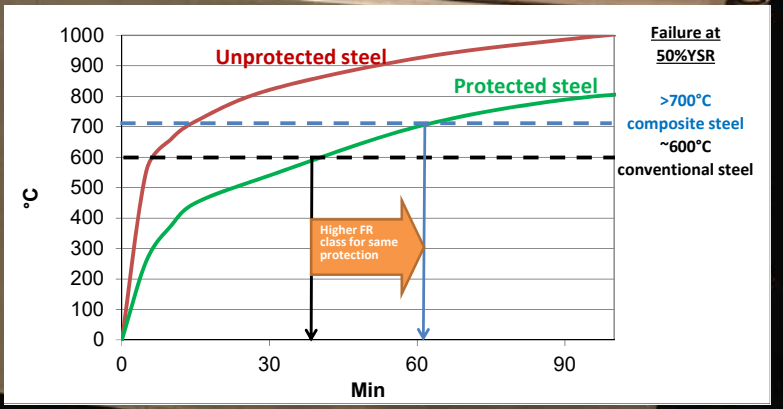
Together with the ArcelorMittal technical team in Houston, OCAS has developed a state-of-the-art premium threaded pipe connection, branded AM-BLADE. The connection design was optimised through extensive finite element analysis and features the highest technical performance while meeting the most stringent testing qualification conditions.

ENABLING EXTREME TESTING CONDITIONS SAFELY

These testing conditions are applied inside the OCAS test pits. Large components can be subjected to high internal and/or external pressure in combination with axial loading, bending, elevated temperature, fatigue and dynamic tearing, producing extreme testing conditions typical for high pressure - high temperature (HPHT) applications, leak tightness tests, and proof of concept tests in a contained environment.
Pressure can be applied with either liquid or gas as pressurisation media. Pressures up to 3000 bar can be applied. These severe testing conditions are necessary to guarantee safe and gas-tight operation of the AM-BLADE connection.

Our unique and flexible test device can perform several mechanical tests up to 1000°C. Hardness testing is just one of the many high-temperature properties we can explore.

Michiel Corryn



Measuring high-temperature hardness to save lives

With an ever-increasing number of steel constructions in residential and industrial buildings, fire safety remains a work of continuous improvement. The main parameter used is the 'fire resistance period' – which is the time in which all occupants must leave to avoid the risk of the building collapsing.

Standard steel constructions lose their strength around 600°C. With insulation and concrete protecting the steel beams, this temperature is reached after about 40 minutes of fire. However, this timeframe can be tight for emergency workers to clear out a building, certainly with response time taken into account. If the steel would keep its strength up to 700°C (and higher), the fire resistance period would be extended to at least 1 hour, providing extra time for everyone to get out safely.

FINDING A SCREENING METHOD

The standard method for assessing fire resistance is to carry out a series of tensile tests at elevated temperature (ISO 6892-2: 2018). Above a certain temperature, the steel will have lost 40% of its tensile strength, compared to its initial strength at room temperature. Comparing this temperature with the heating curve of a standard fire provides a value for the fire resistance period. However, this test method is highly time-consuming and requires large volumes of machined test samples for each grade – so it's not really suited for screening 100+ novel grades.

That's why OCAS has turned to high-temperature hardness measurement as an alternative to screen the loss of strength as a function of the temperature. The softening of a steel is well correlated with its loss of strength – and our automated test device can measure hardness up to 1000°C. The major advantage lies in the fact that only one sample of a few square centimetres is sufficient to plot the hardness evolution across the full temperature range. The most promising materials are then selected for further testing in the standard manner.

4 MATERIALS FOR THE FUTURE

In the last decades, the big majority of steel developments were concentrated on small additions of alloying elements, combined with more than 98% of iron. Only within this relatively small domain of alloying variation, metallurgists managed to make an impressive series of different steel families with specific properties ranging from soft steels with ultra deep drawing capability to high strength steels with 5 times higher tensile strengths.
In recent years, a significant shift in mindset has been observed for two reasons. First and obvious reason is the everlasting quest for higher performance of materials, mostly translated these days in a challenging combination of properties that need to be fulfilled. Second reason is the improved capability of steel plants to alloy more in a cost efficient and qualitative way.
Result of this extra degree of freedom for the metallurgical designers is another massive layer of new materials coming closer to industrial reality.

OCAS is strongly involved in the development and industrialisation of this next generation of products, ranging from the more classical, high-end product range of micro-alloyed and martensitic steels, to more exotic solutions like Quench & Partitioning steels pushing the strength ductility balance to the next level, pure austenitic iron manganese steels with a whole range of outstanding properties such as extreme formability and toughness at cryogenic temperatures, and maraging steels with the capability to increase multiple times in strength due to heat treatments.
All these developments only make sense if one manages to make optimal use of the offered performance. OCAS has a strong tradition in developing generic steel solutions guiding steel users how to take maximal benefit out of the offered steel properties, and setting up co-engineering projects with interested customers to translate the theory into an in-field example.

These evolutions also create needs and opportunities for wire products. First of all, these new substrate metallurgies for flat products require to be weldable, and as they exceed the range of available welding consumables, dedicated developments of welding wire are needed to be able to offer a complete solution to our customers. Also, some of these metallurgies open up very interesting opportunities for components produced via Wire Arc Additive Manufacturing (WAAM) technology. For non-ferrous alloys, opportunities exist for dedicated metallurgies for WAAM parts. Both tendencies pushed OCAS to install lab scale bar rolling capacity, in order to be able to make small material batches in an accelerated manner, so that developments can be offered quicker.
Meanwhile, we pay special attention to the surface quality of the developed products. To further improve the performance of the steel solution, OCAS has a number of projects focusing on improving the surface.

Given the huge success of Magnelis®, a metallic coating with outstanding corrosion protection, a strong effort is put in the development of the next generation metallic coating. This is an exciting program exploring old and new metallic coating production methods hunting several new challenges such as durability, appearance, sustainability and efficiency.
Our sustainability efforts are not limited to metallic coatings only but cover a broad variety of different types of coating activities. We continue to work on several REACH compliant solutions, such as nickel and cobalt oxides-free enamelling systems or a hexavalent chromium-free solution for plating.

— *Tom Waterschoot and Lode Duprez*

After decades of optimising steel grades based on limited alloy content, it's exciting to now try out new alloying approaches for the development of future generation steel grades.

Laura Moli Sanchez, Elvan Ekiz, Rolf Berghammer, Ulrike Lorenz, Lode Duprez, Tom Waterschoot

Ever stronger and longer-lasting, ever thinner or thicker

The flourishing market segment of yellow & green goods and heavy transport applications continues to evolve to larger, higher-performance constructions. This feeds the need for higher strength grades in moderate and heavy gauges.

Currently, such products are mainly available as quenched and tempered plate products. Metallurgists at OCAS are not only developing more cost-effective plate solutions, but also hot strip products, which can guarantee properties similar to plate grades, such as strength, low-temperature toughness, weldability and formability.

NEXT GENERATION MICRO-ALLOYED AND MARTENSITIC DEVELOPMENTS

Moving to heavier gauges while keeping good mechanical properties is becoming increasingly challenging. Therefore, OCAS has developed and tested new metallurgies, as well as adapted processing, on lab scale, before they are implemented industrially. These next generation micro-alloyed developments will help ArcelorMittal's hot strip mills make full use of their capabilities. The extension of dimensional feasibility will be rolled out step-by-step for other grades and thereby broaden ArcelorMittal's offer. In addition to these micro-alloyed grades, OCAS is also developing hot rolled quenchable boron grades dedicated to the yellow and green goods market. Our developments focus on outperforming standard properties – for example, making production at the customer easier, but still guaranteeing the final performance of the application. The high mechanical properties achieved after quenching and tempering, and the soft hot-rolled material (easy to post-process), have allowed us to go from prototyping at the customer's site to full industrialisation.

A growing family of quenched hot rolled products is being developed for both structural applications with stringent and severe quality requirements and wear applications extending the lifetime of the components.

PUSHING THE LIMITS OF PROCESSING TECHNOLOGY

In the longer run, we are evaluating new alloying approaches to introduce specific microstructural features to raise the steel performance to another level. For this purpose, OCAS is intensively screening several potential new metallurgies of the future.
One of the more advanced solutions is the addition of significant amounts of manganese to typical martensitic

compositions. These so-called medium manganese steels modify martensitic structures and introduce retained austenite, which allows to improve the combination of strength, formability and toughness in a spectacular way.
Even stronger alloyed, high manganese austenitic steels (FeMn) display a unique combination of strength and formability with good toughness at high and low impact speeds. This steel's high work hardening capability makes it get harder as it wears down. Hence, it is ideal for applications that require high lifetime of components subjected to wear and impact, such as in the yellow and green goods and the rail industry. The outstanding mechanical properties also make this grade promising for structural parts, where complex shape and high-strength requirements can be met by this steel's high formability and weight reduction potential.
The higher alloy content compared to conventional steels makes the production of high Mn steels very challenging. OCAS and ArcelorMittal are working on the development of a new processing route, pushing the limits of existing processing technology to novel boundaries. As the industrial route trials deliver the first product ready for customer assessment, OCAS is continuing to work on improving concepts to enhance industrial robustness as well as extending the lifetime of components made from this exceptional steel.

We could even think of reducing the density of steel by a smart alloying approach, bringing us high strength at lower weight. OCAS is involved in several tracks to establish this game changer material – two tracks of which have already evolved to industrial feasibility assessments.
At OCAS, we're working on even more complex metallurgical concepts such as breakthrough maraging steels, which are known for their unique capability to show huge strength increases by high temperature tempering treatment. These could be good solutions for niche market applications that require a combination of high strength and corrosion resistance, for example.

This optimisation will pave the way for both the new generation of hot rolled grades and cost reduction of existing products.

Klaas Poppe

Multiple revamps have resulted in today's versatile equipment, allowing to respond to numerous demands for lab materials with customised geometries and dimensions, processed according to specific metallurgical concepts.

Johan Verlee, Kris Hertschap & Alexandre Van Sintejan

Fully automated lab scale heavy gauge hot rolling and cooling

To further enhance our service offer in the field of metal processing, exciting industrially relevant improvements have recently been implemented in our lab.

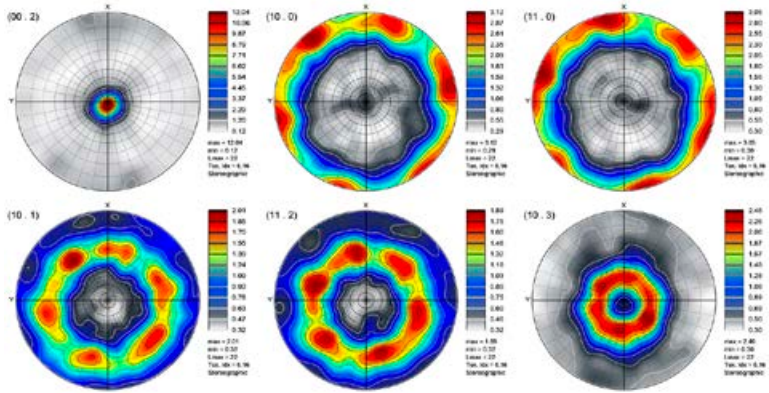
Lab tools are ideal for cost-effective product development. In order to ensure reliability and to collect all the necessary data needed for industrial upscaling, precise control and full data logging is vital.
The OCAS engineering team EMTEC automated our heavy gauge reversible hot rolling lab scale mill. As manual manipulations are no longer required, blocks with a weight up to 65 kg can now be rolled. The minimal starting thickness is 200 mm and can roll down to 5 mm, which makes the mill suitable for roughing and finish rolling. The max. dimensions after rolling 1600 mm (length) x 500 mm (width) allow sampling for a large range of test samples.

The block temperature and dozens of other material and process parameters are measured and logged throughout the whole process in order to accurately control the thermal profile from start to end.
Besides carbon steel, OCAS rolls other materials, such as aluminium, stainless steel grades, Inconel, copper, etc. We can reheat up to 1280°C in a convection furnace. Our air circulation furnace is better suited for lower reheating temperatures, allowing highly homogeneous temperatures in the range 350-600°C, which is suited for e.g. aluminium for aerospace applications.
The fully automated high width rolling mill is connected to the cooling pilot, by an automatic transfer system.

After rolling, air cooling or controlled water cooling in the laminar cooling line is carried out, with minimal time loss and following a preprogrammed scheme.
Thanks to the sectional design of the table, a multitude of cooling patterns can be achieved.
The advanced and versatile rolling and cooling equipment have become state-of-the-art tools, ready to support new developments in hot rolled skelp and heavy plate.

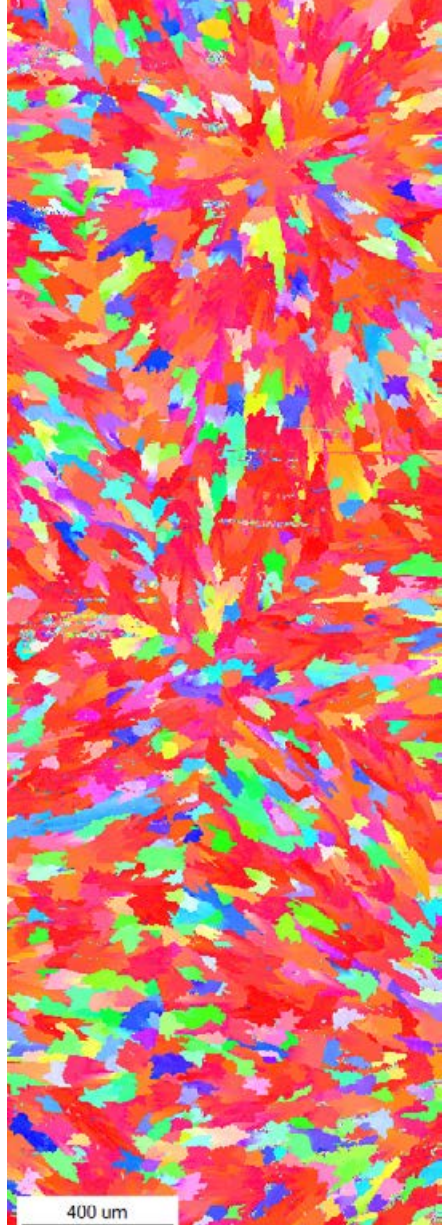
In defining IMpACT, we raised the bar very high. I am delighted to witness the creativity of the team that has been triggered by this breakthrough project.

Beril Corlu



A good surface is only ensured by optimising manufacturing process parameters but also storage conditions and the entire logistics chain – a true challenge!

Marc Leveaux & Filip Geenen



Surfaces with impact

impact: /ˈɪm.pækt/: a marked effect or influence;
IMpACT: innovative metallic coating platform.

IMpACT: A BREAKTHROUGH R&D PROJECT GENERATING METALLIC COATINGS OF THE FUTURE

This is where our challenge lies: developing the future generation of metallic coatings with outstanding properties. For this purpose, OCAS is screening a wide range of production techniques and alloy compositions in the light of key drivers: ecology, durability and efficiency. The IMpACT programme approaches this demanding challenge from several angles, including the development of new compositions for hot dip coatings, exploring electroplating solutions, and using PVD technology for products showing stronger protection in combination with excellent appearance, always with an eye for industrial applicability.

Since its foundation 30 years ago, OCAS has been active in applied research in the field of metallic coatings. Today, the OCAS coating team has the know-how, the network and the equipment necessary to pull off this challenge. Shortly after its kick-off, IMpACT already started to produce novel ideas on promising products and processes, which are currently being tested on pilot scale.

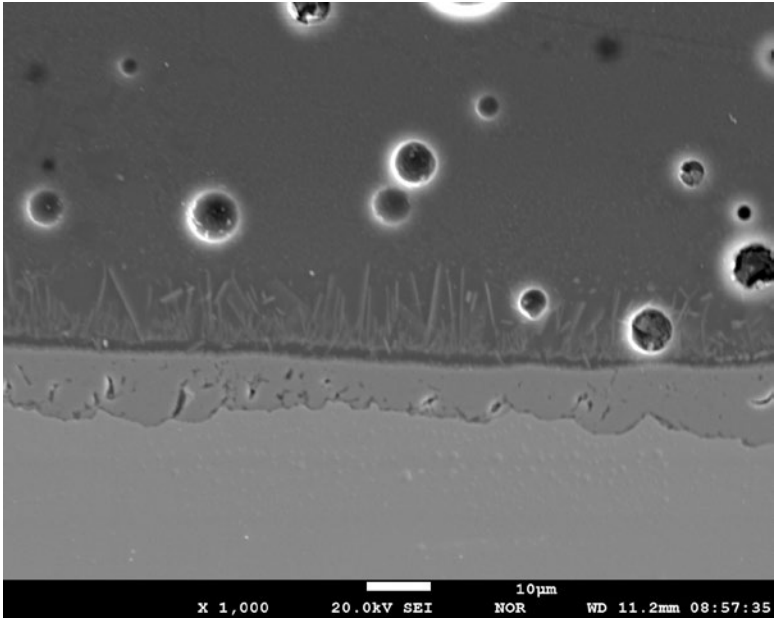
IMPROVED SURFACE QUALITY FOR HOT ROLLED STEEL

A smooth and clean surface simplifies and decreases the cost of downstream processes, and this is exactly what custormers are demanding in hot rolled mill-finished steel. Specific metallurgical routes have been defined for structural grades as well as high-strength low-alloyed steel grades in order to provide end-users with this improved surface. The Micro-Adhesive Scale (branded by ArcelorMittal as MASc) label guarantees top surface quality for hot-rolled mill-finished products that can be used, e.g. for direct painting after decoiling and levelling. In addition to the MASc label, actions have been taken to implement a concept to bring the standard hot-rolled mill-finished surface to a higher level. All users appreciate cleaner workshops, faster processes and cost savings – so, this concept has already been extended to several mills in Europe (some of them now in the ramp-up phase) registering official orders from customers. A good surface is only ensured by optimising manufacturing process parameters but also storage conditions and the entire logistics chain.

