ANNUAL REPORT
2020

FOR A BETTER FUTURE

D/2020/0124/1

CONTENTS

FOREWORD

The CRM not-for-profit organisation, part of CRM Group, provides technological R&D innovation in the fields of metal and steel production processes, product development and a wide range of metal applications, using a truly and genuine holistic product-process-application approach and focussing on industrial implementation of its developments.

CRM is supported by more than 45 industrial members, ranging from international steel groups (ArcelorMittal and Tata Steel), raw material suppliers, non-ferrous metal producers, OEM's, metal transforming companies, to members from the aeronautical, defence, energy and recycling sectors. In 2020 CRM also delivered various services to more than 285 non-member customers.

At CRM Group, health and safety remained more than ever the first priority in 2020. Sanitary measures to face the COVID pandemic were continuously updated, adapted and strictly applied. Regarding safety, VCA-training sessions were widely rolled-out, allowing to envisage an ISO45001 certification in the near future. This certification will testify the strong commitment of CRM regarding Health and Safety performance.

To fulfil its mission, CRM Group is organised around 6 research units that are backed up by a world class material characterisation laboratory:

1 | Metal production and recycling (MPR): covering raw material processing, melting & refining, by-products treatment & valorisation

2 | Energy & Low Impact Manufacturing Industry (ELIMIN): focussing on the development of energy efficient and low CO2 emitting production technologies and CCU applications

3 | Metal processing and metallurgy: including casting & solidification, rolling & thermal treatment, product metallurgy and process control & measurement

4 | Advanced & smart surface solutions (A3S): ranging from functional coatings and smart surfaces including printed electronics on steel to surfaces for renewable energy applications

5 | Innovative designs and assembly solutions (IDEAS) in the fields of Civil engineering, Construction, Assembly & Testing and Hybrid manufacturing

6 | Industrial solutions (IS): embracing in-house Engineering, finishing & metallic coating processes, organic coating and sandwich panels products & continuous annealing and/or coating pilot line

The Covid pandemic impacted the metals industry significantly in 2020. This led to some R&D budget reductions, also at the CRM Group level. Based on a very strict application of the sanitary measures, a rigorous monitoring and control over expenses and an agile allocation of resources, CRM managed to serve its customers without interruption. R&D project deliverables were successfully achieved within the revised budgets. Furthermore, the flexibility measures that were put in place allowed to fully maintain CRM's research capabilities.

The pandemic also acted as a true catalyst for the implementation of CRM's strategic plan. This plan aims to build R&D capabilities and generate associated project portfolios to address key societal challenges in the following areas:

1 | circular economy

2 | energy shift

3 | hybrid manufacturing

4 | digitalisation

5 | construction

The deliberate specific focus on a wide range of project calls in these areas has generated a record high budget of new funded R&D projects, with the support of the European as well as regional Belgian authorities. These projects will start from 2021 onwards and shall be the cornerstone of CRM's relaunch plan. They will position CRM as a key R&D player in the forementioned fields of activity, for the benefit of CRM's members.

A first tangible result is that prestigious organisations have joined as new associated members since.

At European or regional level, CRM has continued to invest in partnerships with other research organisations.

The present annual report highlights the main achievements of the year 2020.

Paul PERDANG
President CRM

Joeri NEUTJENS
General Manager CRM

COMPANY MEMBERS

ON APRIL 21, 2021*

Active Members of CRM

ARCELORMITTAL S.A. ..... G.D. Luxembourg
TATA STEEL EUROPE LIMITED ..... United Kingdom

An updated list of the subsidiaries considered as Active Members is available on the internet site of CRM.

THE MAIN AFFILIATED COMPANIES ARE :

ARCELORMITTAL Group :

ARCELORMITTAL BELGIUM N.V. ..... Belgium
ARCELORMITTAL BELVAL & DIFFERDANGE S.A. ..... G.D. Luxembourg
ARCELORMITTAL FRANCE S.A. ..... France
ARCELORMITTAL LUXEMBOURG S.A. ..... G.D. Luxembourg
ARCELORMITTAL SCHIFFLANGE S.A. ..... G.D. Luxembourg
INDUSTEEL BELGIUM S.A. ..... Belgium

TATA STEEL Group :

SEGAL S.A. ..... Belgium
TATA STEEL IJMUIDEN BV ..... The Netherlands
TATA STEEL NEDERLAND TECHNOLOGY BV ..... The Netherlands
TATA STEEL UK LIMITED ..... United Kingdom

Associated Members of CRM

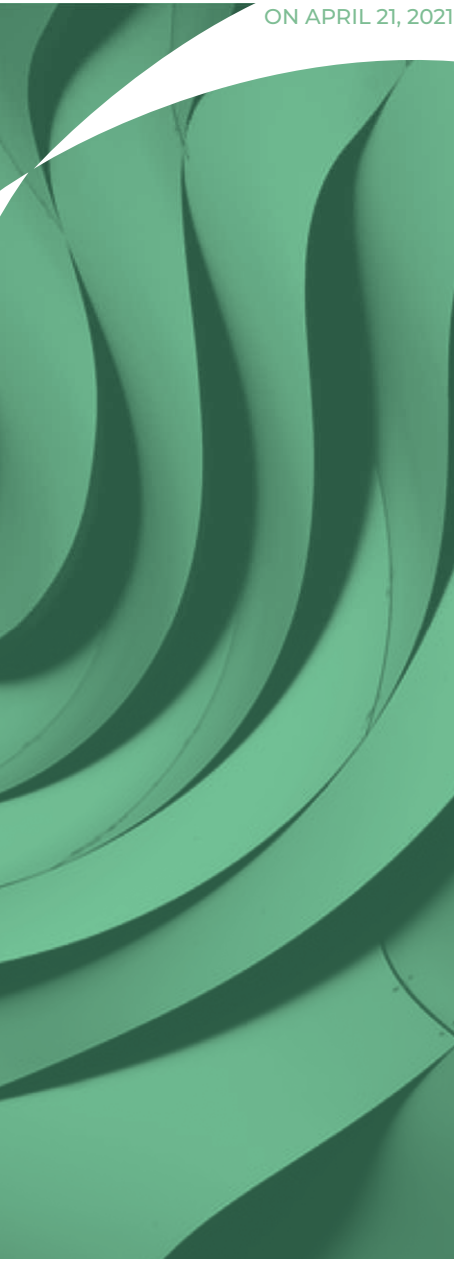
AIR LIQUIDE INDUSTRIES BELGIUM S.A. ..... Belgium
AMEPA GmbH ..... Germany
AMETEK LAND ..... United Kingdom
APERAM Stainless France S.A.S. ..... France
ARCEO Engineering ..... Belgium
ATELIERS DE LA MEUSE* ..... Belgium
AURUBIS BELGIUM N.V. ..... Belgium
BASF SE* ..... Germany
BEKAERT N.V. / S.A. ..... Belgium
BIOCARBON INDUSTRIES Sàrl ..... G.D. Luxembourg
CARMEUSE S.A. ..... Belgium
CBR S.A. ..... Belgium

* To be approved by the General Meeting of April 21, 2021

COMET TRAITEMENTS S.A.	Belgium
DE LEUZE S.A.	Belgium
DREVER INTERNATIONAL S.A.	Belgium
DUFERCO S.A.	Switzerland
EMG Automation GmbH	Germany
E.S.W. A.G.	Austria
FABRICOM INDUSTRIE SUD S.A. (ENGIE SOLUTIONS)	Belgium
FONDERIES MARICHAL, KETIN & Cie S.A.	Belgium
HERAEUS ELECTRO-NITE INTERNATIONAL N.V.	Belgium
HERSTAL S.A.	Belgium
HYDROMETAL*	Belgium
INDUCTOTHERM S.A.	Belgium
INSTITUT BELGE DE LA SOUDURE asbl	Belgium
INTERNATIONAL MANGANESE INSTITUTE	France
JOHN COCKERILL S.A.	Belgium
LHOIST Recherche & Développement S.A.	Belgium
LIBERTY LIEGE-DUDELANGE S.A.	Belgium
MAGOTTEAUX INTERNATIONAL S.A.	Belgium
MATÉRIAUX CÉRAMIQUES S.A. (FIVEN)*	Belgium
NLMK CLABECQ S.A. – Plates	Belgium
NLMK LA LOUVIÈRE S.A. – Strips	Belgium
ORBIX SOLUTIONS S.P.R.L	Belgium
PAUL WURTH S.A.	G.D. Luxembourg
PHARMA TECHNOLOGY S.A.	Belgium
PRAYON S.A.	Belgium
PRIMETALS TECHNOLOGIES AUSTRIA GmbH	Austria
RECYDEL S.A.	Belgium
RESA S.A.	Belgium
R-TECH S.A.	Belgium
SABCA*	Belgium
SAFRAN AERO BOOSTERS S.A.	Belgium
SARCLAD Ltd	United Kingdom
SONACA*	Belgium
THY-MARCINELLE S.A.	Belgium
TI GROUP AUTOMOTIVE SYSTEMS S.A.	Belgium
TMT sarl	G.D. Luxembourg
WESTINGHOUSE ELECTRIC BELGIUM S.A.	Belgium

ORGANISATION

ON APRIL 21, 2021



Board of Directors of CRM

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Jean-Luc THIRION, General Manager Global Research and Development, ARCELORMITTAL

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Philippe COIGNE, Directeur Général, Groupement de la Sidérurgie (GSV)
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Leo KESTENS, Professor, Universiteit Gent
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Nicoleta POPA, Head of Construction applications, Infrastructures and Long Products, ARCELORMITTAL Global R&D
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Manfred VAN VLIERBERGHE, CEO ARCELORMITTAL Belgium
Michael VENTURI, Secrétaire Général Adjoint, MWB-FGTB
Simone VOOIJS, Director Technical Tata Steel Downstream Operations, TATA STEEL
Laurent WENKIN, Chef de Service Normalisation et Compétitivité, SPF Economie, PME, Classes moyennes et Energie

OBSERVERS

Jean-François HEUSE, Inspecteur Général ff, Département de la Recherche et du développement technologique, Service Public de Wallonie
Yvon MASYN, Adviseur, Vlaams Agentschap Innoveren en Ondernemen
Joeri NEUTJENS, Directeur Général, CRM

AUDITOR

Dominique JACQUET-HERMANS

* To be approved by the General Meeting of April 21, 2021

Iron and Steel Committee of CRM

Members

ARCELORMITTAL

Jean-Paul ALLEMAND
Michel BABBIT
Marc DI FANT
Eric HESS
Pedro PRENDES
Mayte RODRIGUEZ
Sven VANDEPUTTE

TATA STEEL

Loes JANSEN
Carel KLEEMANS
Wim MOONEN
Hans VAN DER WEIJDE

CRM

Joeri NEUTJENS
Griet LANNOO
Eric SILBERBERG

QUALITY MANAGEMENT

The CRM is accredited **ISO 17025** for calibration & testing and certified **ISO 9001:2015** for all its activities.

BQA

CERTIFICAT DU SYSTEME DE MANAGEMENT DE QUALITE

ISO 9001 : 2015

Par la présente, BQA sa déclare que le système de management de la qualité de la société ***CRM Group***

CRM GROUP

dont les sites des sociétés sont établis
Avenue du Bois Saint-Jean, 21 B27 – Quartier Polytech 4 - 4000 Liège et Rue du Bois Saint Jean, 8 – 4102 Ougrée et Rue du Chéra, 200 – 4000 Liège
et Technologiepark 903c – 9052 Zwijnaarde – Belgique
pour ***CRM asbl*** *– Centre for Research in Metallurgy asbl, et par*
Allée de l'Innovation, 1 B 57 – Quartier Polytech 3 – 4000 Liège et Rue Sompré, 1 – 4400 Flemalle – Belgique
pour ***AC&CS scrl*** *– Advanced Coatings and Construction Solutions scrl,*
a été examiné le 28-05-2018 et a été jugé conforme à la norme ISO 9001, édition 2015 pour le domaine d'application suivant:

Recherche appliquée et activités associées telles que les essais, l'étalonnage et l'expertise.

Ce certificat est délivré par BQA sa conformément à son manuel de qualité relatif à la certification de système et après conclusion du contrat de certification N° CER_CDP_QMS_16-04-2021_336_F aux termes desquels la firme accepte un contrôle régulier de son système de management.

Certificat N° BQA_QMS_C_2006336
Date d'émission 2021-04-12
Valable jusqu'au 2024-05-27

BELAC 019-QMS

D. SIMOENS
Directeur

Toute personne ayant connaissance de l'emploi abusif de ce certificat doit en avertir BQA sa. Ce certificat ne peut être divulgué que dans son intégralité.
BQA sa - Technologiepark Zwijnaarde 70 - 9052 Gent-Zwijnaarde

Organisme belge d'Accréditation
Belgische Accreditatieinstelling
Belgische Akkreditierungsstelle
Belgian Accreditation Body

Signatory to EA, ILAC and IAF Multilateral Agreements

Accreditation Certificate No. 267-CAL

In compliance with the provisions of the Royal Decree of 31 January 2006 setting up BELAC, the Accreditation Board hereby declares, that the calibration laboratory

CRM
CENTRE DE RECHERCHES METALLURGIQUES ASBL
Domaine Universitaire du Sart Tilman (p59) Avenue du Bois Saint-Jean, 21
4000 LIEGE - Belgium

has the competence to perform the calibrations as described in the annex which is an integral part of the present certificate, in accordance with the requirements of the standard EN ISO/IEC 17025:2005. The present accreditation is the subject of regular surveillance in order to confirm the compliance with the accreditation conditions.

The Chair of the Accreditation Board BELAC,

Issue date : **2017-12-07**
Validity date : **2022-10-27**

Nicole MEURÉE-VANLAETHEM

Original version of this certificate is in French.