OCAS is actively supporting all ArcelorMittal facilities: checking the quality of the products after industrial trials, performing local audits, and developing customised test methods.

Over the years, the Ready-to-Paint development and its industrial implementation have enabled us to build substantial knowledge regarding surface treatment. We are already looking forward to consolidating this expertise in future products.

Nathalie Van den Bossche & Lien Van de Voorde



The new enamel-to-metal link is just about 5 µm thick, and it replaces the functionality of traditional enamel layers between 30 to 120 µm!

Marc Leveaux

New tracks for green coatings

In recent years, driven by ever-stricter environmental legislation, the surface treatment and enamelling industry have evolved by limiting the use of hazardous compounds, or avoiding them altogether.

PEAK LIFE CYCLE ASSESSMENT (LCA) PERFORMANCE FOR ENAMELLED STEEL

Vitreous enamelling has been acknowledged for centuries as one of the most durable ways to protect metals against abrasion, temperature and corrosion. Recent progress have significantly reduced the environmental footprint of enamelled steel, but this is not enough. We need to increase the lifetime of manufactured products, improve their recyclability, and reduce the consumption of raw materials and energy. In order to solve all of the drawbacks – technical as well as economical – OCAS has launched a 'green enamelling' project. Its goal is to propose several new enamelling concepts for the enamelled steel of the future, without compromising on performance.

Since 2018, a new track has been opened by looking back and rethinking an old, yet efficient, enamelling process known as 'Direct White Enamelling' or DWE. In DWE, the enamel-to-metal link is obtained thanks to an elaborate preparation of the steel's surface. The steel substrate is pickled first using a strong acid, followed by nickel treatment. Nickel is key in bonding enamel to steel, as it ensures the formation of complex phases with iron from the steel substrate and silicon or titanium from the enamel coating. In just a single enamel layer, DWE provides aesthetics, chemical resistance and colour to the steel. Nevertheless, the DWE process was abandoned as it generates waste. Moreover, today, nickel is classified as CMR (Carcinogenic, Mutagenic or Toxic for Reproduction).

By replacing nickel with other metals that are REACH compliant, OCAS can present an alternative. The new metallic layer is applied by electrodeposition on flat sheet, making this substrate ready to enamel in just one single layer. This concept allows the end-user to form the sheet prior to enamelling. The new enamel-to-metal link is just about 5 µm thick, and it replaces the functionality of traditional enamel layers between 30 to 120 µm!

READY WHEN YOU ARE

Ready-to-Paint, the first dry surface treatment available for cold-rolled steel, enables customers to reduce their waste and energy consumption. It avoids oiling, degreasing, and the application of a phosphate or passivation layer, and still it enhances paint adhesion.

Our semi-industrial plating unit not only allows us to coat prototypes, it can also be used to prepare and test new ionic liquids at tonne scale.

Ansbert De Cleene

So far, feedback from the customers has been very positive, leading to consistent customer orders. Pushed by market demand, production has been extended to another production line in order to enlarge its feasibility window. With the roll-out of Ready-to-Paint, the overall quality level of the production lines has been brought to a higher level. After years of close follow up, Ready-to-Paint is now a mature product.

REACH-COMPLIANT CHROME PLATING

Back in 2012, driven by the need for REACH-compliant alternatives, OCAS initiated a project on hexavalent chromium-free hard chrome plating. OCAS focuses on the development of alternative plating technologies for these processes and their up-scaling, and we have been supporting industrial partners in their quest for suitable alternatives for conventional plating processes.

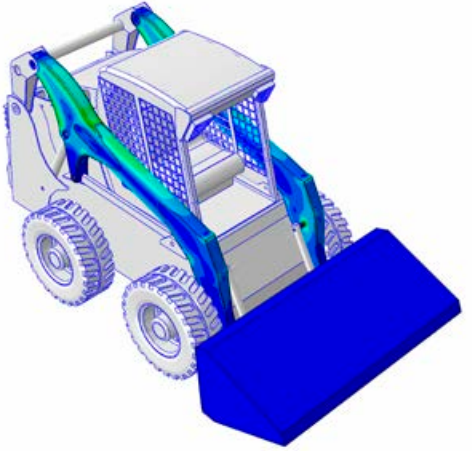
Thanks to OCAS's research & development efforts since then, this hexavalent chromium-free technology has now matured to semi-industrial level. In addition to enhancing our knowledge of plating technology in general, it has also provided OCAS with fundamental insights into the fine-tuning of process parameters, microstructure and the final properties of the coating.

EVALUATING ALTERNATIVES FOR HEXAVALENT CHROMIUM ELECTRODEPOSITION

Using finite element plating reactor models, taking fluid dynamics and electrochemical deposition kinetics into account, good process control and thus bath monitoring could be achieved. The models have enabled us to design experiments in a more straightforward manner, speeding up the development of durable layers on various prototype alloys in different shapes.
For example, careful bath monitoring significantly increased the hardness of the final hard chrome coating and transformed the dull aspect of the deposited coating at the start of the project into a shiny and bright chrome appearance. Several surface treatment procedures were optimised to improve the adhesion on various substrates. Furthermore, the corrosion resistance of the hard chrome layer could be brought to the level comparable to traditional hexavalent chromium applications.
OCAS has built substantial expertise in the field of electrodeposition and the evaluation of metallic coatings from ionic liquids as well as from aqueous solutions. A lot of electrodeposition research with ionic liquids is already being performed on lab scale. OCAS's semi-industrial plating unit allows us to coat different applications and to prepare new ionic liquids at tonne scale. The expertise we have developed in this field is highly valuable for partners evaluating alternatives for hexavalent chromium electrodeposition.

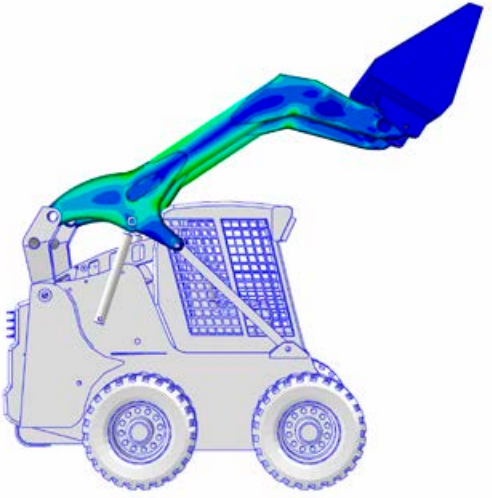
The drive for thinner material will continue and future ultra-high-strength grades will be able to satisfy that need!

Koenraad Theuwissen



We believe that steel is still the most suitable material for making transport more efficient and eco-friendly – and we're continuously developing the microstructures and the tools to make this vision a reality.

John Vande Voorde



Heavy-duty loses weight

In recent years, OCAS has developed several new ultra-high-strength products for use in different market segments. In addition to new ultra-high-strength grade development, OCAS also has long-standing experience in weight-reducing solutions for steel structures, ranging from washing machines and agricultural machines, to trucks and trailers and even offshore structures.

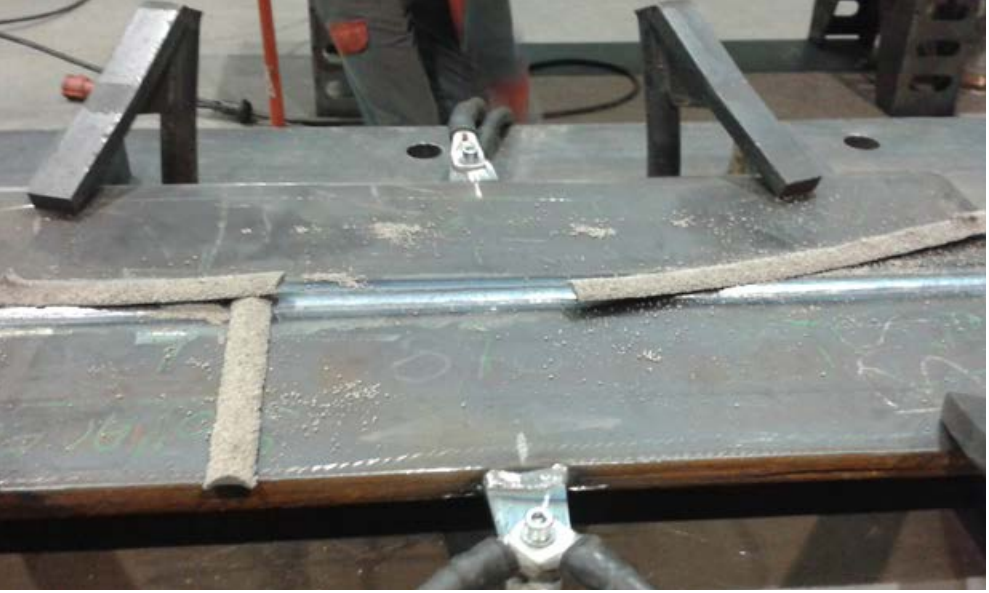
FUTURE GENERATION OF ULTRA-HIGH-STRENGTH STEELS

To reach the optimal design, OCAS combines finite element analysis, expert knowledge of material properties, and judiciously selected experimental testing. Applications for ultra-high-strength products include trucks and trailers for transport, agricultural equipment, and crane-booms that enable the construction of cranes with longer reach and higher allowable lifting weight. Weight and cost reduction are the main drivers behind developments aiming for thinner and stronger material.

Now, OCAS has already started working on the future generation of such materials, in which the higher strength is accompanied by even better elongation and better in-use properties such as toughness and bendability. Indeed, this new generation is no longer based on 'conventional' metallurgy but on new and innovative concepts.

WEIGHT- AND COST-REDUCING SOLUTIONS

By exploiting the particular properties of the next-generation steel grades being developed at OCAS – be it extreme strength, extraordinary elongation or superior wear resistance – the design of components and structures is optimised and customised to the exigencies specific to the application at hand. By balancing the structural requirements, the specifics of the customer's production and assembly method, and the demands put forward by the application environment, impressive savings in both mass and cost can be achieved.



Without doubt, tailored welding solutions will bring added value to new applications.

Özlem Esma Ayas Güngör, Elke Leunis & Michal Mroz

Lab wire with tailored chemistry for accelerated research

In different research portfolios, new steel metallurgies are currently under development which often require new solutions for welding, including the development of an adapted filler wire.

OCAS has developed a laboratory synthesis route for wire rods with tailored chemistries, via casting and rod rolling. Today, this allows us to quickly produce small batches of customised wire for research studies, where small quantities of tailored wire are needed (e.g. investigations related to welding wire, wire for thermal spraying, or wire for additive manufacturing).

VALIDATION OF SOLID WIRE PRODUCTION METHODOLOGY

In order to validate the method of producing welding wire on lab scale, a commercially available submerged arc welding wire was reproduced. Both the commercial and the lab processed wire were then used for submerged arc welding (SAW) trials. The performance of the lab-processed wire was assessed through submerged arc welding experiments performed on line pipe steel. Two-wire welding was used for inside and outside diameter welding on sheets. The behaviour of the lab wire during welding was similar to that of the commercial wire, and no problems were experienced in terms of wire feeding, arc stability or slag removal. When characterising the weld metal, no difference in the hardness of the welds was observed, and the Charpy impact toughness performance was similar.

NEW WELDING WIRE FOR NEW STEEL PRODUCT

This validation of the laboratory route allowed us to start using lab wire in dedicated developments, one being a welding wire with saline corrosion resistance. After achieving exceptional corrosion properties on a newly developed saline-resistant weathering steel substrate, the development of a dedicated welding wire was launched. Submerged arc welding wires in different chemistries compatible with the steel were processed and tested in the lab. In addition to the expected corrosion performance, excellent toughness and tensile properties could be achieved in the weld metal, showing the potential for a complete ‘substrate + welding wire’ solution.

WIRE ARC ADDITIVE MANUFACTURING

Similar to welding, the lab wire synthesis route is under validation for wire arc additive manufacturing (WAAM) research. Successful single and multiple line printing trials were performed using commercial wire compositions as a benchmark to the R&D lab-produced wire. Tensile testing, Charpy testing and microstructural analysis will be performed to confirm the correct quality and representativeness of the laboratory wire.

5 NANO MATTERS

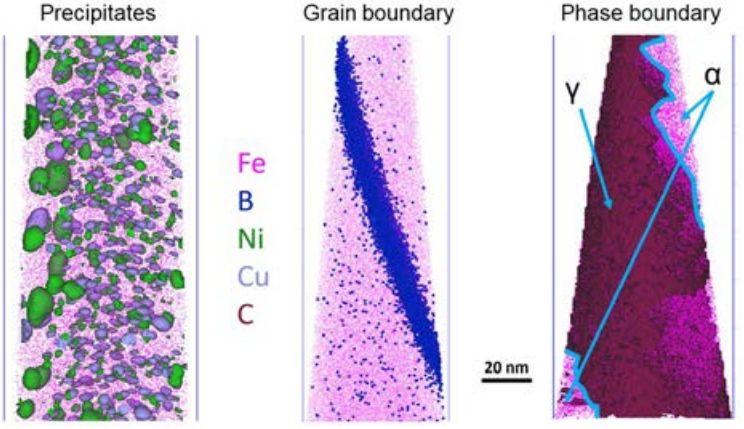
To understand our world, we need to analyse it. And we need to do this for many reasons, safety being one of them. OCAS has acquired a lot of experience in product safety over the last several years. To comply with safety regulations, accurate measurements are required on the release of toxic substances during the entire lifetime of the product. This may comprise high-end organic analyses as well as nanometric studies of dust. Failure analysis is also a matter of safety – this enables us to understand failure and to prevent it in the future. OCAS uses a wide range of equipment to carry out failure analysis. From a simple optical microscope to find point defects, to depth profiling equipment for coating analyses, to atomic resolution to understand bonding mechanisms.

In the development and successful deployment of new steel grades, metal alloys and associated coatings or surface technologies, it is ever more important to control the microstructure and surface conditions in the (sub)nanometre range. At the same time, elucidating these structures is becoming more and more complicated due to their size and composition. In this year's edition of our Activity Review, we present some metallurgical examples to show how the combination of high-end microscopic techniques leads to further understanding of material behaviour. OCAS's broad array of equipment enables us to tackle various problems from different angles.

— *Ann De Vyt & Jan Scheers*

Advanced materials research evolved into an astonishing insight into the atomic composition of complex 3D-nanostructures with unprecedented resolution. Whereas there are many characterisation techniques providing spatial and compositional information, atom probe tomography is the only one offering extensive capabilities for both 3D-imaging and chemical composition measurements at the atomic-scale.