.be

Organisme belge d'Accréditation
Belgische Accreditatieinstelling
Belgische Akkreditierungsstelle
Belgian Accreditation Body

Signatory to EA, ILAC and IAF Multilateral Agreements

Accreditation Certificate No. 267-TEST

In compliance with the provisions of the Royal Decree of 31 January 2006 setting up BELAC, the Accreditation Board hereby declares, that the test laboratory

CRM
CENTRE DE RECHERCHES METALLURGIQUES ASBL
Domaine Universitaire du Sart Tilman (p59) Avenue du Bois Saint-Jean, 21
4000 LIEGE - Belgium

has the competence to perform the tests as described in the annex which is an integral part of the present certificate, in accordance with the requirements of the standard EN ISO/IEC 17025:2005. The present accreditation is the subject of regular surveillance in order to confirm the compliance with the accreditation conditions.

The Chair of the Accreditation Board BELAC,

Issue date : **2017-12-07**
Validity date : **2022-10-27**

Nicole MEURÉE-VANLAETHEM

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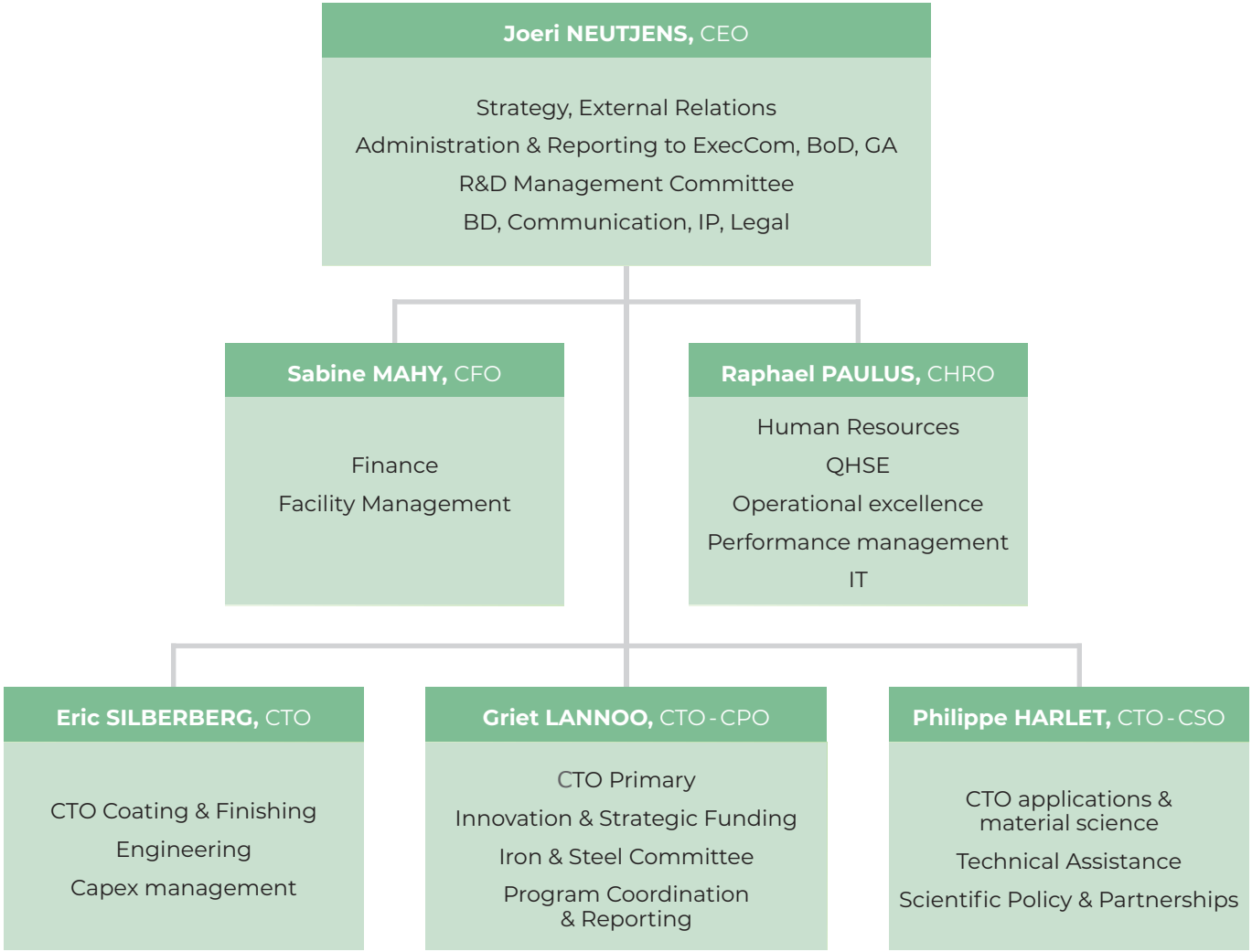
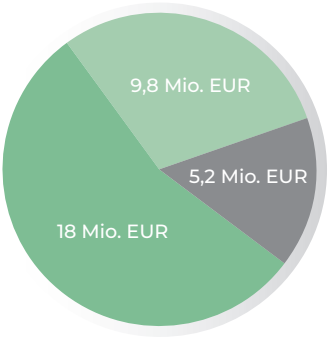
LEADERSHIP TEAM



CEO: Chief Executive Officer
CPO: Chef Program Officer
CFO: Chief Financial Officer
CSO: Chief Scientific Officer
CHRO: Chief Human Resource Officer
CTO: Chief Technical Officer

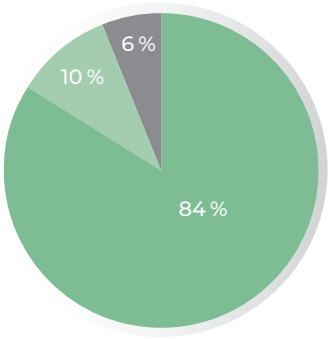
KEY FIGURES

Income by program



- Steel Collective
- Steel effective collaboration
- Other

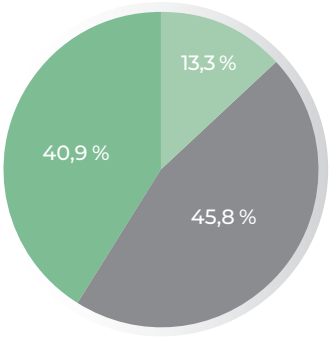
Income by financing



- Industrial collaboration
- National & Regional Grants
- European Grants

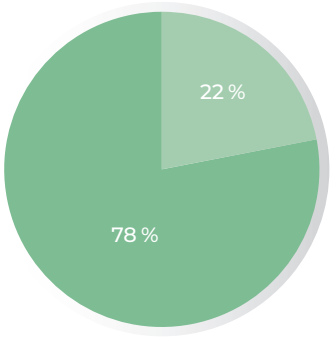
Total Income (CRM asbl): 33 Mio. EUR

CRM Group: 264 people



- Researchers
- Technicians
- Administrative staff

Gender balance



- Female
- Male

REPORT ON R&D ACTIVITIES

CRM GROUP EMPOWERS THE **ROLE OF METALS** IN THE SOCIETAL, ENVIRONMENTAL AND ECONOMIC CHALLENGES STRIVING TOWARDS A BETTER FUTURE.