Hui ‘Maggie’ Shi & Davit Melkonyan



How Atom Probe Tomography can expand your horizons

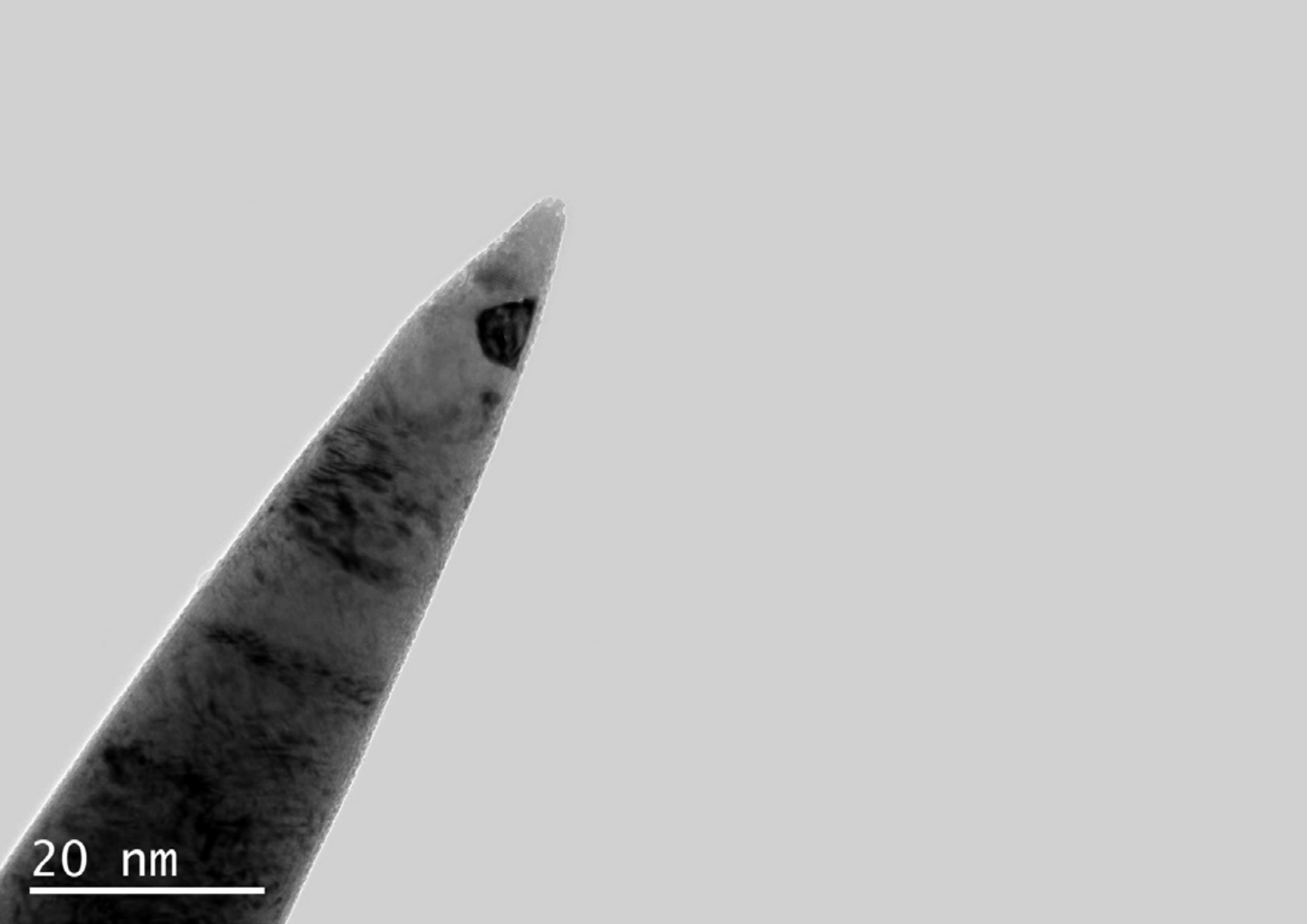
Future generations of wear-resistant, electrical, high-strength-structural and sour-service steel grades will require a much more detailed understanding of the metallurgical mechanisms leading to corrosion protection, ductility and bendability improvement, temper and precipitation strengthening, toughness maximisation, hydrogen trapping, etc.

To tailor the macroscopic properties of materials so that all of the boxes are ticked, it is crucial to control atomic distribution. To achieve this, various material characterisation techniques are available to probe and measure the properties of materials. Microscopic information enables concepts to be developed to engineer materials with tailored macroscopic properties.

A UNIQUE ATOMIC-SCALE 3D-ANALYSIS TECHNIQUE FOR STEELS

Within materials characterisation field, Atom Probe Tomography (APT) occupies a unique place, as it is the only technique offering extensive capabilities in both 3D-imaging and revealing chemical composition at the atomic-scale. OCAS started using APT* in steel research in 2016. The APT technique requires nano-scale needle-shaped specimens of about 50 nm apex radius. OCAS prepares these samples in-house by means of a focused ion/scanning electron (FIB/SEM) dual beam system. The configuration with coinciding electron and ion beam enables simultaneous SEM imaging during FIB milling tasks to achieve ultimate levels of precision.

In this process, part of the bulk sample is milled away and sharpened by FIB to create the needle-shaped specimen. In many cases, these specimens need to be taken from a specific place of the bulk sample containing regions such as grain or phase boundaries. Often, electron backscatter diffraction (EBSD) or transmission electron microscopy (TEM) is required to successfully localise the region of interest in a nano-scale sample before the final APT analysis is conducted.

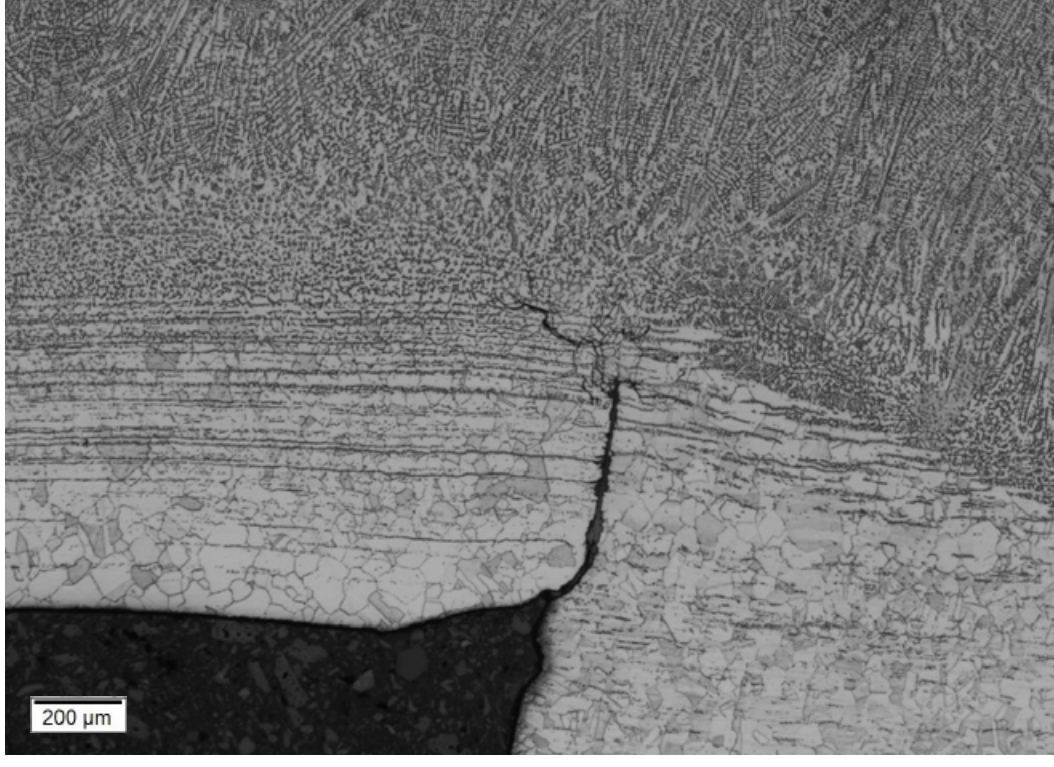

20 nm

MANUFACTURING STEELS WITH TAILORED PROPERTIES

OCAS has developed a methodology to routinely analyse prior-austenite grain boundaries (PAGB) and phase boundaries. This allows us to quantify the presence of different elemental segregations at these boundaries for different steel grades and to evaluate their dependence on the processing routes. The segregation of different solutes at grain and phase boundaries can noticeably alter the macroscopic properties of steels. For instance, adding a small amount of boron to low-alloy steels can improve their hardenability, which is attributed to the segregation of boron at PAGBs. Therefore, the nano-scale grain boundary analysis is useful for the manufacturing of steels with tailored properties.

Studying precipitation in steels is another aspect for which APT has proven to be very useful. Precipitation hardening improves the mechanical properties of steels. Other processes, such as constraining grain growth and stabilising the microstructure, are also closely linked to precipitation. OCAS uses APT to study the mechanisms leading to nucleation of precipitates and precipitate evolution for varying processing conditions of different steel grades. APT allows us to extract composition, size distribution, volume fraction and 3D morphology of precipitates.

* OCAS wishes to acknowledge the Flemish Hercules Foundation for large-scale research infrastructure.



It’s exciting to be able to zoom in from what is visible with the naked eye to magnifications up to 30,000 times, or even more, in order to determine the cause of the failure and help the customer with the corrective actions needed to prevent failure in the future.

Annick Dhont

Zoom into the problem and see the solution

When an installation fails, the customer needs to know why. OCAS's technical support team helps customers get to the source of a failure as quickly as possible. More importantly, the root cause analysis provides recommendations for addressing and correcting the issue causing the failure.

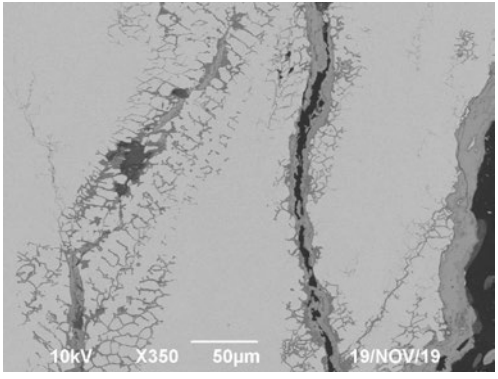
In most cases, failure analysis is a multidisciplinary process. OCAS has a wide range of equipment to carry out failure analysis: from visual inspection to metallographic microscopy, down to scanning electron microscopy. In addition, chemical analysis and mapping, and even numerical simulations, are also often used to identify the root cause.

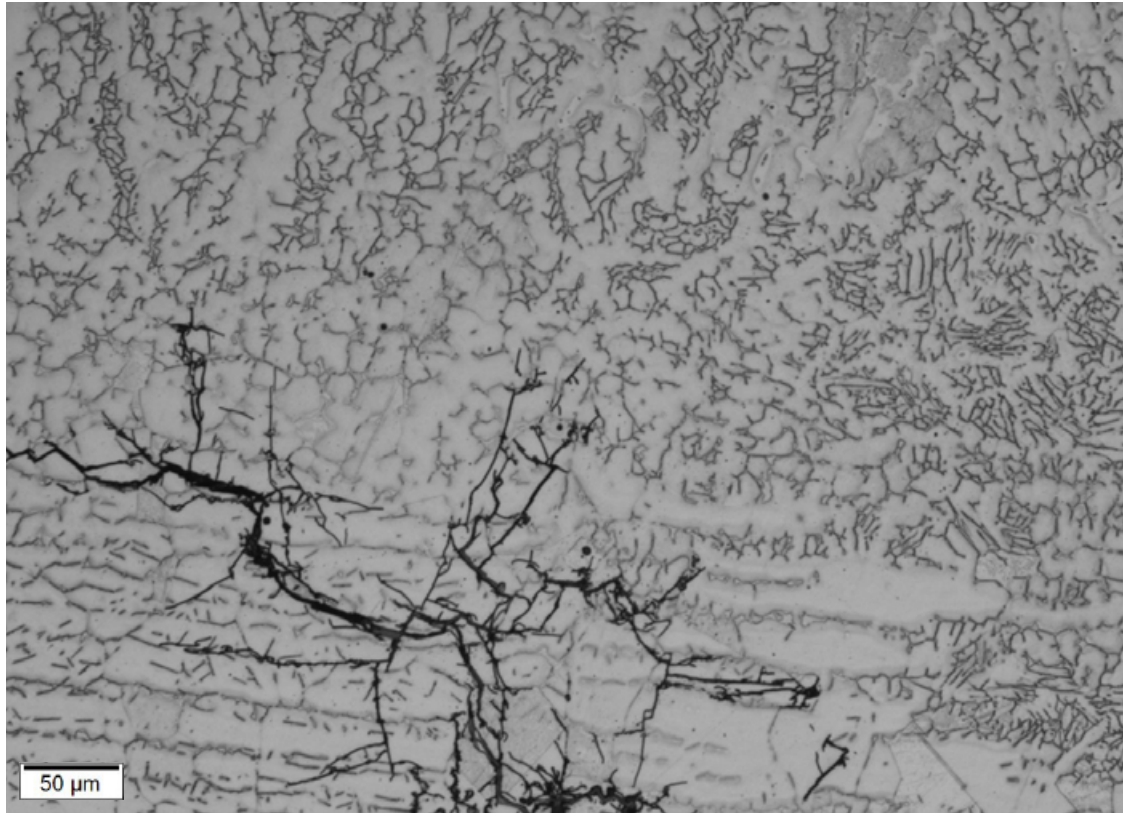
UNDERSTANDING THE FAILURE

A customer from the food processing industry called on OCAS to investigate the leakage of a stainless-steel tubing system. Although the design conforms to food processing standards, leakage is being observed in several positions only two years after installation. Leakage of an installation is a disaster in any case. But in a food processing environment, with stringent regulations concerning food safety, leakage might require a production shutdown resulting in serious economic damage for the company. So, understanding the cause of the problem is of great importance for the food processing company as well as for the designer and supplier of the installation. Many questions arise in every failure analysis case: does the material meet its specifications? Is there an overlooked corrosion problem? Do environmental conditions play a role? Using the right tools, our skilled staff addresses the problem with the highest priority. The first step in the investigation consists of listing the operating conditions. Linking these conditions to observed features during the investigation often leads to an understanding of the failure.

MACRO LEAKAGE CAUSED BY MICRO CRACKS

In this case, visual observation revealed that all affected areas were located in the immediate vicinity of a weld in the tubing system. Optical microscopy showed small cracks in the affected areas. No pitting or red rust spots were observed, meaning


10kV X350 50µm 19/NOV/19


50 µm

that no corrosion occurred. Based on these findings, we identified the primary areas for cross-section preparation. These cross-sections were studied by means of optical and electron microscopy (the latter is also equipped for chemical analysis and mapping). Electron microscopy revealed the presence of chromium carbides and delta ferrite phases in the weld area where the present cracks were initiated. These phases typically influence toughness and crack resistance. Analysis of the chemical composition confirmed that the right stainless-steel grade had been used for the installation.

As no corrosion was observed, the material that was used is compliant for use in this application. However, during the welding of the concerned tubes, irregularities occurred, causing the material to become sensitive to cracking in the heat-affected zone of the weld. To avoid similar issues in the future, OCAS provided recommendations for optimising the welding parameters: alignment, composition of the filler material, welding speed, protective gas composition and flow, cooling rate, etc.

At OCAS, measurements are much more than merely a list of results. Thanks to our experience, we know how to address safety topics. We can help in selecting the best formulations and provide recommendations for adapted collective and personal protection.

Philippe Legros

To measure is to know

REACH* and CLP** regulations improve the protection of human health and the environment from the risks that can be posed by hazardous chemicals. To comply with these regulations, accurate measurements are required not only on the release of these substances from end-products, but also from the raw materials used during the production process or in the air at the workplace during processing.

For more than a decade, OCAS has gained experience in checking paints, varnishes and coated samples or air for the presence of potentially hazardous substances. OCAS is equipped to collect the air samples at the customer and carry out the analysis of dust and gases with its state-of-the-art equipment. Examples below illustrate recent work.

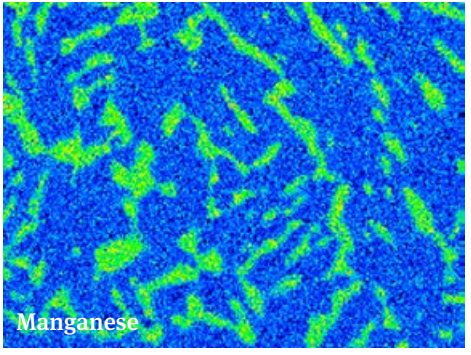
CASE FORMALDEHYDE

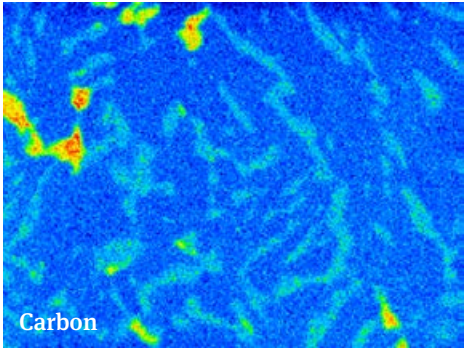
To perform risk assessment, OCAS investigated the release of formaldehyde, volatile organic compounds (VOCs) and isocyanates from a range of paint systems as well as from panels coated with these paints. The OCAS team selected the best sampling method and analysed the samples in-house.
Formaldehyde was measured in water solution using UV-spectrometry after hot leaching tests of coated panels. During painting, the concentration of formaldehyde sampled at the workplace was measured by high-performance liquid chromatography (HPLC). Test results were used to compare and rank different coatings and enabled the customer to identify compliant paint formulations.
Regarding insulating varnishes for electrical steel, the presence of formaldehyde, a carcinogenic compound, in liquid varnishes and from coated plates has been evaluated. The results are being used for communication with the factory and customers.