In 2020 CRM Group continued to further expand its expertise and lab &pilot installations in order to support the metals related industry in its relaunch after the Covid crisis and to accelerate its transition towards a cleaner, smarter, more resource efficient and competitive industry.

Convinced by the key role that metals plays in this transformation towards a sustainable economy, as independent and collective research centre, we focus on applied and demand-driven research in many different topics associated to metals: from their energy & resource efficient production integrating advanced and digital technologies to the development of high quality smart products, their recycling as well as the use of metal-based solutions in many emerging domains related to energy production, storage, transport, mobility,...

It is in close partnership with our industrial partners that we develop processes, products and solutions for their current and future challenges. This continuous interaction with the industrial actors active in a wide range of sectors (metallurgical, industry, energy, aeronautics, defence, ...) together with our more than 70 years of experience in metals related research ensures that our solutions will create value for our stakeholders.

Our unique versatile large-scale test facilities and pilot lines are together with our engineering capabilities and industrial knowledge the key success factors to turn innovation into industrial practice.

More than 260 highly skilled technical experts collaborate together in multi-disciplinary teams in order to develop solutions in 6 strategic axes :

- Process – product – application development
- Circular economy
- Energy Shift
- Advanced Manufacturing
- Industry 4.0 and digitalisation
- Construction

This 2020 activity report illustrates how our expertise, updated lab & pilot facilities and innovation spirit resulted in some major achievements.

CRM gratefully thanks its industrial and research partners as well as the funding authorities for their collaboration and support.

CIRCULAR ECONOMY

TOWARDS A **SUSTAINABLE** METALS INDUSTRY

The European environmental and climate goals as set out in the European Green Deal resulted in an ambitious strategy to make the transition towards a circular economy. CRM Group is participating with key activities to this action plan for increasing resource efficiency, prolonging product life cycles and reducing waste generation.

The 2020 CRM Group activities on circular economy have been structured around three key topics: enhanced recycling through waste pre-processing, increased ferrous scrap recycling and recycling of manufacturing residues and end-of-life products.

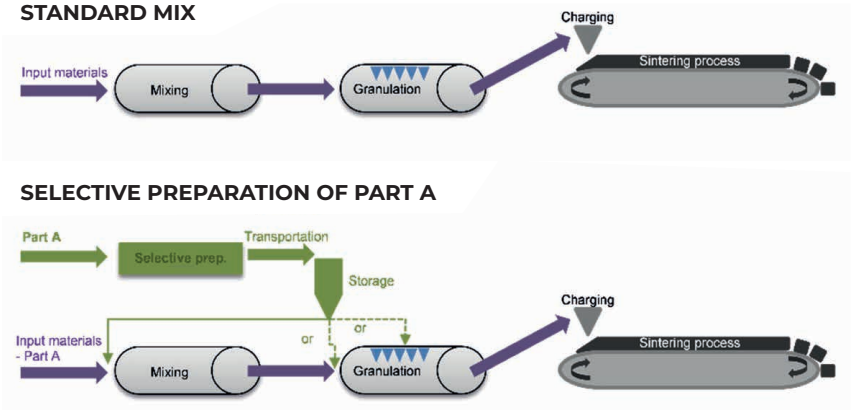
ENHANCED RECYCLING THROUGH WASTE PROCESSING

In steel industry, the preparation of ferrous burden for the blast furnace by high temperature pelletising and sintering is a costly, energy intensive process associated with high CO_2 emission. We are therefore developing in partnership with ArcelorMittal, Tata Steel and BASF with the support of the Research Fund for Coal and Steel (RFCS), a

Extruded agglomerates from steelmaking by-products – Stiff vacuum extruder.

novel method for the **ferrous burden preparation based on a cold agglomeration** by stiff extrusion technology combined with a custom made binder developed by BASF. The use of this cold bonded agglomerates, developed in the COACH project, will not only allow to drastically reduce the cost and the CO_2 emission but also to maximise the recycling of steelmaking by-products as shown by the first experimental trials.

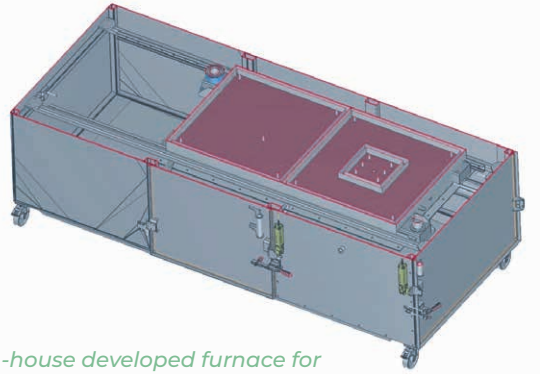
Another example of improved processing of by-products is in the sinter plants. The RFCS project 'SinByose' focuses on enlarging the selective preparation approach of the sinter mix to deal with lower quality ores and to **increase the recycling of by-product at this sinter plants**. Indeed, a selective preparation allows acting at the origin of those problems with no or limited impact on the rest of the sinter mix. A methodology is being developed to provide guidelines for optimal selective preparation to tackle the possible issues existing in European sinter plants as well as recommendations on the technology to be used.



Selective sinter mix preparation concept.

The **recycling of iron, silicon, carbon and manganese containing waste streams in foundries** is studied in collaboration with REVATECH, a Suez subsidiary specialised in the recycling of toxic and non-toxic industrial waste, within the CarSiFer project co-funded by EIT Raw Material. Many wastes have been identified for recycling, providing an appropriate agglomeration since they are often powdered and therefore not usable in current processes. A major study was carried out this year to compare the three main compaction technologies: the extruder, the roll press and the vibro-press. In addition, different recipes were tested to study the impact of the binders to optimise the process. On the basis of the study, REVATECH decided to invest in a vibro-press with a production of 15 kt/year and melting trials of the agglomerated material have been carried out by foundries. We continue to optimise this process in order to reduce the dose of binders and make the briquettes as high-performance as possible.

To support our developments on waste processing and recycling, we are continuously updating our lab and pilot installations. One of the latest developments concerns a new unique furnace for the **production of Direct Reduced Iron out of iron and zinc bearing by-products** The in-house designed electrically heated furnace is fully instrumented allowing the measurement of the in-depth heating profile as well as the full analysis of the generated off-gas.

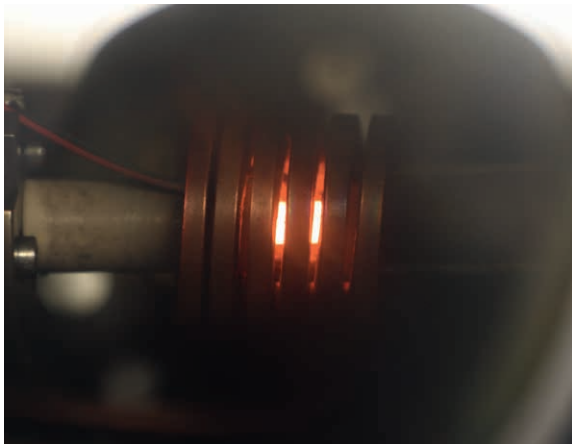


In-house developed furnace for the production of Direct Reduced Iron out of iron and zinc bearing by-products.