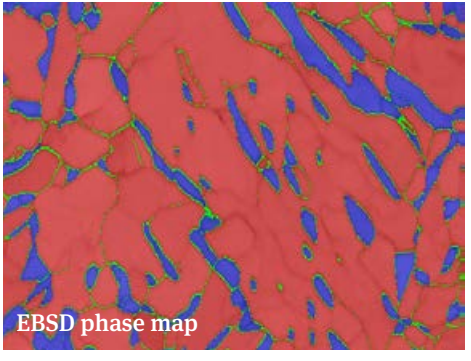
FROM PRESS SHOP TO OFFSHORE AND MARITIME CONSTRUCTIONS

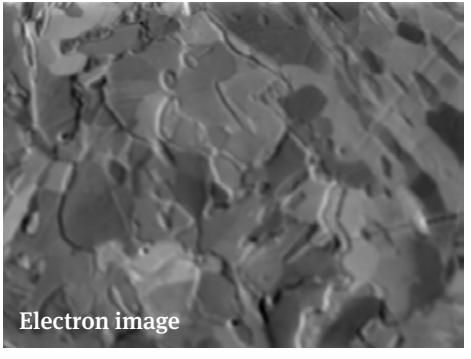
OCAS carried out measurements on combustion gas in and outside thermal treatment furnaces for a manufacturer of safety parts for cars, which are hot formed. This allowed us to ensure the air quality at the workplace.
The risk associated with ultra-fine particles emitted through plasma cutting of metallic coated plates for offshore wind has been evaluated to validate the collective and personal protection of workers.
The risk associated with the presence of hazardous and toxic residual compounds in marine paints, such as lead and hexavalent chromium, has been assessed. The painted steel structures for a lock had to be repaired: cutting and welding had to be performed.

* REACH: European regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals
** CLP: Classification, Labelling and Packaging of substances and mixtures









OCAS's know-how and state-of-the-art equipment enable the interpretation of more complex multi-component metallic microstructures, raising product development to a new level.

Mélanie Gauvin & Ann De Vyt

The power of combining micro- and nano-analysis equipment

In the previous edition of this report, we zoomed in on the OCAS equipment used to perform micro- and nano-analysis. Now, we focus on the strength of combining these state-of-the-art instruments.

OCAS combined its brand-new Field Emission Gun – Electron Probe Micro Analyser (FEG-EPMA), equipped with four Wavelength Dispersive Spectrometers (WDS) and a Soft X-ray Emission Spectrometer (SXES), with its Field Emission Gun – Scanning Electron Microscope (FEG-SEM) and Electron Back-Scattering Diffraction (EBSD). Whereas, EPMA-WDS is a micro-analysis tool providing the chemical distribution of elements, SXES is dedicated to trace analysis of light elements. As such, SXES is complementary to EPMA-WDS for carbon analysis. EBSD is a micro-analysis tool that identifies the orientation and phases of crystalline samples.

HIGH IMAGE RESOLUTION, HIGH SPATIAL RESOLUTION, AND HIGH SENSITIVITY

Austenite Reverted Transformation (ART) steels rely on the stabilisation of austenite by Mn diffusion to obtain their excellent mechanical properties. The amount of austenite, and its morphology, location and stability greatly affect these properties. In-depth characterisation of micro/nanometre-sized austenite domains is challenging and requires our most powerful analytical tools. Techniques combining high image resolution, high spatial resolution and high sensitivity are essential. We combined EPMA and EBSD analyses to correlate both chemical and structural information at the same location in the sample. High resolution C and Mn mappings acquired by EPMA-WDS are used to validate and improve the identification of the constituents (ferrite, martensite, austenite and pearlite) performed by EBSD. SXES is used locally to quantify the concentration of C.

AN EXHAUSTIVE PICTURE OF THE MICROSTRUCTURE

The comparison between EPMA and EBSD mappings shows that most microstructural features are consistently observed at the same location. Austenite domains (blue domains) on the EBSD phase map correlate directly with carbon/manganese-rich domains evidenced by EPMA. Other carbon-rich phases such as pearlite or cementite particles can be found. These are known to modify mechanical properties. Although, usually invisible for EBSD, they are very well evidenced by EPMA, illustrating the power of combining structural with chemical analyses at the very same spot to reveal an exhaustive picture of the microstructure. The amount of austenite as detected by EPMA is in good correlation with X-ray Diffraction measurements. Moreover, the general conclusions made from this study are well in accordance with equilibrium calculations.

6 WORKING WITH OCAS

To speed up the R&D processes of our customers, OCAS makes sure to have all assets in place and continuously strives to improve the quality of its services and increase its output by adding value and/or reducing costs.
Next to aiming to consistently deliver high-quality R&D services, supported by several ISO17025 accredited tests, we combine the expertise of our teams with our engineering and testing capability to deliver a total solution approach addressing our customers' ever more complex problems: from product design all the way through the optimisation phase.

Striving to be a research facilitator for its customers, over the last few years OCAS has invested immensely in three research domains to keep our performance at the highest level: combinatorial research, digitisation and nano investigation.
This way, we focus on more efficient data generation, data capture and data visualisation. By also targeting the data-mining side, we enable smarter experimentation by performing digital screenings using advanced computational tools. The nano axis allows us to investigate materials down to the atomic level to acquire fundamental understanding of the mechanisms behind material behaviour.

OCAS continues to invest strongly in both building competence and developing business in the following focus areas:

— **Environmentally supportive, 'green' alloy and metallic coating developments** such as low-weight steel solutions, taking not only strength requirements into account but other production and design requirements too (such as bendability, formability, etc.), as well as in-use durability and sustainability. In the field of metallic coating, a REACH-compliant hard chrome plating technology has been further matured towards industrial levels.

— **Non-standard, large-scale testing capabilities and modelling tools of material and component damage mechanisms,** such as fatigue, wear, corrosion, hydrogen embrittlement, and combinations thereof. In 2019, our innovative, large-scale accelerated fatigue testing set-up for welded nodes was successfully bench-marked against the traditional test methods within our JaCo project (same results, 20 times faster).

— **Support to, and co-engineering with, FININDUS portfolio companies,** where the deep-niche specialisation of these companies is complemented by OCAS's multi-competence capabilities.

In this context, OCAS is excited to announce its collaboration with the ENDURES team. By joining forces, we extend our on/offshore and maritime service offer by combining our expertise in the field of corrosion.

In 2019, GUARANTEED was created as a spin-off company from OCAS, FININDUS and ArcelorMittal Belgium. The new company repairs, refurbishes and produces large metal parts, using wire arc additive manufacturing to extend the lifetime, or reduce the downtime, of industrial equipment.

OCAS has won a tender for projects from the Belgian Energy Transition Fund and is now leading a consortium whose objective is to investigate the combination of fatigue and corrosion of offshore structures to extend the life of wind energy convertors. Furthermore, OCAS was chosen as the preferred partner for a flagship project of the Carbon Trust Offshore Wind Accelerator. We also participated in the European JaBaCo project to develop a modular concept for jacket foundations for offshore wind turbines.

— *Nico De Wispelaere & Marc Vanderschueren*

ENDURES

An **OCAS** sister company

Synergy and complementarity between Endures and OCAS were evident from the very first moment.

Joost De Strycker

OCAS and Endures embark on joint offshore and maritime journey

In June 2019, Finocas Group NV and First Dutch Innovations (FDI) BV agreed with a FINOCAS majority stake in Endures BV – an independent contract research company, specialising in applied research on marine corrosion and anti-fouling, based in Den Helder (The Netherlands). Thus, Endures BV became a sister company of OCAS.

Estimated at roughly 3-4% of the global GDP by NACE, protection against corrosion in industry and society is a multi-million business each year. By selecting appropriate materials and protection systems in various environments, customers can reduce their corrosion costs.

ADDING VALUE AND REDUCING COSTS

OCAS is excited to announce its collaboration with the Endures team. By joining forces, we combine our expertise in the field of materials science to extend our on/offshore service offer and provide custom-made solutions adding value, reducing costs and preventing materials damage for our customers.
Based in the harbour of Den Helder, Endures has a C3/C4 seaside testing location to expose samples to maritime weathering conditions, both aerial and immersed, as well as in the tidal or splash zone. Endures also has a raft for efficacy tests of anti-fouling paints and can carry out lab experiments in running natural seawater. In addition, Endures has all of the tools to estimate the contribution of microbiologically influenced corrosion (MIC) to failure mechanisms with sampling procedures, micro-organism culture breeding capabilities, DNA mapping equipment and in-house microbiological experts. Endures conducts applied research on vessels, offshore installations and land-based structures and buildings to determine the type of corrosion damage, and to prevent future damage. Certified corrosion inspectors are also part of the Endures team.

AN ENDURING COLLABORATION

OCAS's expertise in alloy and coating design, metal surface engineering, non-standard testing and modelling complements Endures's in-field inspections and current knowledge of corrosion, electrochemistry, MIC, anti-fouling and protective coatings.
After barely six months of intensive collaboration, we've already solved several customer cases via common inspections, sampling and in-depth analysis. The complementarity of our welding and corrosion expertise has been especially noteworthy. In addition to these services, even a first common investment file for a customised set-up for accelerated testing in living sea water was launched.
OCAS and Endures will further deepen their offshore and maritime activities in an integrated approach.

Born from Innovation, GUARANTEED uses unique state-of-the-art simulation, monitoring and inspection tools to guarantee 'right first time' production. Being raised in Industry, we guarantee one-stop-shop industrial reliability.

Joachim Antonissen

Value the future, upgrade the past

GUARANTEED was created in 2019 as a spin-off company of OCAS, Finindus and ArcelorMittal Belgium. The new company creates value for its customers by repairing, refurbishing and producing large metal parts, using wire arc additive manufacturing to extend the lifetime or reduce the downtime of industrial equipment. This initiative is establishing a worldwide unique ecosystem in which cutting-edge metal innovation is combined with entrepreneurship and supported by an industrial footprint to guarantee 'right first time' part production and provide one-stop-shop reliability.

In an industrial environment, large production equipment is often tailor-made and exposed to severe operational conditions that demand high structural integrity for a long lifetime. This results in long lead times when components break down or sometimes even entire installations must be replaced as components have become obsolete, moulds have been lost, or suppliers have gone bankrupt. This either leads to huge financial losses due to unforeseen lengthy production standstills or to high storage and logistics costs. GUARANTEED offers a solution to these problems, as its technology allows these large slow-movers to be repaired and rebuilt on demand, reducing the long lead times and eliminating the storage costs. Moreover, as no dies, tools, moulds or set-up costs are required, manufacturing cost reduction can be an additional advantage.

BEYOND CONVENTIONAL TECHNIQUES

GUARANTEED's focus is on repairing or rebuilding large slow-moving components beyond conventional techniques, thereby prolonging the life of ageing industrial equipment, reducing long lead times, and eliminating storage costs. As our customers rely on us to respect tight lead-times, we work with proven and robust industrial components to ensure a high TRL-level and the reliability of our production equipment. In-situ process monitoring capabilities allow for closed-loop process control to minimise the risk of defect formation, while on-line NDT implementation guarantees any residual defects are detected and corrected on the fly in order to achieve zero-defect manufacturing capabilities – which is fully aligned with the GUARANTEED brand.

ONE-STOP-SHOP TO GUARANTEE QUALITY

GUARANTEED offers a one-stop-shop approach in order to maintain full control over our quality and lead-times as well as to respond to our customers' needs to receive ready-to-install parts at the lowest possible TCO (Total Cost of Ownership). This is why GUARANTEED's operations are currently embedded within ArcelorMittal Belgium, which provides us direct access to a state-of-the-art workshop, and even more importantly to highly skilled workers within an environment where safety, quality and customers are the top priorities.
A key element in achieving short lead-times and ensuring high-quality components is the 'right first time' zero-defect capability of our process. For this purpose, GUARANTEED uses the most advanced WAAM process software currently available, which is developed by one of our strategic partners. This is complemented with unique in-house-developed specific welding, metallurgical and in-use property simulation capabilities, which ensure that optimal production parameters are selected from the very first produced part.

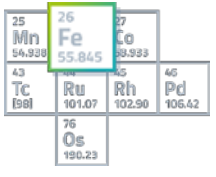
Finindus has been an ideal shareholder for us, investing with a long-term horizon and showing commitment in everything they do. Over the past 10 years, and by participating actively in our board, they have contributed with very valuable strategic as well as more industry-specific knowledge, and have shown a tremendous engagement in the development of the company.

Per Wassén, President and CEO of PowerCell Sweden AB (publ)

PowerCell

STRONG MOMENTUM

Finindus is an investment company backed by ArcelorMittal and the Flemish region. Finindus invests in early stage and growth companies at the forefront of innovation in materials, material processing, sustainable manufacturing and industry 4.0, with a positive impact on the planet. We differentiate ourselves through our industrial DNA and the hands-on support to the entrepreneurs we partner with.



materials

material processing

sustainable manufacturing

industry 4.0

Over the period 2018-2019, we screened over 400 technology companies. As we have intensified our cooperation with ArcelorMittal's global CTO and global R&D organisations, a substantial part of these companies has been introduced to OCAS and ArcelorMittal.

During the same period, we made two new investments: SENTEA, which is developing robust, low-cost FBG interrogators for condition monitoring and GUARANTEED, a JV with OCAS and ArcelorMittal, aiming at repairing and hybrid manufacturing of industrial parts using direct energy deposition technologies. Unfortunately, we also had to let go two of our portfolio companies.

We are proud that most of our portfolio companies have gained significant traction and recognition from customers and partners and are entering a new phase in their development.

PORTFOLIO HIGHLIGHTS

borit Borit has successfully completed its investment program aiming at a more automated production of bipolar plate assemblies. This platform was of paramount importance to be able to reliably deliver components in high volumes to a premium automotive OEM. Borit also received external recognition in 2018, as “Factory of the Future”. In 2019, the company has reached a positive operating cash-flow and bottom-line profitability.

PowerCell Sweden AB (publ) In April 2019, Powercell entered into a joint-development and license agreement with Robert Bosch for its 100 kW automotive stack. The deal included a 50 MEUR upfront payment and additional royalties. Later in 2019, Robert Bosch also decided to acquire a substantial stake in Powercell. Powercell has furthermore been quite successful in attracting Chinese customers for its S2 fuel stack platform (up to 35 kW). On Finindus side, we have successfully divested part of our shareholdings.

Keystone Tower Systems 2019 was a banner year for Keystone Tower Systems. The company succeeded in landing its first commercial contract to supply wind turbine tower segments to a major wind turbine OEM in the US, and brought a strategic partner on board to build and operate the first full-scale industrial plant implementing Keystone’s patented spiral welding technology. The plant is expected to be fully operational in the second half of 2020. In addition, KTS was awarded a 5 MUSD grant from the Department of Energy (DOE) to demonstrate its ‘in-field’ manufacturing technology to build a first tall tower (> 160 m hub height) on the US East Coast, enabling a whole new wind energy market in the US.

Expanite After years of double digit growth in its service centers in Europe and the US, 2019 was the year of further global expansion. Expanite commissioned two additional furnaces in the Far East as part of two license deals, one for a customer in China and one for a customer in South-Korea. The full range of Expanite technologies is now available to customers in China, a milestone in the company’s history.

Rein4ced 2019 was a pivotal year for Rein4ced. What started out a couple of years ago as an engineering consultancy in composites, has now transformed into a developer and manufacturer of bike frames using a proprietary hybrid composite material and a new manufacturing approach. Rein4ced succeeded in securing its first customer contracts and in commissioning its manufacturing plant.

INVESTMENT PORTFOLIO

finindus

BORIT (BE, 2010)
One-stop-shop for metal bipolar plates for fuel cells and electrolysers with a proprietary forming technology.

www.borit.be

CALYOS (BE, 2012)
Two-phase passive heat transfer systems for cooling power electronics and electronic components. Calyos targets applications in automotive and high-performance computing.

www.calyos-tm.com

EXPANITE (DK, 2014)
Surface hardening technologies for stainless steel and titanium based on proprietary gas phase processes.

www.expanite.com

KEYSTONE TOWER SYSTEMS (US, 2017)
Design and fully automated (in-field) manufacturing of (tall) tapered wind turbine towers.
www.keystonetowersystems.com

POWERCELL SWEDEN AB (publ) (SE, 2009)
Leading European producer of fuel cell stacks and fuel cell systems for stationary and mobile applications. Listed on Nasdaq First North since 2014.
www.powercell.se

REIN4CED (BE, 2017)
Development and manufacturing of bike frames made using a hybrid composite material containing thin steel fibers thereby increasing safety and durability, while maintaining lightweight.
www.rein4ced.com

SENTEA (BE, 2018)
Low-cost, robust and reliable interrogators for fibre optic sensors.

www.sentea.com

GUARANTEED (BE, 2019)
Repair and hybrid manufacturing of large industrial parts using direct energy deposition technologies.
www.guaranteed.be

Sharing experiences among multi-disciplinary teams is key to accelerating the success of innovations.

Joost De Strycker

Ionic liquid technology – green alternative to hexavalent chromium

In the past, hard chrome plating was typically performed with hexavalent chromium electrolytes. However, REACH environmental legislation banned the use of hexavalent chromium processes, unless special authorisation was acquired. Driven by this need for REACH-compliant alternatives, OCAS further matured a project on hexavalent chromium-free hard chrome plating from ionic liquids.

Thanks to OCAS's research & development efforts, a lab concept invented at university was scaled up from litres to tonnes. Basic requirements such as hardness, corrosion protection, friction, etc. were checked and optimised.

A ROBUST GREEN ALTERNATIVE

In this way, the technology has now matured to enter the prototyping stage and field testing in several applications. Partnering is one of the key factors for success at this stage – so, partners in different areas of the value chain were approached to make an in-depth evaluation of the technology. Some technical bottlenecks surfaced from these evaluations. Several lab programmes were launched and are running to resolve these issues to result in a robust green alternative to hexavalent chromium.