INCREASED FERROUS SCRAP RECYCLING

Although **ferrous metals** are already one of the best recycled and recyclable materials, more attention should be paid to **selective recycling and re-use**. To increase the awareness and identify opportunities for **an improved 'value-in-use'**, CRM Group in collaboration with Sirris and Clusta and with the support of the VLAIO & SIM, mapped and analysed on site the scraps in workshops and foundries in the CLEANSCRAP project. Subsequently, we have performed trials (agglomeration, melting, separation...) on targeted scrap for the formulation of guidelines on how to improve the internal reuse of scrap in the meltshop and have demonstrated the potential gain of storage, of direct reusability as raw material like ferro-alloy, and of a higher market value of scrap for metal transforming companies if sold with few logistic adaptation or low equipment investment.

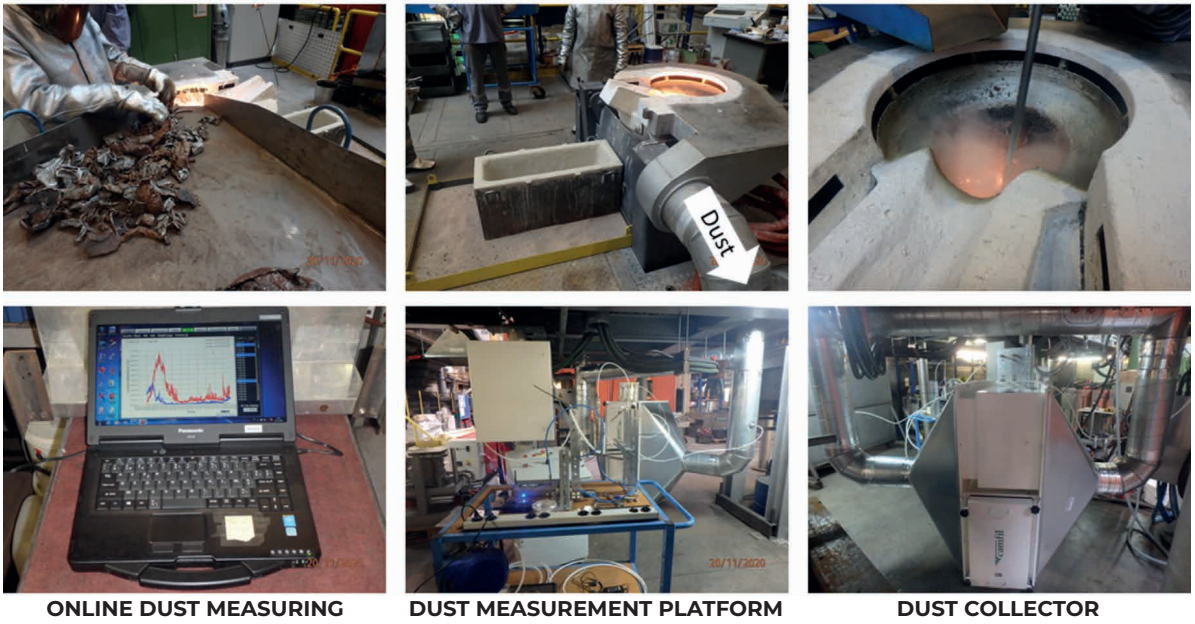
In steel industry, the use of recycled scrap has increased over the past few decades and the recycling of ever higher volumes are forecasted in the future. In addition, the complexity of EOL products as well as the presence of high strength steels (containing specific alloying elements such as Si, Mn, Cr, Ni, Mo, V and B) will increase year over year in the use of steel grades and hence also in the composition of the mixture of recycled scrap. Therefore we are studying the **impact of those alloying and tramp elements on the hot processing** (eg hot shortness) **and on the properties of advanced high strength steels.**



Thermomechanical study to map the impact of tramp elements.

The increasing variety of primary and secondary metal grades used in steel shops requires also new **predictive tools** and capabilities. Thanks to new skills and modelling capabilities gained in the Reverse Metallurgy project supported by the Walloon region, a predictive tool calculating the yield of the decarburisation steps at the AOD (Argon-Oxygen-Decarburisation) process has been developed. The tool, combining FactSage with home-made add-ons, allows the user to improve the sequencing of the decarburisation steps for new metal grades or other modifications of the process resulting in money, time and energy savings. This achievement illustrates how new skills developed in the frame of the Reverse Metallurgy project can be leveraged and transposed in other field of interest for the industrial members of CRM Group.

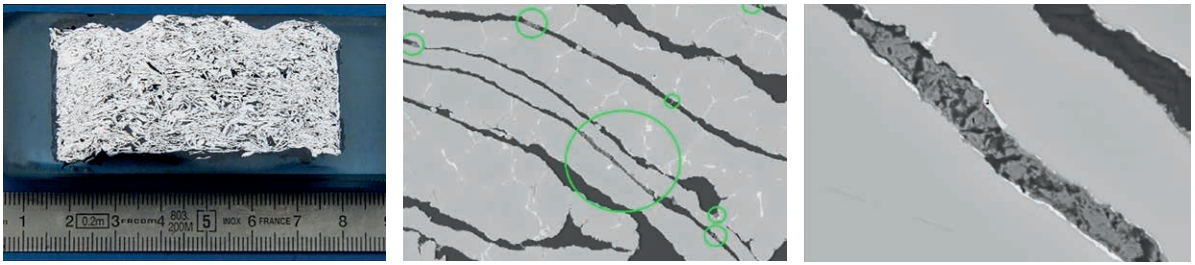
Within the EIT Raw Materials project RECLAMET, CRM Group is studying in collaboration with Tata Steel the **recycling of Zn bearing by-products and galvanised scrap** in the Hisarna process. The objective is to produce a rich Zn dust directly valuable as raw material for Zn-producers. After having successfully developed recipes and processes to produce suitable agglomerates in the two first years of the project, the focus of 2020 activities was on the galvanised scrap injection. Around 1.1 ton of shredded consumer scrap was melted in our induction furnace. In order to capture and subsequently analyse the dusts generated during the melting trials, a dust collector was designed and connected to the induction furnace. The collector has a very high capture efficiency of particles down to nano level. Thanks to this upgrade of the furnace, the different volatile metal elements within the scrap (e.g. Zn and Pb) could be quantified.



Capture & measurement of produced Zn-rich dust when simulating galvanised scrap injection in Hisarna.