During exchanges with partners, it was also proposed to provide an economical solution in addition to a technical answer.

A basic cost model was built and is now being challenged by different partners at multiple positions in the value chain. Fine-tuning will require in-depth process studies on bath and electrode life-time, replenishment strategies, etc. Taking these last steps will bring the technology close to industrial validation readiness.

Such a programme is usually too large for one operator only. So, collaboration through a central platform, such as the OWA initiative in the UK, was crucial to a successful outcome. We are now on track to reducing the jacket production cost by more than 10%.

Marc Vanderschueren

Teaming up to combat climate change

LEADING FATCOR, A BELGIAN FEDERAL ENERGY TRANSITION FUND PROJECT

The Belgian Energy Transition Fund supports research projects and research infrastructure contributing to various aspects of energy supply to Belgium, including renewable energy from the North Sea.

OCAS has won a tender for projects from the Belgian Energy Transition Fund and is now leading a consortium composed of Ghent University, the Belgian Welding Institute, two wind farm owners (Parkwind and Rentel), and one steel fabrication company (Smulders). The total budget for the project is close to €1.2 million and will span four years.

The objective of the project – called FATCOR – is to investigate the combination of fatigue and corrosion. It is well known that corrosion leads to faster fatigue degradation of components, either because it supports the creation of pits that will provoke cracks, or because it accelerates the growth of cracks. Therefore, offshore structures are generally protected against corrosion either by paint or cathodic protection.

The problem that the FATCOR project will investigate is the degradation of materials that were initially protected against corrosion, but for some operational reason the corrosion protection did not completely perform its task. Examples are impressed current cathodic protection where the electrical system is interrupted, or paints that have been damaged by impact. So, should such materials be considered to be un-protected – and, as a result, have only 1/3 of their originally estimated fatigue life – or should they be classified as almost protected?

The project will provide the wind park owners with a more quantitative method for estimating the degradation caused by the combination of fatigue and corrosion and will potentially extend the life of the wind energy convertors installed in the Belgian part of the North Sea.

CARBON TRUST OFFSHORE WIND ACCELERATOR TEAMS UP WITH OCAS FOR FLAGSHIP PROJECT

The Carbon Trust Offshore Wind Accelerator (OWA) has initiated a project towards reducing the cost of new jacket structures for offshore wind foundations. With the ever-growing importance of offshore wind for producing electricity, the turbines are being installed in deeper waters and sometimes difficult soil conditions. Jacket structures are becoming increasingly more competitive.

The design of these structures is governed by fatigue loads and must follow strict rules established by certification authorities who have based their codes on testing data from the 1970s and 80s. However, taking new steel-making processes and evolutions in welding technology into consideration, it's time for a thorough update.
OCAS has proposed a programme to push the limits of the offshore design codes to upgrade the fatigue performance of welded jacket nodes. The objective is to reduce the thickness of critical joints so that they need less welding and are lighter and cheaper. Executing such a programme means that a lot of data points are needed, which requires time-consuming testing. Through its patented resonant bending methodology, OCAS has made it possible to reduce this testing time by a factor of 20 compared to traditional hydraulic testing. Now, it is possible to collect enough fatigue data for comparison to the current standards in a reasonable project time. As such a programme is usually too large for one operator only, it has been crucial to be able to collaborate through a central platform such as the OWA initiative in the UK.

JACO JOINT INDUSTRY PROJECT IS EXPANDING!

The overall framework has convinced leading developers ORSTED, VATTENFALL, EQUINOR, SIEMENS GAMESA, SCOTTISH POWER (Iberdrola) and ENBW to join forces with us. The great news is that SSE and SHELL have recently joined as well. Today, the JaCo (Jacket Connections) Joint Industry Project now consists of 8 top-notch offshore wind developers. The certification bodies DNV-GL, Bureau Veritas and technical authority BAM are also an integral part of the project, with the aim of checking whether we can obtain upgraded S-N curves for implementation in real projects.
The offshore wind supply chain is very active in the project and is contributing substantially too. In this respect, it is important to mention that we are focusing on robot-welded node technology, which can fabricate critical components more consistently and at a lower cost. Therefore, we are benchmarking automatic-welded components with manual-welded ones.
The project is running very well to the participants' great satisfaction. We are currently coming to the end of a work package that benchmarked classical hydraulic testing against OCAS's accelerated method with very promising results. This means that we plan to move ahead solely with the OCAS testing method, which is best placed to obtain fatigue data of the end-of-life of a critical component. Thus, we are on track to reducing the jacket production cost.

OPTIMISING AND VALIDATING MODULAR JACKET DESIGN

OCAS participated in the European JaBaCo project, which developed a modular concept for jacket foundations for offshore wind turbines, using prefabricated standardised components. Thanks to these components, the investment costs of offshore wind energy can be reduced by implementing prefabrication of sub-structures that are based on prefabricated components and are scalable in a significant range of environmental conditions. The consortium was led by RINA, with the collaboration of Ramboll, National Technical University of Athens (NTUA), IDESA, University of Thessaly (UTH), and OCAS.

OCAS successfully performed large-scale accelerated tests from the very beginning of the JaBaCo project.

Philippe Thibaux

The concept was based on an integrated design for water depths of 30-80 metres and turbine sizes of 5-10 MW in the North and the Mediterranean Seas. In the last case, seismic loading was considered. The project included the design of six structures (depending on water depth and metocean data) for fatigue testing and numerical simulations of structural components, conducted with a sensitivity analysis.
In this project, OCAS was responsible for fatigue testing of large-scale components performed at high frequency. This included detection of crack initiation, non-destructive testing to monitor crack growth, and post-mortem analysis of the fracture surfaces. Four X-joints with a brace diameter of 711 mm were tested until failure. The failure location differs between specimens, indicating that the manufacturing has an influence on the construction's weak points. The fatigue resistance of these tubular joints was compared to the fatigue design curve.

The fruitful cooperation of the four partners has resulted in a joint scientific publication. Going forward, research data can now be used to optimise the design of metal-to-metal seals.

Marc Vanderschueren & Dennis Van Hoecke

Optimising the design of metal-to-metal seals

Metal-to-metal seals are used in threaded pin/box connections of casing and tubing in oil and gas wells.

SHELL Projects and Technology decided to set up a multi-year programme in order to better describe the mechanisms of metal-to-metal sealing, focusing on the surface conditions in particular. This has not only required specialised levels of expertise, but SHELL has also needed their various partners to be able to work in an open and collaborative way. SHELL decided to work with OCAS. Moreover, to add fundamental academic knowledge about modelling of wear evolution and sealing behaviour, they established a consortium between SHELL, OCAS and the partner universities of Lulea and Twente. The methodology they have implemented takes advantage of a numerical sealing model and a co-developed experimental setup called SSMUR (SHELL Sealing & Mock-Up Rig) for which OCAS designed and realised the hard and software.
In this set-up, assembly, micro-sliding, and seal-ability can be investigated with scaled (100 mm diameter) metal-to-metal seal specimens at gas or liquid pressures up to 1500 bar. The set-up and experimental design are aimed at simulating conditions during a full-scale ISO 13679:2011 (2011) CAL IV test programme. Whereas the CAL test is aimed at qualifying leak tightness, the SSMUR is used to deliberately find the onset and the location of leakage. The testing can include multiple make-up and breakout cycles to modify the metal-to-metal seal through wear and plastic deformation. In addition, micro-sliding can be imposed to simulate the additional wear caused by the movement of (cyclic) mechanical loads.

DEPENDING ON THE TYPE OF THREAD COMPOUND

The effect on the seal-ability can subsequently be quantified by a leakage test using gas or fluid pressure. This is performed both to validate the models and to differentiate the performance of different samples. Several experiments have been conducted for a variety of thread compounds and applied pin/box surface coatings. These results were then used to validate a stochastic numerical sealing model for seal-ability. Once validated, the model was used with the experimental results to better understand the sealing mechanisms of metal-to-metal seals. At the same time, OCAS developed a numerical model to demonstrate the effects of out-of-roundness deviations of the pipe geometry on the connection sealing performance. The test and model results indicate that the onset of leakage depends strongly on the type of thread compound that is used. The thread compound affects the amount of wear and thus changes the surface topography of the interacting surfaces. Furthermore, the model shows that certain surface topographical features improve the sealing performance. This has proven to be novel, so that the validated models can subsequently be used to predict the seal-ability of casing-connection metal-to-metal seals in combination with their thread compound.


GAMEN

Collaborative materials' research to accelerate the R&D of our customers

Belgian Nuclear Research Centre SCK.CEN and DEME Offshore, explain the benefits of working with OCAS.

HIGH-TEMPERATURE-RESISTANT MATERIAL WITH IMPROVED INITIAL BRITTLENESS AND DAMAGE RESISTANCE

In the fusion reactor under construction in France (ITER), tungsten (W) is the main candidate to create an armour for plasma-facing components in spite of its principal drawback: brittleness!
Commercially produced W already has a rather high ductile to brittle transition (about 300°C) and prolonged operation in a fusion environment will raise it up further, causing a risk to the component's structural integrity.

OCAS's metallurgical expertise and SCK.CEN's long-standing nuclear material science knowledge have been put in synergy to launch a joint project to explore composites and high-entropy alloys based on refractory metals (tungsten and chromium). Such binary alloys are potential options for alleviating the initial brittleness as well as improving resistance to the harsh irradiation damage caused by the post-products of the fusion reaction.
This collaboration in the field of synthesis of high melting point elements/alloys was highly appreciated by the customer, as it opened up a broad range of fascinating exploratory domains. A good knowledge of the application requirements is key to developing a suitable material. Although, at OCAS, we only have minimal knowledge of what happens in a nuclear reactor, our long-standing partnership with SCK.CEN ensures the needed exchange of information with its specialists to co-develop good lab materials for advanced, international R&D programmes.

Our vessels are part of our critical assets, so they need to operate under harsh conditions. In order to counter specific degradation on a critical component in one of our vessels, we needed specialist steel know-how. OCAS provided us with an innovative testing solution to screen the available options in a fast and very flexible way. This has enabled us to choose the best possible material combination and meet the challenging timeline to upgrade the part. Thus we could significantly reduce degradation and obtain operational savings, improving the vessel's performance over time.

Luca Zanette, Project Engineer at DEME Offshore

Factual, flexible, fast and fit for purpose. This is how we operate with our customers in an industrial environment to bring them value for money.

Marc Vanderschueren & Steven Keyzer

LIFE EXTENSION OF A CRITICAL COMPONENT ON AN OFFSHORE JACK-UP RIG

Jack-up rigs are intensively used in the wind energy market to install turbines offshore. DEME Offshore bought an existing model that had previously been used in the oil & gas segment. For offshore wind operations, jack-up platforms need to move up and down many times more than in the traditional markets for which the vessels were originally designed.

This has an impact on the lifetime of some of the rig's key components. The problem was that exchanging such large components during operations at sea is not possible; the works had to be done during the limited time the vessel was in drydock. This also meant that analysis and solutions needed to be made very quickly and efficiently from data collected offshore, so that the solutions could be implemented straightaway when the vessel was under maintenance in a port. Therefore, DEME Offshore came to OCAS to benefit from our very interactive and flexible way of working, combined with the available expertise and equipment, to reproduce the life the vessel's critical components had seen. OCAS has been able to satisfy both challenging criteria in a record timeframe.

In this investigation, OCAS and DEME Offshore were looking for the optimum combination of material to minimise wear of a critical component of the ship. An automatically controlled test system allowed us to investigate the wear under high pressure for a contact length of hundreds of meters. The results revealed that some material combinations were significantly more efficient than others. In the meantime, the proposed solution has been implemented full-scale onto the vessel to the great satisfaction of all!

At OCAS, we strive to bring tailored solutions to our customers.

John Vande Voorde & Katia Linck

Bringing tailored solutions to our customers

OCAS is collaborating closely with customers to solve their design and engineering challenges. The objective is to position ArcelorMittal as a highly competent supplier and to support the implementation and marketing of new products such as Amstrong®Ultra 900MCL and Relia®450 high-strength hot rolled grades or Magnelis® coated steel grades.

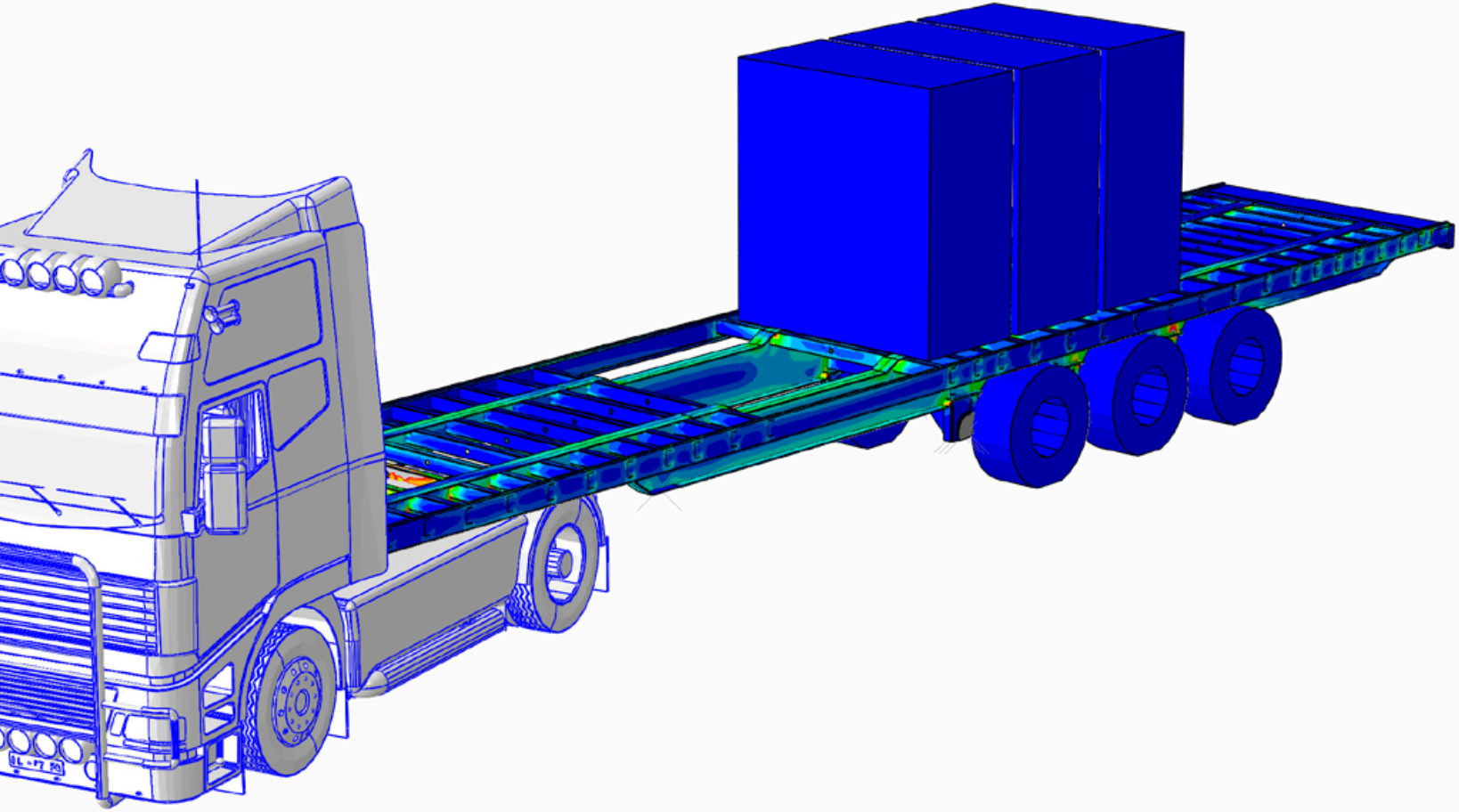
CO-ENGINEERING WITH CUSTOMERS

In 2018-2019, the OCAS team conducted co-engineering projects with customers in a wide variety of market segments, including transportation, agricultural machinery, household appliances and heating ventilation and air conditioning. The key drivers are most often cost and weight reduction, energy savings, and improved performance.

In the first stage, the team works with the customer to identify the customer's needs. They also discuss the technical specifications and the requirements and constraints of the application. Using this input, they then make a first analysis and offer some suggestions for improvement, which can include a switch to other steel grades or even design changes. At this stage, Finite Element Analysis is very often used to study the behaviour of the application.

The customer considers the recommendations, along with the cost impact. Then, the team supports the customer with experimental testing, as required. In a final stage, the team can assist in prototyping and, ultimately, in testing the final design.

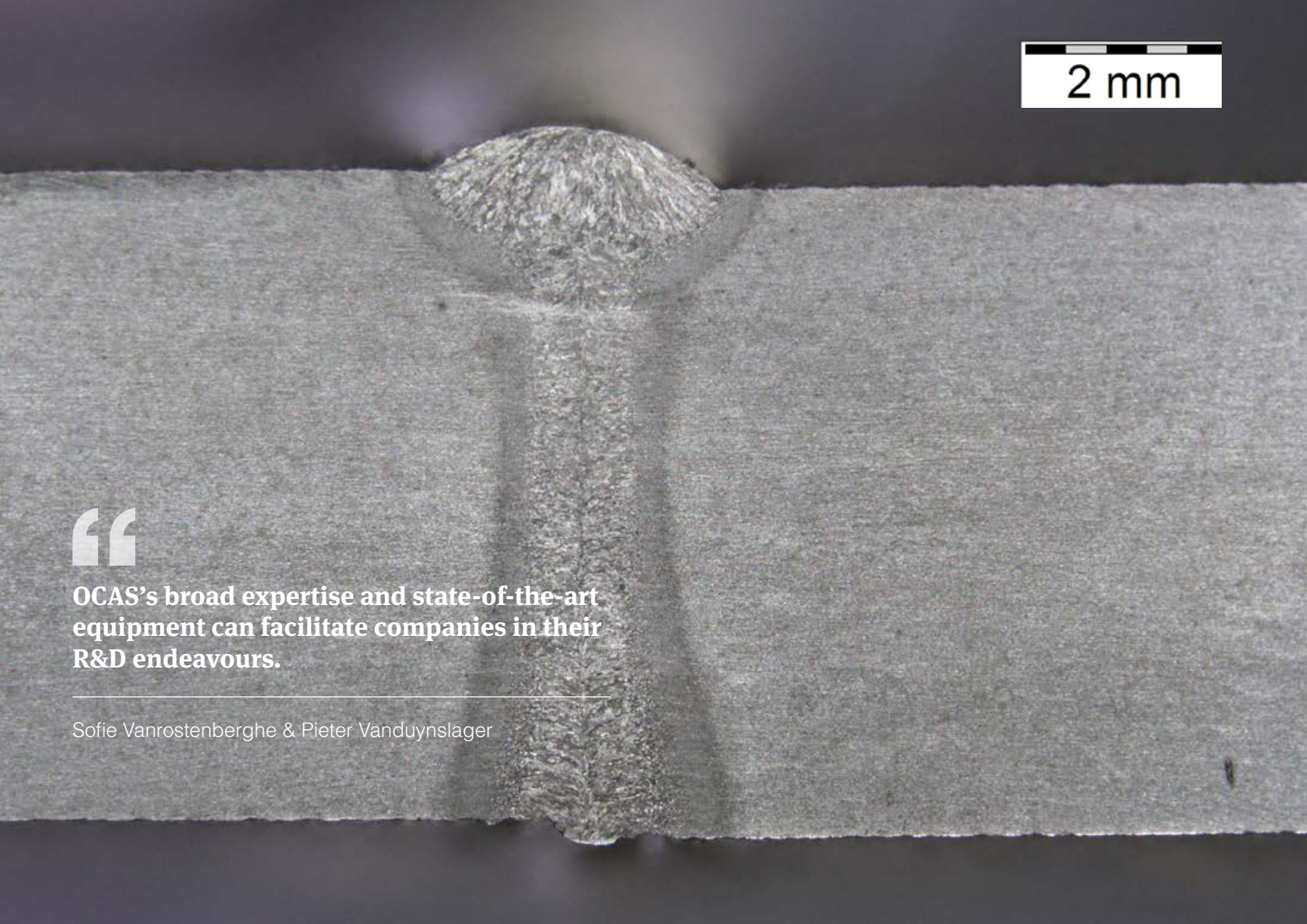
In a recent project, a heating ventilation and air conditioning manufacturer had been making its products out of commodity steels. However, for a new product line, the company wanted to optimise the steel grades used while improving the product's performance. The team proposed a design based on Magnelis® coated higher strength steel, which the customer is currently implementing.



GENERIC SOLUTIONS

Customer service and collaboration are of central importance to OCAS. To help grow budding contacts and relationships with customers, OCAS has put considerable effort into illustrating the benefits that can be attained when the latest steel grades and design revisions are joined. OCAS has developed several example cases in a range of markets with the explicit goal of opening up new vistas for our customers and sparking collaboration.

Each of these examples is based on a generic, relevant and representative design. Using the latest Finite Element techniques, the design and the selection of steel grades are optimised with the objective of substantially lowering the cost, reducing the weight, extending the functionality, and combinations of these aims. The relevant production methods – welding, bending, etc. – as well as the fatigue and wear behaviour are studied, and general guidelines for implementing modern steel grades are included in the show cases. In 2018-2019, OCAS updated such show cases for applications in the trailer and tipper market and launched a new study for the container market. The results are made available in presentations distributed to our customers and in dedicated workshops and during customer visits.



OCAS's broad expertise and state-of-the-art equipment can facilitate companies in their R&D endeavours.

Sofie Vanrostenberghe & Pieter Vanduynslager

Facilitating companies in their R&D endeavours

OCAS assists its customers successfully in a variety of sectors with a wide spectrum of technical issues.

With our multi-disciplinary teams, we support customers from product design all the way through the optimisation phase. This can be achieved by combining experimental work and finite element modelling tools available within the lab. Technical support can be provided on diverse topics covering metallurgical, surface or application related expertise, in fields including:

- forming
- welding
- durability: fatigue, wear, corrosion

Furthermore, OCAS has a dedicated team that handles assignments for which we already have the equipment and expertise. This approach ensures efficiency and short response times, which are highly appreciated when providing technical support to production plants as well as other customers.

AN EXAMPLE FROM WELDING

Support was delivered first of all to optimise the bias weld to improve fatigue resistance of the final product, while at the same time bearing in mind production efficiency improvements. After having supported laser welding experiments in Northern America, OCAS arranged and supervised experiments at two laser manufacturers' facilities in Europe. Furthermore, OCAS assisted the customer on the lay-out of a new heat treatment line and proposed a physical model capable of predicting the mechanical properties after heat treatment. The customer appreciated the research assistance highly.

Our front & back office model ensures a good combination of availability and expertise. The plant has direct access to all of the competencies and advanced equipment available in the R&D centre at an affordable cost.

Nico De Wispelaere, Veerle Van Lierde
& Annick Willems

Front & back office model quickly meets technical support requests from neighbouring plants

For more than 15 years, OCAS has been providing technical support to ArcelorMittal Belgium. Through these support activities, neighbouring plants have access to all of the lab's competencies. At the same time, researchers are given the opportunity to valorise their knowledge in real-life situations.

As technical issues occurring in a production environment always demand urgent assistance, the effectiveness of the technical support delivered by OCAS is of utmost importance. That's why a 'front & back office model' is successfully employed: the front office is staffed with dedicated generalists, who have access to the assistance of various experts from all of the teams of the R&D centre, which make up the back office. Thus, a good combination of availability and expertise is ensured, and the customer has direct access to all competencies and advanced equipment available in the R&D centre at an affordable cost.

SUPPORT FOR A WIDE VARIETY OF TASKS

These support activities cover a wide range of tasks. A first example concerns production and quality follow-up. If the neighbouring plant does not have the necessary equipment at hand, OCAS carries out a validated procedure guaranteeing a quick response time for a continuous sample flow. Test results can automatically be uploaded into the plant's mainframe database. In 2019, OCAS tested approx. 2500 coils for hole expansion, performing five measurements per coil, to evaluate the formability of specific steel grades in combination with a cut edge.

Another example involves a working group investigating a technical problem for which OCAS provides support – for example, by assisting in material selection, optimisation of welding parameters, etc. – to ensure long-lasting and robust performance in a production environment.
Of course, OCAS is also called upon for ad hoc requests: troubleshooting and random sudden short-term requests for which urgent assistance is needed to resolve the issue. This is often the case when components of production installations show early damage or even break down. The affected part is then sent to OCAS for investigation and advice. In a lot of cases, the root cause of the

failure leading to rapid material degradation is a combination of mechanisms (fatigue & stress concentrations, corrosion, wear, ...). In addition to analysing the failure, OCAS can also be included in discussions with the supplier's material specialists and help the production plant claim compensation.

TRAINING ON FAILURE MECHANISMS

Following similar requests from several departments within ArcelorMittal Belgium, a training programme on failure mechanisms was developed in close collaboration with OCAS experts. The training primarily targeted support functions in maintenance and engineering and focused on failure mechanisms of metal components in the field of corrosion, fatigue and wear.

Participants gave positive feedback and requested that this initiative be continued, as it became apparent that similar material problems were being encountered in different departments. Thus a self-learning network, which would ensure a continuous sharing and learning of each other's experiences, was launched with Arcelormittal Belgium.

OCAS assists customers in their production process to achieve the desired bend angle after load removal, even for heavy-gauge and high-strength steel grades.

Steven Cooreman

Bending the rules

Bending is the main deformation mode for heavy-gauge, advanced high-strength steel grades. Although bending a steel sheet may seem to be straightforward, one should respect some basic rules. Therefore, OCAS provides theoretical and practical guidelines to help customers choose the appropriate tools and machine settings to obtain a high-quality product.

BENDABILITY, REQUIRED BENDING FORCE AND SPRINGBACK

When bending a steel sheet, one must consider three things: the material's bendability, the required bending force, and the springback phenomenon.

To avoid the appearance of cracks in the bent material, one should respect the minimum guaranteed bending ratio, which is a measure of the material's bendability. The minimum guaranteed bending ratio is defined as the smallest possible ratio of punch radius to sheet thickness for which no cracks can be observed by visual inspection. This ratio is determined through lab-scale bending tests during which the material is bent to either 90° or 180°.

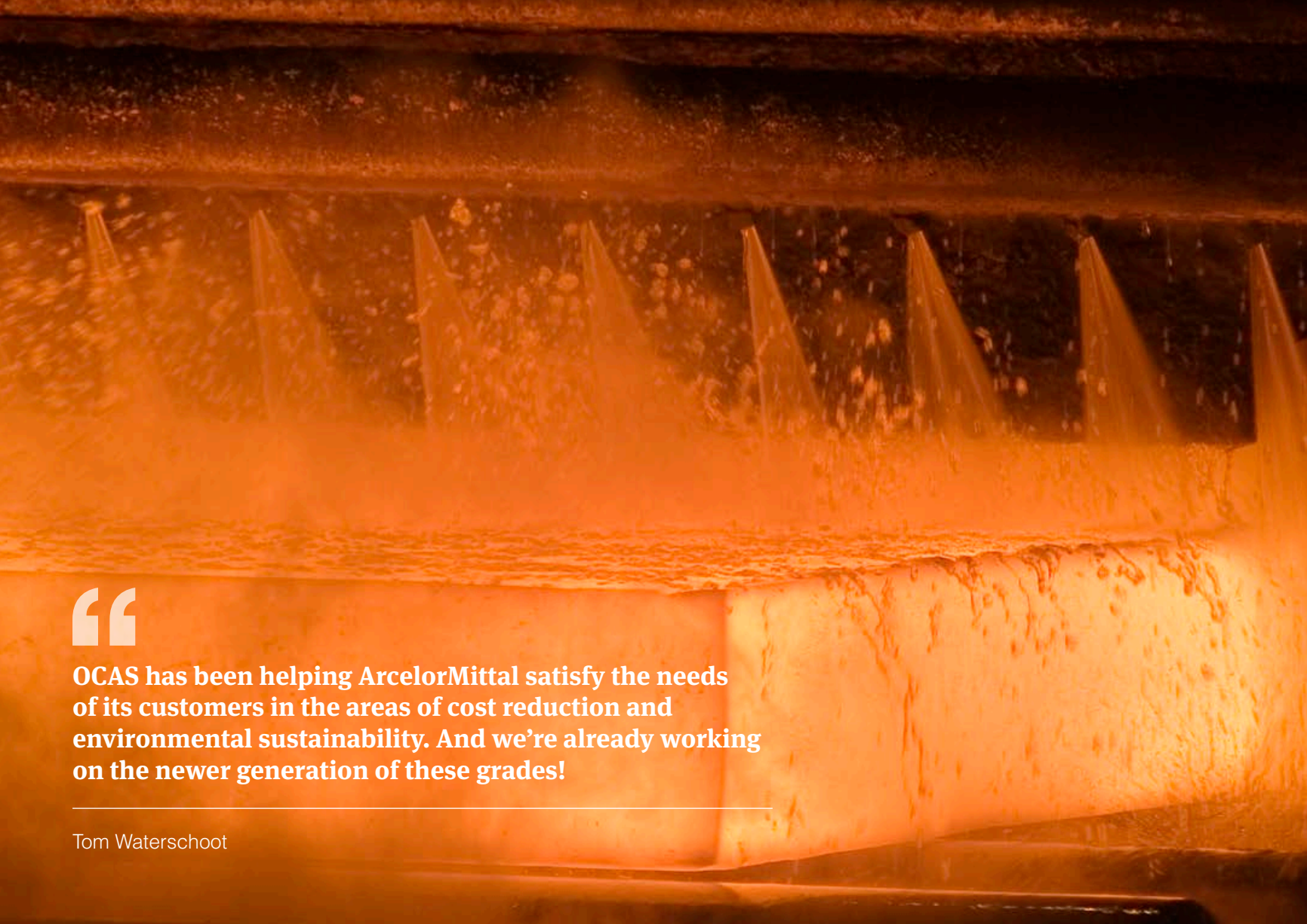
It can be imagined that powerful presses are needed to bend heavy-gauge, high-strength steel sheets. However, in addition to thickness and material strength, other parameters such as die width, friction between the tools and the steel sheet, and punch radius also strongly affect the required bending force.

Springback refers to the phenomenon of elastic recovery after load removal. When bending a steel sheet, both elastic and plastic deformation occur. Furthermore, the induced strain varies over the sheet's thickness. After removing the load, part of the elastic strain is recovered. Consequently, both the bend angle and the bend radius change. This phenomenon can be easily counterbalanced by over-bending the sheet so that the desired bend angle is achieved after load removal. However, the level of springback depends on many parameters, including sheet thickness, the material's strength, punch radius and die width.

GUIDELINES FOR CUSTOMERS

To gain detailed understanding of the bending behaviour of high-strength steel grades, OCAS conducts extensive experimental campaigns in the lab, supported by FEA (Finite Element Analysis) studies. FEA makes it possible to study the effects of different parameters on the bending behaviour.

Furthermore, FE simulations provide more insight into the deformation process and help explain experimental observations. The data gathered from these experimental and numerical studies typically result in general guidelines, recommendations and even analytical formulas which we share with our customers.



OCAS has been helping ArcelorMittal satisfy the needs of its customers in the areas of cost reduction and environmental sustainability. And we're already working on the newer generation of these grades!

Tom Waterschoot

Expanding the product range in a cost-effective manner

ArcelorMittal strives to continuously innovate and improve their products for its many customers. Reducing cost, while expanding the usability of the grades for more extreme environments and ever-demanding applications in industry, requires applied research. Thanks to our expertise and to our broad range of research equipment available, OCAS is a natural R&D partner to ArcelorMittal. OCAS can reproduce the entire process of industrial steel production, at a cost-effective lab scale, significantly reducing the overall cost of commercialising the product.

OCAS has been helping ArcelorMittal satisfy the needs of its customers in the areas of cost reduction and environmental sustainability. Structural and wear-resistant steels are good examples of new concepts developed by OCAS that have been industrialised and commercialised by ArcelorMittal in the last few years.