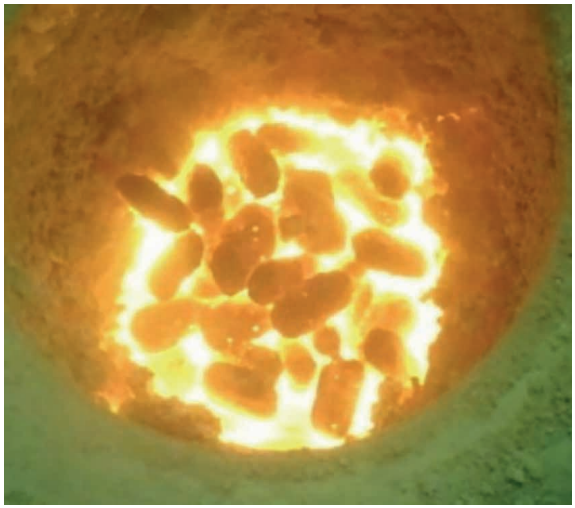
RECYCLING OF MANUFACTURING RESIDUES AND END OF LIFE PRODUCTS

In view of the final optimisation of the **secondary aluminium recycling process** before a potential industrialisation in the Walloon Region, additional aluminium melting trials on various recipes containing fine packaging aluminium wastes have been realised. The target was to further increase the mastering of the pre-processing steps and its impact on the process outcomes (yield, energy consumption…). It has been highlighted that the nature of the alloy plays a particularly important role in controlling the melting of aluminium because it can amplify surface oxidation and block the melting mechanisms. Thanks to an improved pre-processing and optimised control of the remelting furnace feed, we succeed to recover a large part of the aluminium from these fine and complex packaging wastes. Furthermore the process takes profit of the energy released by the organic matter present in the waste and thereby reduces drastically the energy consumption and CO_2 emissions of the process.



Aluminium waste : detailed analysis of the oxidation to master the melting process.

Besides the recovery of aluminium from waste, we have also developed expertise in the **processing of aluminium wastes linked to the additive manufacturing process**. In the CheapShape MANUNET project, it was already shown how domestic wastes could be turned into ingots for the production of powders for additive manufacturing to produce parts that reached equal performance as those produced with commercial powders. In order to further optimise the efficient use of the alloys, the **recycling of the residual powders from the additive manufacturing process**, which currently have no recovery route has also been studied. These aluminium powders were used as a reduction element in self-reducing briquettes containing chromium and nickel. When smelted in a steel bath, the aluminium reduced the other metals and allowed these alloying elements to be recovered for the production of stainless steel.



Melting in steel bath of self-reducing briquettes produced from waste Al-powder from additive manufacturing.

Thanks to the experience gained in aluminium waste recycling, CRM Group had the opportunity to propose innovative activities to increase the **circularity of the aeronautic manufacturing industry** in the ambitious WINGS project. Within this framework, we are studying the valorisation of residual powders from plasma spraying processes by two valorisation routes: the production of self-reducing briquettes and the reuse of powders in less critical technologies or sectors.

In the context of end-of-life (EOF) product Recycling, the Valomag project coordinated by Suez in the EIT Raw Material frame, aims to develop an innovative industrial **recycling process for Rare Earth Elements magnets from end-of-life products** such as hard disk drives (HDD), wind turbine, loudspeaker, etc. During the process, the magnets have to be separated from the other components of the hard disk drive which demands a demagnetisation of the magnet before the dismantling. This step was studied by testing different heat treatments on the HDD. The main constraint is linked to the organic content of the HDD that must be preserved without degradation to optimise the yield of the separation, the value and quality of each fraction and reduce the global CO_2 emissions of the process. A particular innovative use of a heating technology combined with the physical properties of the EOL products led to a demagnetisation yield reaching until 100% for a very low organic degradation and a very short reaction time. The upscaling has started and already 1.1 t of demagnetised HDD were delivered to the partners.

Recycling of hard disk drives : demagnetised magnets.

A new **zinc recycling process** will be developed with the support of the “Pôle Mecatech”. The consortium involves PEPS Engineering, Zinacor, ULiège and Comet Traitements covering all the actors from scrap collection to the zinc user as the perfect example of a circular economy development. We will work on the design of a new vacuum purification process to produce a high purity metallic zinc (99.999%) from scrap. The pilots will be settled and operated by CRM Group and will be able to purify 200kg of zinc per batch.

The preparation of the implementation of the plasma furnace is continuing and commissioning of the furnace is scheduled in the first trimester 2022. Its operation on the industrial site of Hydrometal together with the integration of all the required technologies to ensure safety and environmental compliance will allow to operate the furnace with hazardous materials. First developments of this new cutting edge recycling facility will be on the fuming of critical metals in collaboration with Hydrometal in the frame of the Reverse Metallurgy project. In parallel, we are preparing a roadmap to address the priority issues faced by our industrial members driven by CO_2 reduction objectives in a context of raw material scarcity.

Plasma Furnace

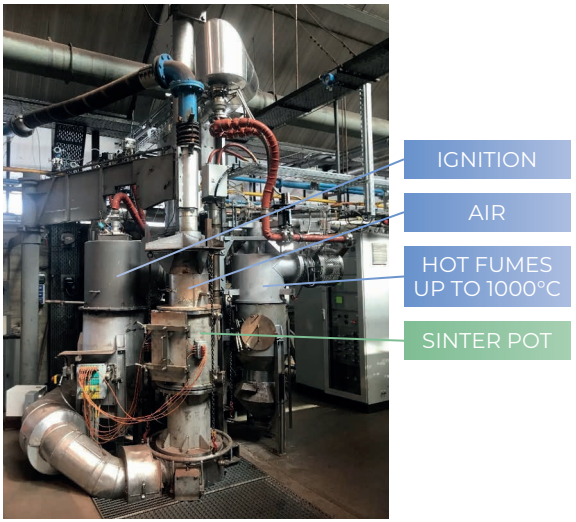
ENERGY SHIFT

THE PATHWAY TO A **CO_2-NEUTRAL INDUSTRY** AND **RENEWABLE ENERGY**

Tackling climate and environmental-related challenges are, as also stated in the European Green Deal, urgent challenges to stop the atmosphere warming up and the climate changes. The transformation to a resource efficient, modern and competitive economy with a drastic reduction of greenhouse gas emissions is eminent. The research for new green energies and their storage have also become a major concern for the safeguard of our planet.

As energy and carbon-intensive industry, the steel industry needs breakthrough technologies leading to zero-carbon steelmaking processes by 2050.

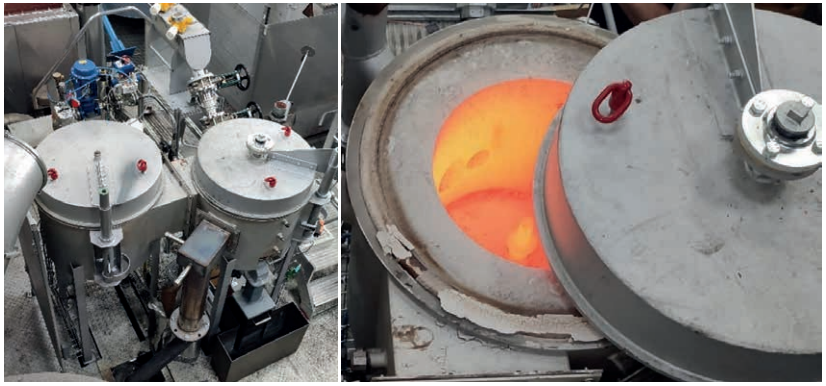
In sinter plants in particular **the abatement of the CO_2 emission** up to 50% is a key point to cope with the climate challenges. To reach this CO_2 reduction different paths can be chosen: the use of alternative solid fuels achieved by pyrolysis of waste or switching to alternative heat inputs, through gases. Options include Waste Gas Recirculation and innovative solutions integrating the production of hot fumes in an external combustion chamber. In order to meet the needs of this ambitious program, our unique combination of sintering tools are continuously upgraded. It consists in a mathematical model of the sintering process, a pilot station and a set of measuring devices (regrouped in a container) developed for full assessment of industrial sinter plants. The sintering pilot station has been adapted to allow pre-heating of the input gases (gas preparation line mixing pure gases to reach the desired composition, moisture content and temperature) up to 1000°C. This modification allows also the simulation of the pellets induration process.