STEELS FOR CHEAPER, GREENER PRODUCTS

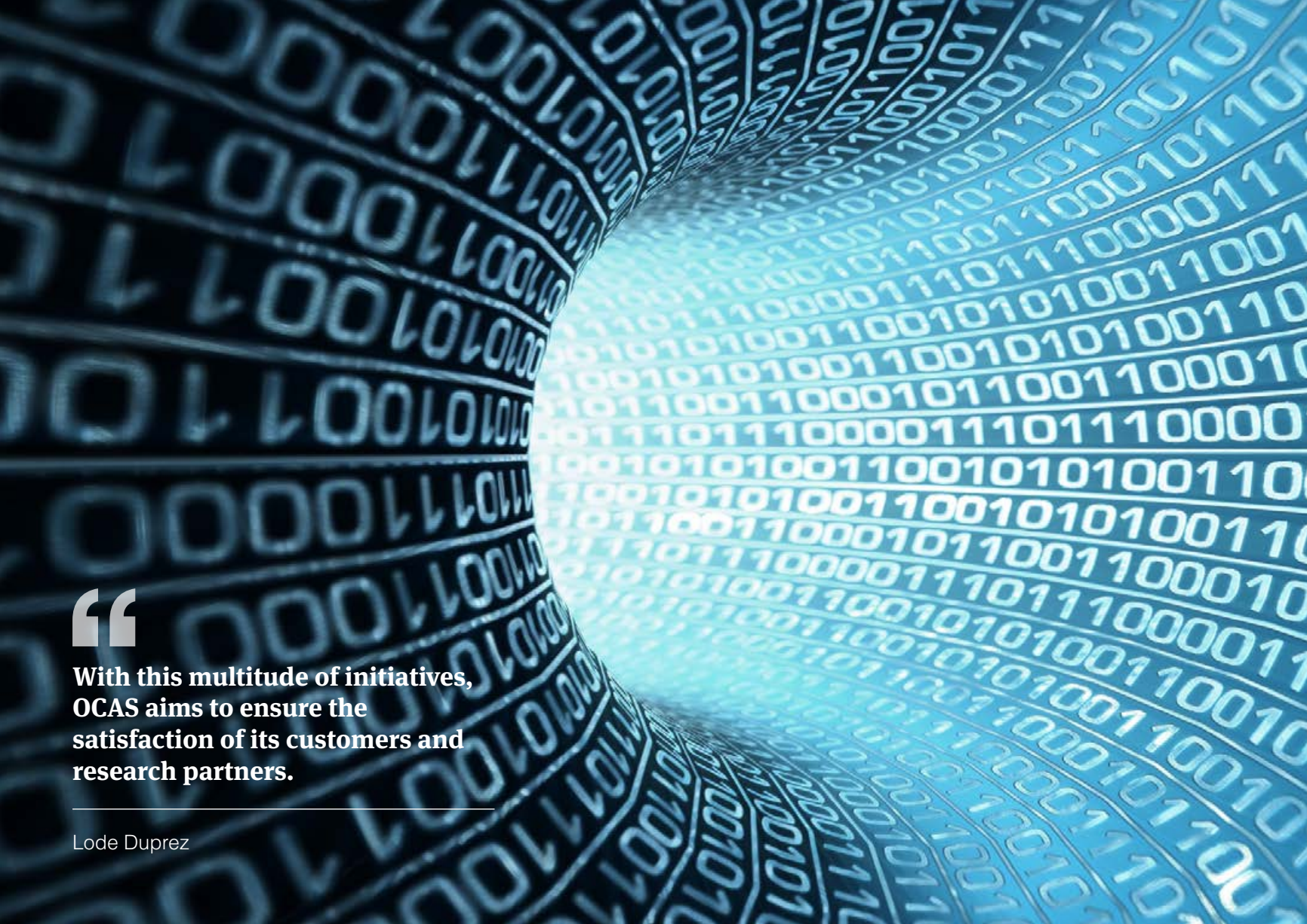
Trucks and trailers can be made cheaper by using stronger steels in lighter constructions, resulting in lower fuel consumption for a given payload. In addition, current developments at OCAS have made it possible to guarantee strength and toughness in both directions in steel sheet, providing more freedom when cutting blanks from the sheets and thus improving material yield. Further reducing the cost for the end-customer.

OCAS is also expanding the applicability of hot-rolled products by developing abrasion-resistant steel with prolonged lifetime for the thin-gauge product segment and high-strength materials in thicker gauges. Providing these thicknesses as hot-strip products delivers a pronounced cost advantage over the quench and tempered plate alternative. Developments that are favourable for both the environment and lower costs.

In the yellow and green goods sector, aesthetic aspects are becoming increasingly important. Therefore, OCAS's metallurgists are developing new concepts to minimise surface defects on hot-rolled sheets.

The development of the above-mentioned grades has been possible thanks to OCAS's level of expertise and to the refinement of our instruments and equipment.

In the meantime, OCAS has already started tackling the newer generation of these products!



With this multitude of initiatives, OCAS aims to ensure the satisfaction of its customers and research partners.

Lode Duprez

Research 4.0 – Efficient and smart, with an eye for detail

The holy grail for industrial research is to have technological solutions at the push of a button. The reality is that research is still a costly and time-consuming activity. Consequently, for a research lab such as OCAS, striving to be a research facilitator for its customers, continual improvement is key to maximising our output quality and offering a highly differentiating and competitive service catalogue of research capabilities to our customers.

In this context, over the last few years, OCAS has invested immensely in three research domains to keep our research performance at the highest level:

- Digitisation
- Combinatorial
- Nano investigation

COMPETENCE AND STATE-OF-THE-ART EQUIPMENT

The focus of the combinatorial domain is to have more efficient data generation, data capture and data visualisation. Digitisation has multiple targets on the data-mining side, which enables smarter experimentation by performing digital screenings using advanced computational tools. Digitisation also allows us to extract much more information from complex data sets (such as images via artificial intelligence and machine learning techniques). The third axis addresses the opposite side of the research spectrum: looking at nano areas of well-selected samples to investigate those materials down to the atomic level in order to acquire fundamental understanding of the mechanisms behind material behaviour. OCAS has the competence and access to state-of-the-art equipment in this field. Furthermore, our researchers have regular exchanges with the scientific and academic community worldwide.

CROSS-FERTILISING FOR AGILITY, VERSATILITY AND TRANSVERSALITY

Next to equipment and competencies, the appropriate laboratory organisation also needs to be implemented to achieve maximum agility, versatility and transversality. For that reason, ‘cells’ have been created that team up researchers from different departments to cross-fertilise among these domains:

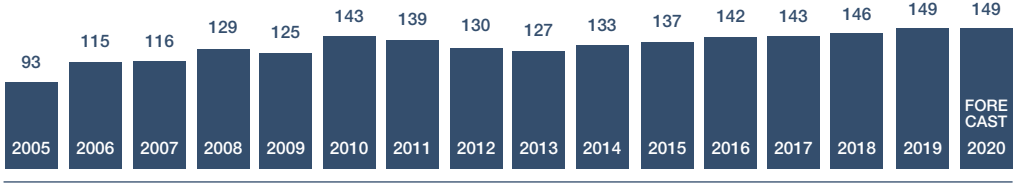
- The digital cell
- The combinatorial cell
- The nano-investigation cell

With this multitude of initiatives, OCAS aims to ensure the satisfaction of its customers and research partners.

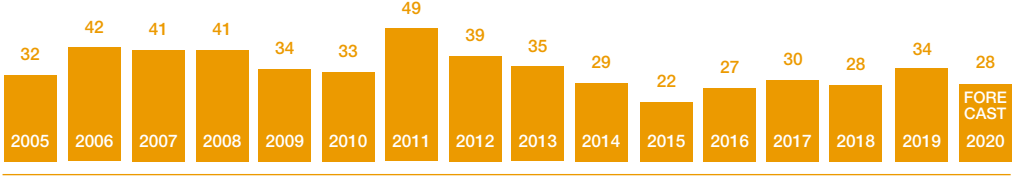
FACT SHEET

evolution of turnover of OCAS (M€)

evolution of staff (FTE)



number of trainees



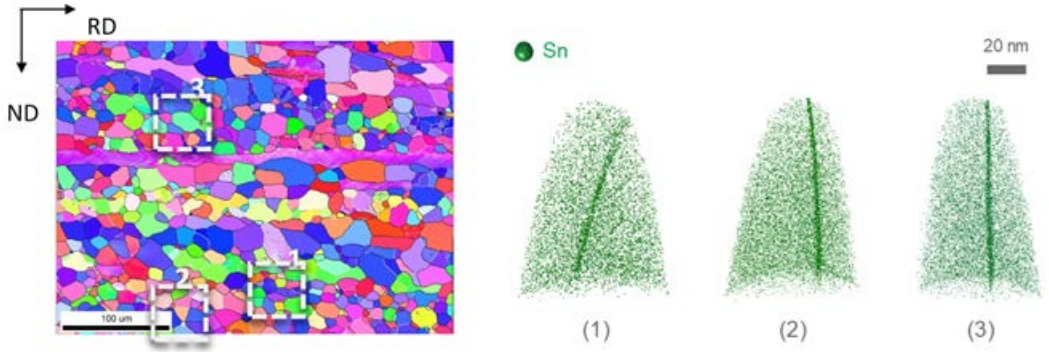
Knowledge building

In order to support OCAS's major activities in product & solution development, the necessary methodology and fundamental insights must be obtained in parallel to those developments. This is exactly the goal of the research carried out in the framework of 'knowledge building', and therefore knowledge building activities are of key importance to reach the objectives set.

Knowledge building projects are often supported by PhD theses, or include collaboration with third parties adding valuable expertise. Sharing knowledge on generic topics proves to have an important leverage effect. Furthermore, through the knowledge building projects ideas arise for renewal of portfolios.

In 2018-2019, significant progress has been achieved in multiple research domains of the knowledge building programmes. Examples of realisations include:

- Via extensive **nano-scale** characterisation experiments, an in-depth insight was obtained in the **Sn segregation behaviour in Fe-Si steels**. Multi-technique characterisation over various process steps and with variation of key process parameters allowed to map and quantify the Sn enrichments, which in combination with modelling allowed to propose and verify different hypotheses.
- A clear step forward has been achieved in the understanding of **material degradation mechanisms in H_2S environments**. This progress was realised via the implementation of various advanced new methodologies. From a mechanical point of view, it concerned instrumented double cantilever beam (DCB) testing in combination with a hydrogen diffusion model. From a surface point of view: a "hydrogen permeation test under stress" was designed for H_2S environment. Combining all these techniques with classical hydrogen thermal desorption tests allowed to



get new insights in the H_2S response of various sour grades.

— Mechanical properties of zinc coatings are well-known and have been studied in detail during the last decades. However, the fundamental behaviour of coatings of zinc- or aluminium-based alloys is much less understood. Above, understanding the contribution of the different phases in their complex structure requires new approaches. **Mechanical property maps** were built using a **grid nano-indentation** technique and were **quantitatively correlated to the microstructure map**. Then, phase volume fractions and mechanical properties of each individual phase were extracted using image correlation based targeted indentation (ICBTI) analysis and using the fit of probability distribution plots. The ICBTI method is a new way to analyse nanoindentation grid dataset. An **automatic correlation** procedure between mechanical property and microstructure maps is applied and leads to the exclusion of measurement artefacts, ensuring a more reliable quantification of the mechanical properties of each phase.

— High strength steels offer a unique opportunity to reduce weight in heavy-duty machinery such as trucks, trailers and agricultural machinery. These types of applications require significant fatigue resistance. It is well-known that fatigue failure typically originates at stress concentrations caused by the joining procedures. The main objective of the collaborative EU funded DURAMECH project was to investigate the possibilities to convert a welded assembly to a bolted one, whilst increasing the fatigue strength. Practical design rules were developed for **dimensioning of bolted joints in applications involving fatigue of high strength steel grades**. Furthermore, guidelines were developed on how to transform either a welded or a bolted low strength steel assembly into a high strength steel bolted assembly that has at least the same static strength but an increased fatigue strength.

— *Nikolas Mavrikakis, Franck Nozahic, Lode Duprez, Joost De Strycker & Sofie Vanrostenberghe*

OCAS PROVIDES WORKSHOPS TO SUPPORT STEM ACTIVITIES


CARHARTT
ESCAPED IN
2019

Seminars

Pursuing our tradition and expertise in organising scientific and technical conferences, OCAS organised a series of seminars in 2018-2019. We were able to attract highly motivated and enthusiastic “out-of-the-box” international speakers, willing to share novelties and knowledge insights.

“Use of EPMA in materials research” seminar

January 29th, 2018

This seminar brought together users and suppliers to exchange experiences with this technique in different application domains. An overview of the evolution of the EPMA technique and available detectors, including the latest soft X-ray emission spectrometer allowing for even better detection limits, was given. Various users presented case studies illustrating the assets of EPMA analysis.

Programme

- *“Electron Probe Microanalysis: something old, something new”*, Stefan Kuypers, Jeol Europe
- *“Some decades of EPMA analysis in metallurgy”*, Blandine Remy, ArcelorMittal Global R&D Maizières
- *“Soft X-ray emission spectrometer for EPMA: a new micro-analytical tool for steel research”*, Mélanie Gauvin, OCAS
- *“Six years of FEG EPMA at KU Leuven and its application in the field of metals, metallurgical residues and refractories”*, Annelies Malfliet, KULeuven

3rd Structural Integrity seminar (OCAS and its MSC partners)

May 24th, 2018

This seminar was organised in collaboration with OCAS's Metal Structures Centre partners. Structural integrity evaluations serve to judge the acceptability of detected or assumed defects. This method relies on the actual performance of the material as used in the structure and has proven on numerous occasions to give the best performance at minimum cost.

Programme

- *"Structural integrity challenges for power plants in the current energy transition race"*, by Frits Petit, Engie Laborelec
- *"FFS assessment reactor case: out of roundness reactor"*, by Willem Deraedt, Sintra engineers
- *"Design, build and in-service follow-up of a dynamically loaded steel structure"*, by Peter Neven, TCS
- *"Structural integrity beyond the standard"*, by Stijn Hertelé, UGent & Philippe Thibaux, OCAS
- *"Assessment of corrosion damage affecting the girth or long seam weld in vintage pipelines"*, by Troy Swankie, DNV-GL
- *"Challenges and opportunities for offshore single sided welded tubular joints"*, by Jo Willems, Smulders
- *"Structural integrity in risk based design of inland waterway tankers"*, by Joep Broekhuijsen, Damen Schelde Naval Shipbuilding

"Abrasion resistant steels: modelling and experimental challenges" wear seminar

June 15th, 2018

The abrasion resistance of a material is not solely determined by the ratio of its hardness as compared to the hardness of the abrasive medium. It is also affected by the surface state and the level of residual stresses at the surface. At the same time, systematic screening has indicated that the material's microstructure as well as its mechanical response to impact have a pronounced effect on the abrasion resistance. This effect is not captured in the conventional design criteria, where only the material hardness is taken into account.

Programme

- Keynote presentation *"Atomistic simulation in tribology: potentials, perspectives and limitations"*, by Michael Moseler, Fraunhofer IWM, Microtribology Center µTC (Germany)
- *"Materials, service life and wear mechanisms in agricultural tools"*, by Jacob Sukumaran, UGent (Belgium)
- *"Modelling of macroscopic loads on agricultural tools with the Discrete Element Method"*, by Florian Schramm, TU-Braunschweig (Germany)
- *"Micromechanical modelling in design of wear resistant microstructures"*, by Anssi Laukkanen, VTT (Finland)
- *"Macro-damage mechanical modelling of abrasion in agricultural tools"*, by Peerapon Wechsuwanmanee, RWTH Aachen (Germany)

“Artificial intelligence for image processing in metallurgy” seminar

February 1st, 2019

At present, digital images of the microstructure of metals must be analysed by expert scientists who are trained for this task. This leads to a bottleneck on the number of images that can be analysed, and a certain subjectivity in the resulting classification of the image. By organising this seminar, OCAS aimed to shed a light on the latest techniques to process and classify images by machines, using methods derived from artificial intelligence, machine learning, big data and computer vision. The development of such algorithms promises to significantly increase the understanding of materials and accelerate research in metallurgy.

Programme

- *“Person identification (classification) from radar images”*, by Dr. Ivo Couckuyt, IDLab research group, Department of Information Technology, UGent (Belgium)
- *“AI for image and video processing: applications and model architectures”*, by Jean-Yves Parfait, Multitel (Belgium)
- *Presentation on the correlation between microstructure and mechanical properties*, by Prof. Geurt Jongbloed, Delft Institute of Applied Mathematics, TU Delft (The Netherlands)
- *“Advanced Steel Microstructural Classification by Classic and Deep Learning Methods”*, by Dr. Seyed Majid Azimi, German Aerospace Center (Germany)
- *“Metallography 4.0 – How Machine Learning can help to make Microstructural Classification more reliable”*, by Dr Dominik Britz, Material Engineering Center Saarland (MECS) (Germany)

Integrated computational materials engineering (ICME) seminar

July 9th, 2019

The properties of steel must be continuously improved to perform well in the challenging competition with other materials on the one hand, and to fulfil sustainability requirements on the other hand. The conventional measures for mechanical property optimisation have been widely exploited for many years, so that tailoring the microstructure morphology is the most promising approach for future steel development.
This seminar was organised in the framework of RFCS project *"Toolkit for the design of damage tolerant microstructures"*. The overall objective of the RFCS project TOOLKIT was to develop a simulation toolbox for the computer-assisted design of damage tolerant microstructures. Involved partners: RWTH Aachen, Universiteit Gent, University of Thessaly, Corinth Pipeworks, thyssenkrupp and OCAS.

Programme

- *"Keynote lecture: DAMASK – The Düsseldorf Advanced MAterial Simulation Kit for studying multi-physics crystal plasticity phenomena"*, Franz Roters, Max-Planck-Institut für Eisenforschung
- *"Toolkit for the design of damage tolerant microstructures"*, Sebastian Münstermann, RWTH Aachen University
- *"Identification of relevant mechanical properties and numerical simulations"*, Sarath Chandran, Gent University & Nikolaos Aravas, University of Thessaly
- *"Tailored microstructure configurations for required mechanical properties"*, Wenqi Liu, RWTH Aachen University
- *"Process design to achieve improved microstructures"*, Margianna Tzini, University of Thessaly
- *"Complementarity of computational design versus experimental screening in metallurgical developments"*, Lode Duprez, OCAS

Metal plasticity seminar: Towards a virtual test environment

October 1st, 2019

This seminar was organised in collaboration with KU Leuven.
Material forming and shaping through plastic deformation is still one of the most efficient and economical manufacturing processes and is therefore extensively used in large industries such as automotive, appliance, energy, etc. Since many years, FEA (Finite Element Analysis) is used to optimise metal forming processes, as it reduces the cost of the trial-and-error phase and the time-to- market. The reliability of such FE simulations to a large extent depends on the capability of the constitutive model to reproduce the mechanical material behaviour, which can be quite challenging in the case of metals.
The aim of this seminar is to promote a platform for people working in the field of metal plasticity, to discuss the state-of-the-art, the current research and future developments. The intent is to strengthen the cross-fertilisation between theoretical material modelling, computational and experimental plasticity and the development of industrial applications.