Sinter pilot station with external combustion chamber for studying very low sintering concepts.

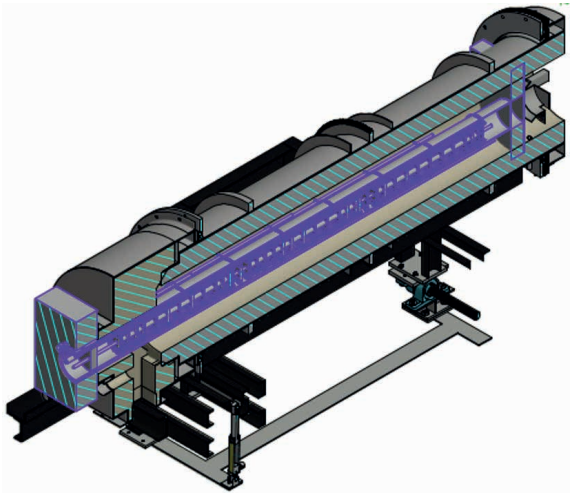
For the production of **alternative reductants for steelmaking from various societal waste flows** the upgrading of our unique laboratory and pilot facilities for thermo-conversion and pyrolysis of solid fuels and waste materials has carried on. Two of the pilot facilities were upgraded to improve safety, reliability and control and to allow operation under full inert atmosphere thanks to electrical heating systems.

- In collaboration with John Cockerill, the BATCH18'' furnace, which is an intermediate-scale model of one hearth of the Multiple Hearth Furnace (MHF) has been fully renewed. The main new features of this piece of equipment are a lock-hopper connected straight to the reaction chamber for tight introduction of raw materials, a tight sampling device to extract material samples during treatment without contact with ambient air, an improved remote control system with regulated steam injection and new heating systems.



Revamped BATCH furnace with systems for tight introduction of raw materials, tight sampling and new heating systems.

- A new 100 kW electrical heating system has also been engineered for the pilot rotary kiln to substitute the gas burner when indirect heating at moderate temperature is necessary. A radiant tube will be placed inside the kiln drum.

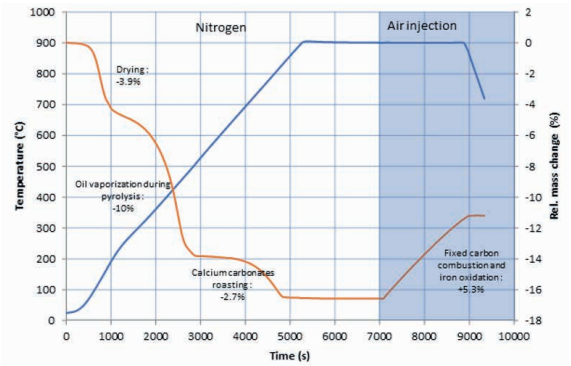


Schematic representation of rotary kiln with radiant tube inside the drum.

At laboratory scale, developments were conducted on the TGA/DTA/DSC equipment. New capabilities result from the coupling of gas analyses to the thermo-gravimetric analyser: a FTIR and a MS are now operational to analyse the gas emitted during the TGA-DSC measurement (mass variation and heat flows measurement of a sample following a heat profile in a specific atmosphere). Our device can operate up to a temperature of 1550°C and a pressure of 5 bar with a wide range of atmospheres.

TGA/DTA/DSC equipment coupled with gas analysis.

It can for example be used for the analysis of a steel mill by-product for which a process is under investigation in order to be used as secondary ferrous raw material for ironmaking.



Treatment of steel mill by-product in TGA.

To support the European industry, we are contributing also to two main initiatives aiming at developing **technology roadmaps for the definition of the mid- and long-term pathways for the decarbonisation of the steel industry** and at the promotion of the knowledge dealing with CO_2 mitigation projects and technologies in iron and steelmaking. In 2020 the actions in the RFCS funded project 'LowCarbonFuture' were focused on Carbon Direct Avoidance (CDA) and Smart Carbon Usage (SCU) as possible CO_2 mitigation pathways. A R&D roadmap for future Low-Carbon emission steel production has been proposed encompassing technology aspects with their challenges and constraints and recommendation on how to overcome them as well as legal and financial aspects and the environmental, social and economic impact. Extensive publication and dissemination actions have been performed and the information is continuously updated on the project website.

Low Carbon Future

GREENSTEEL FOR EUROPE

This project has received funding from the European Union under grant agreement NUMBER — 882151 — GREENSTEEL

With its unique pilot facilities and expertise, CRM Group is also supporting other sectors in their transition to a climate neutral industry.

Several campaigns of pilot trials were run on the Multiple Hearth Furnace for John Cockerill Environment (JCE) and its customers. Among these, a 3-day trial campaign was notably performed in order to confirm the viability of a new one-step industrial process for **the production of activated carbon** from non-conventional raw materials. Positive results have given the greenlight for final industrial implementation of the process at JCE customer's factory.

RESA is the largest intermunicipal utility company in east-Wallonia operating large distribution networks for natural gas and electricity. RESA is a new member of CRM Group. In 2020, we performed for RESA a preliminary study on the practical **ways to store excess renewable electricity by Power-to-Gas (P2G) options**, i.e. by intermittently producing methane to be injected in gas distribution network. Methanation can be performed in catalytic or biological reactors, from hydrogen resulting from water electrolysis and from CO_2 captured from atmosphere, combustion fumes or raw biogas. The study covered both technological and economical assessments of the various process combinations, including options for materials and energy integration of the three basic processes (H_2 production, CO_2 capture and methanation). A multi-MW pilot plant for demonstrating P2G in Wallonia is envisioned.

Energy efficiency and heat recovery are other important fields in which we support our industrial members to achieve the climate ambitions. In this context we have realised, with the help of Walloon partners and with the support of the EFRD, a thermo electric thin film module using low cost materials such as Fe, Al & V for **waste heat energy harvesting application**. Fe_2VAl intermetallic alloy thin film were grown by using the co-sputtering technique. With the Seebeck coefficients obtained

Proposed thermoelectric module and their mask preparation for the sputter deposition.

for P and N-type elements it is now possible to manufacture printed thermoelectric devices.

For the new sources of **green energy, their ways to store and transport** the global solution will consist most certainly in a mixed energy vector such as the production of green hydrogen using intermittent energies by the hydrolysis of water, the recovery of this hydrogen via fuel cells or the storage of energy in chemical form (battery). We develop electrochemical energy conversion systems for short and long term storage.