Programme

- *"Steel industry – latest developments and future trends"*, Dr. L. Bracke, ArcelorMittal Global R&D
- *"Some features of the strain rate dependence of metal plasticity"*, Prof. P. Verleysen, Universiteit Gent
- *"Advanced phenomenological models"*, Prof. A. H. van den Boogaard, University of Twente
- *"New advances for evolving meshes/discretization methods in 3D large deformation problems. Application to metal forming, wear, crack propagation and fluid-structure interactions using FEM, DEM and PFEM"*, Prof. J.-P. Ponthot, Université de Liège
- *"Statistical crystal plasticity models and their implementation in FE models for plastic forming simulations"*, Prof. A. Van Bael, KU Leuven
- *"Application of plasticity models for the design of damage tolerant microstructures, Prof. S. Münstermann"*, RWTH Aachen University
- *"Quantitative full-field measurements for material identification and model validation"*, Dr. P. Lava, MatchID NV

High productivity welding processes for thick section steels seminar

October 23rd, 2019

This seminar was organised in collaboration with the Belgian Welding Institute.
This international seminar highlighted some welding options available for increasing productivity when welding thick section steels. These include both traditional and more modern arc welding techniques, as well as other options, such as beam and friction welding. Aim of the seminar was to provide a non-commercial introduction to some of these lesser used techniques, with a focus on (near) industry-readiness. In addition to the lectures from international speakers, there was a short tour of the welding facilities and a visit to the large-scale testing laboratory. The target audience includes welding engineers and co-ordinators, production and operations managers and R&D personnel.

Programme

- *"Friction-based welding processes for thick section steels"*, by Koen Faes, Belgian Welding Institute
- *"Welding of high thickness plates using different methods – laser submerged arc hybrid welding and laser beam welding under vacuum"*, by Simon Olschok, Welding and Joining Institute ISF of Aachen University
- *"Advances in high productivity electron beam welding processes for power generation and related industry sectors"*, by Chris Punshon, TWI Ltd.
- *"Old technologies facing new requirements – (Re-)Introduction of electrogas-arc- and electroslag-welding in shipbuilding"*, by Andreas Gericke, Fraunhofer Research Institution for Large Structures in Production Engineering
- *"High productivity welding processes for thick section steels – Narrow Gap welding"*, by Alexis Ferrari, Institut de Soudure
- *"Productivity improvement methods for submerged arc welding of thick section steels"*, by Christoph Gerritsen, OCAS .

LIST OF PUBLICATIONS 2018/2019

PAPERS PUBLISHED IN SCIENTIFIC JOURNALS

Publication Title	Author(s)	Journal/Reference
Corrosion protection of steel cut-edges by hot-dip galvanized Al(Zn,Mg) coatings in 1 wt.% NaCl: I. Experimental study	H. Simillion, O. Dolgikh, S. V Lamaka. H. Xue, A. Bastos, A. R Oliveira, M. G Taryba, C. Allély, B. van den Bossche, K. Van den Bergh, J. De Strycker, J. Deconinck	*Materials And Corrosion - Werkstoffe Und Korrosion* Vol. 70, 5 (2019) pp. 768-779
Corrosion protection of steel cut-edges by hot-dip galvanized Al(Zn,Mg) coatings in 1 wt.% NaCl: II. Numerical simulations	H. Simillion, O. Dolgikh, S.V. Lamaka, A.C. Bastos, H.B. Xue, M.G. Taryba, A. Oliveira, C. Allély, B. Van Den Bossche, K. Van Den Bergh, J. De Strycker, and J. Deconinck	*Materials And Corrosion - Werkstoffe Und Korrosion* Vol. 70, 5 (2019) pp. 780-792
Influence of water content and applied potential on the electrodeposition of Ni coatings from deep eutectic solvents	Jon Ustarroz, Monika Lukaczynska, El Amine Mernissi Cherigui, Andrea Ceglia, Krista Van Den Bergh, Joost De Strycker, Herman Terryn	*Electrochimica Acta* Vol. 319 (2019) pp. 690-704
Can carbides resist nitriding?	E. Leunis, M. Gauvin	*Journal of Heat Treatment and Materials* Vol. 74 (2019) pp. 3-11
A fully coupled fluid-structure interaction simulation of three-dimensional dynamic ductile fracture in a steel pipeline	Reza Talemi, Steven Cooreman, Haroun Mahgerefteh, Sergey Martynov, Solomon Brown	*Theoretical and Applied Fracture Mechanics* Vol. 101 (2019) pp. Pages 224-235
The third Sandia Fracture Challenge: predictions of ductile fracture in additively manufactured metal	S. Kramer et al.; S. Cooreman, P. Thibaux	*International Journal of Fracture* Vol. 218 (2019) pp. 5–61
Effect of Silicon on the Hot Flow Behavior of Ultra-Low Carbon Austenite	P. Rodríguez-Calvillo, J. Schneider, Y. Houbaert, J. Cabrera, and R. Colás	*Materials Performance and Characterization* Vol. 8 (2019) pp. 15

A multi-scale study of the interaction of Sn solutes with dislocations during static recovery in α-Fe	N. Mavrikakis, C.Detlefs, P.K.Cook, M.Kutsal, A.P.C.Campos, M.Gauvin, P.R.Calvillo, W.Saikaly, R.Hubert, H.F.Poulsen, A.Vaugeois, H.Zapolsky, D.Mangelinck, M.Dumont, C.Yildirim	*Acta Materialia* Vol. 174 (2019) pp. 92-104
Combining MCR-ALS and EXAFS as tools for speciation of highly chlorinated chromium(III) in mixtures of deep eutectic solvents and water	Tim Verdonck, Philippe Verpoort, Joost De Strycker, Ansbert De Cleene, Dipanjan Banerjee, Peter Nockemann, Rik Van Deun, Kristof Van Hecke	*Dalton Transactions* Vol. 48 (2019) pp. 2318-2327
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Prediction of Martensite Start Temperature for Lightweight Fe-Mn-Al-C Steels	R. Zhang, W. Zheng, X. Veys, G. Huyberechts, H. Springer, M. Selleby	*Journal of Phase Equilibria And Diffusion* Vol. 39 Issue 5 (2018) pp. 476-489
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CONFERENCE CONTRIBUTIONS

Publication Title	Author(s)	Conference
Large-scale resonant fatigue testing of welded tubular x-joints for offshore jacket foundations	Jeroen Van Wittenberghe, Philippe Thibaux, Maarten Van Poucke	2019/06/09 — Glasgow, United Kingdom *2019 OMAE-International Conference on Ocean, Offshore and Arctic Engineering*
Numerical simulation and result interpretation of large scale fatigue testing of tubular x-joint close to resonance frequency	Philippe Thibaux, Jeroen Van Wittenberghe, Maarten Van Poucke	2019/06/09 — Glasgow, United Kingdom *2019 OMAE-International Conference on Ocean, Offshore and Arctic Engineering*
Saline resistant weathering steel for offshore and naval: corrosion testing?	Krista Van den Bergh, Lucia Fernandez Macia, Joost De Strycker, Martin Liebeherr	2019/09/08 — Seville, Spain *EFC EUROCORR 2019*
Fatigue response of high-strength steel bolted connections under in-plane shear and out-of-plane bending loading modes	Okan Yilmaz, Carlos Jimenez Pena, Dimitri Debruyne	2019/11/20 — Senlis, France *Fatigue Design 2019*
Fatigue testing of large-scale steel structures in resonance with directional loading control	Jeroen Van Wittenberghe, Alexis Coste	2019/11/20 — Senlis, France *Fatigue Design 2019*
Iron loss modelling of electrical traction motors for improved prediction of higher harmonic losses	Johan Rens, Lode Vandenbossche, Ophélie Dorez	2019/05/19 — Lyon, France *32nd Electric Vehicle Symposium (EVS32) Lyon, France, May 19-22, 2019*
Can carbides resist during nitriding?	Elke Leunis, Melanie Gauvin	2018/04/12 — Friedrichshafen, Germany *European Conference on heat treatment: Nitriding and Nitrocarburizing*
influence of the enamelling process on Hydrogen permeation, comparison between permeation & high temperature charging	Marc Leveaux, Laura Moli Sanchez, Zinedine Zermout, Irati Lizarraga Ferro	2018/05/28 — chicago, USA *24th intenrnational enamelling congress*

Brittle out-of-plane cracking in pipeline steels	S. Cooreman, P. Thibaux, F. Tankoua, J. Crépin, A.-F. Gourgues-Lorenzon	2018/04/10 — Gent, Belgium *Technology for Future and Aging Pipelines 2018 10-12 April 2018 Gent*
Prediction of mechanical properties on large diameter welded pipes through advanced constitutive modelling	S. Cooreman, P. Thibaux, M. Liebeherr	2018/07/30 — Tokio, Japan *NUMISHEET 2018*
Advanced constitutive model for the accurate evaluation of the structural performance of welded pipes in offshore applications	S. Cooreman, D. Van Hoecke, M. Liebeherr, P. Thibaux, H. Luccioni	2018/09/24 — Calgary, Canada *12th International Pipeline Conference (IPC 2018)*
Development of a welding sequence optimized for the fatigue resistance of tubular joints with a novel representative welded sample	P. Thibaux, E. Van Pottelberg	2018/06/17 — Madrid, Spain *OMAE : 37th International Conference on Ocean, Offshore & Arctic Engineering*
Towards a better understanding of hydrogen embrittlement of steel in sour service conditions	Krista Van den Bergh, Zinedine Zermout, Dennis Van Hoecke, Lode Duprez, Joost De Strycker	2018/09/09 — Krakow, Poland *Eurocorr 2018*
Towards a better understanding of hydrogen embrittlement testing of steel in sour service conditions by coupling h diffusion to fracture mechanics	Krista Van den Bergh, Zinedine Zermout, Patrick Goes	2018/05/29 — Ghent, Belgium *SteelyHydrogen 2018 29-31 May 2018 Ghent*
Influence of applied potential, water content and forced convection on the electrodeposition of ni films on steel from choline chloride based deep eutectic solvents	Monika Lukaczynska, Krista Van den Bergh, Joost De Strycker, Herman Terryn, Jon Ustarroz	2018/05/13 — Seattle, USA *233rd ECS MEETING*
Recommendations for submerged arc spiral welding with optimized ctod properties	M. Liebeherr, O.E. Gungor, N. Sanchez, He. Luccioni, N. Ilic	2018/09/24 — Calgary, Canada *12th International Pipeline Conference (IPC 2018)*
The influence of chemistry inhomogeneity on microstructure development and residual stress	Junyan Ni, John Vande Voorde, Joachim Antonissen, Magd Abdel Wahab	2018/9/23 — Seggau Austria *12th International Seminar Numerical Analysis of Weldability, 23-26 Sept 2018*

Fretting fatigue fracture in lug joints made of high strength steel	Reza H. Talemi, Jie Zhang, Stijn Hertelé, Wim De Waele	2018/05/27 — Poitiers, France *12th International Fatigue Congress*
Prediction of the leakage threshold for hertzian contact seals: a cellular automata model	John Vande Voorde and Jeroen Van Wittenberghe	2018/07/15 — Prague, Czech Republic *PVP2018*
Prediction of the leakage threshold for hertzian contact seals: an experimental approach	Jeroen Van Wittenberghe and John Vande Voorde	2018/07/15 — Prague, Czech Republic *PVP2018*
Optimization of the structural performance for corrugated blast panels on offshore platforms	John Vande Voorde, Filip Van den Abeele, Steven Cooreman	2018/06/17 — Madrid, Spain *OMAE : 37th International Conference on Ocean, Offshore & Arctic Engineering*
Three-dimensional simulation of dynamic ductile crack propagation in steel pipeline using coupled fluid-structure modelling	Reza Hojjati Talemi, Haroun Mahgerefteh, Sergey Martynov, Solomon Brown	2018/09/19 — Verona, Italy *The 6th International Conference on Crack Paths (CP 2018)*
Cleavage fracture assessment of cold charged steel slabs using experimental and numerical approaches	Reza H. Talemi, Antônio de Souza Braga Neto, Annick Willems, Negar Gilani, Quang Tien Ngo	2018/08/26 — Belgrade, Serbia *22nd European Conference on Fracture — ECF22*
Innovative resonant bending test setup for fatigue testing of pipelines with directional loading control	Jeroen Van Wittenberghe, Philippe Thibaux	2018/04/10 — Gent, Belgium *Technology for Future and Aging Pipelines 2018 10-12 April 2018 Gent*
Improved loss modelling of electrical traction motors by including magnetic skin effect	Jan Rens, Sigrid Jacobs, Emmanual Attrazic	2018/11/07 — Nottingham, United Kingdom *ESARS-ITEC: Electrical systems for aircraft, railway, ship propulsion and road vehicles and international transportation electrification conference*
Improved core loss modelling of electrical traction motors through simulation of skin effect in laminations	Jan Rens, Sigrid Jacobs, Lode Vandenbossche, Emmanuel Attrazic	2018/09/30 — Kobe, Japan *Electrical Vehicle Symposium EVS31*

Dark Field X-ray Microscopy Study of Heat Treatment of Fe-Si and Fe-Si-Sn Alloys	Can Yildirim, Nikolas Mavrikakis, Melanie Gauvin, Phil Cook, Mustafacan Kutsal, Ashley Bucsek, Henning Poulsen, Wahib Saikaly, Roger Hubert, Carsten Detlefs	2018/11/06 — Helsingør (Elsinore), Denmark *4th international congress on 3d materials science (3DMS)*
Iron loss measurements of non-oriented electrical steels at elevated magnetic polarization: comparison of calorimetric and field-metric methods	Lode Vandenbossche, Sigrid Jacobs, Vinicius Araujo Rabello Landeira, Emmanuel Attrazic	2018/09/23 — Portland, USA *ECCE (IEEE Energy Conversion Congress & Exposition)*
Finite element model in abrasion analysis for single-asperity scratch test	P. Wechsuwanmanee, J. Lian, J. Sukumaran, Á. Kalácska, H. Ben Hamouda, P. De Baets, S. Münstermann	2018/06/09 — Gent, Belgium *Fracture Fatigue and Wear 2018 (FFW)*
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Abrasive slurry testing of different type of steels used in agricultural machinery	A. Kalácska, J. Sukumaran, H. Ben Hamouda, P. De Baets	2019/04/14 — Miami, USA *Wear of Materials 2019*
Combined in-field and laboratory monitoring techniques to understand the wear failure origin in martensitic steels	H. Ben Hamouda, S. Vanrostenberghe	2019/04/14 — Miami, USA *Wear of Materials 2019*
Electrochemical deposition of Nickel films from choline chloride based Deep Eutectic Solvents	Monika Lukaczynska, Krista Van den Bergh, Joost De Strycker, Herman Terryn, Jon Ustarroz	2018/02/21 — Blankenberge, Belgium *ChemCYS2018*
Hydrogen uptake by high-strength steels during electrodeposition process	Krista Van den Bergh, Kurt De Sloover, Joachim Noens, Dennis Van Hoecke, Joost De Strycker	2018/05/29 — Ghent, Belgium *SteelyHydrogen 2018 29-31 May 2018 Ghent*
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The 'complex' route to sustainable Cr(VI)-free steel plating	Tim Verdonck, Philippe Verpoort, Rik Van Deun, Kristof Van Hecke	2018/06/17 — Gent, Belgium *ISIEM2018 (International Symposium on Inorganic and Environmental Materials 2018)*
Saline resistant weathering steel for offshore and naval: corrosion testing and characterisation?	Krista Van den Bergh, Lucia Fernandez Macia, Joost De Strycker, Martin Liebeherr	2019/04/01 — Antwerp, Belgium *2nd Corrosion and Fouling Symposium*
Heavy gauge linepipe steel developent and applications research at ArcelorMittal	Christoph Gerritsen, Nuria Sanchez Mourino, Özlem Esma Ayas Güngör and Steven Cooreman	2018/07/18 — Bali, Indonesia *IIW C-XI meeting, 18 July 2018 Bali Indonesia*
The 'complex' route to sustainable Cr(III) steel plating	Tim Verdonck, Philippe Verpoort, Rik Van Deun, Kristof Van Hecke	2018/02/21 — Blankenberge, Belgium *ChemCYS2018 (Chemistry Conference for Young Scientists)*
Quantitative mapping of nanoscale mechanical properties of Zn-Al-(Mg) coatings on steel by nanoindentation	F. Nozahic, D. Rosseel, D. Mercier, M. Gauvin, K. Van den Bergh	2018/09/11 — Liège, Belgium *Indentation 2018*
Combinatorial metallurgical screening: what is in it for high temperature applications?	Nele Van Steenberge, Serge Claessens, Lode Duprez	2018/07/08 — Paris, France — *Thermec'2018 International Conference on Processing & Manufacturing of Advanced Materials*

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