In the field of **fuel cells** our focus is on metal bipolar plates re-engineering through the realisation of **innovative coatings able to be scaled** up and on the development of a characterisation and forming platform for Proton Exchange Membrane Fuel Cell in the EFRD project Inoxypem. The challenge is to find a coating composition and an associated scalable deposition process allowing the bipolar plates to satisfy the objectives, in terms of contact and corrosion resistance. An extensive scan of influencing deposition parameters have led to the optimization of the coating. Their performance have been assessed by forming the plates to evaluate the stamping resistance of the coating as well as the corrosion resistance. To allow the realization of the innovative designs of the canals to optimize coated bipolar plates a high pressure (4000 bar) hydroforming equipment will be acquired and implemented in 2021 thanks to the support of the European Fund for Regional Development.

The research in **batteries** is focused on Li-ion technology and its adaptation to produce greener and safer electrochemical storage solutions. The aim of this development is to **upscale innovative solutions** for electrodes, electrolyte or current collector on our wet and vacuum roll to roll pilot line. The performance of coated electrodes highly depends on the structure of the coating layer and of the interfaces. Therefor coating technologies and metal collectors preparation are critical for electrode manufacturing and coatings properties. The steps of upscaling and pilot lines validation play a key role to manage it.

In the field of **electrolysis of water for the Hydrogen production** we are supporting the development of John Cockerill's electrolyser technology through the optimisation of industrial electrodes and membranes for alkaline electrolysers by different technologies and development of specific characterisation methodologies.

In the field of development of **solar absorbers**, CRM Group develops in the Cornet project 'FutureFacade' 3D-shaped and metal-based facade elements that combine customised design and solar thermal functionality together. To achieve this aim, a novel simplified architectural structure of solar thermal collector is developed using formed sheet metal shells and an optimised thermal layout. For the efficient manufacturing, a novel forming technology is used to generate bionic inspired 3D-shaped collector modules enabling the seamless integration into existing facades.

Internal design of the solar collector.

To support all these developments, the CRM Group has pilot lines dedicated to very thin substrates such as steel, stainless steel, copper, aluminum or even polymers. These remarkable installations allow an unique combination of wet and dry roll to roll coatings in a cleanroom environment for pre-industrial scale up.

Roll-to-roll pilot lines supporting the energy projects (left: vacuum, right: wet coating).

We are also participating in the #SOCCER project, a project that will use a living lab to develop a guide of good practices for citizen and identify key factors for success for stakeholders (citizen, public, business, non-profit and non-market sectors) in order to set up inclusive Renewable Energy Communities (RECs) and shared mobility. On the CRM Group side, we will work on assessing the environmental impact, based on **a greenhouse gas balance sheet type** approach, of the energy transition measures implemented within the Living Lab for the Ans and Chapelle-Lez-Herlaimont renewable energy communities.

ADVANCED & HYBRID MANUFACTURING

Advanced and hybrid manufacturing technologies allow to produce, repair or finish parts in a flexible way with improved resource efficiency and enhanced functionalities. In response to the needs of its industrial members, CRM Group develops new industrial solutions covering the entire manufacturing value chain, from the development of new metal alloys up to the coating of complex parts.

CRM Group is operating a unique **advanced & hybrid manufacturing platform** that has been inaugurated by Minister Borsus, Vice-President of Wallonia, Minister for the Economy, Research and Innovation, Digital Economy, Agriculture, Urban and Regional Planning and Competence Centers. The platform is exceptionally well equipped for producing, repairing and coating of complex parts and focusses, in-line with the industrial needs, on **advanced and hybrid manufacturing of large parts.**

Inauguration of the Advanced & hybrid manufacturing platform by Minister Borsus.

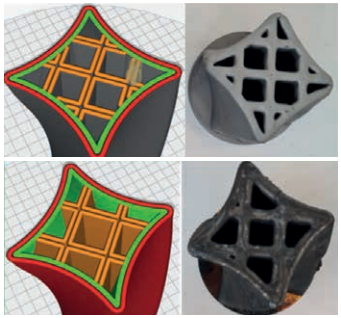
The HYMAX (Hybrid Manufacturing for XL applications) is equipped with both Laser Metal Deposition (LMD) and Wire Arc Additive Manufacturing (WAAM) technologies and was used in 2020 to demonstrate the technologies for various applications:

- The production of good quality aluminum **large parts for space applications** in a project supported by the European Space Agency and in collaboration with Sirris and Sonaca.

First demonstration in view of the 3D additive manufacturing of a full scale launch interface ring for space application.

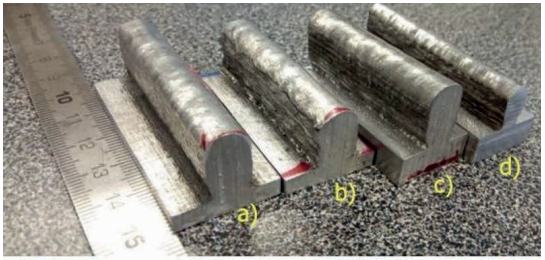
A section of a launch interface ring has been optimised and manufactured through LMD using a high performance Aluminium-magnesium-scandium alloy (Scalmalloy®). The demonstrator part has been successfully tested in the most critical static load case. To further pursue the development, a complete ring (not just a segment) is targeted for 2023. Other improvements are also proposed such as the simulation of the process, enhancements to the design and the heat treatments.

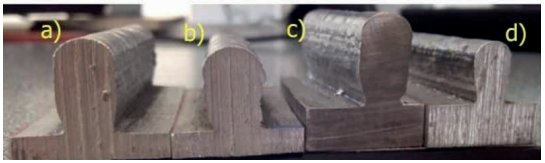
- The feasibility of the manufacturing of a **pump rotor** printed by LMD in an advanced stainless steel alloy 17-4PH for demanding applications combining strength and corrosion resistance has been demonstrated, supported by VLAIO & SIM within the 'INSIDE Metal AM' project. To reduce the weight of the part while keeping its mechanical properties a lattice structure has been printed inside.



Demonstration of 3D printing of a pump rotor in 17-4PH.

- For the development and the validation of a numerical model for **Wire Arc Additive Manufacturing (WAAM) of aluminum** an extensive series of walls has been deposited in well-controlled conditions and with advanced monitoring of all the process parameters and temperature variations. The deformation and residual stresses have also been measured as well as the achieved mechanical properties at different temperatures. The partner developing the numerical tool, has fed all this data in the model that we have validated afterwards through the realisation of two demonstrator cases.





Impact of processing parameters on the WAAM of aluminium parts.

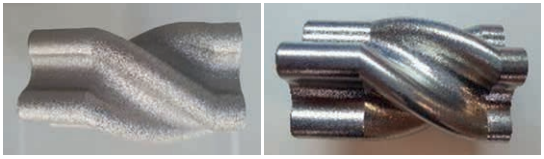
In hybrid manufacturing the **assembling of parts, produced by conventional and/or additive manufacturing technologies** is key. To this end we have performed with the support of the European Space Agency, Euro Heat Pipes and Sirris a study on the weldability of standard extruded aluminum tubes on structures made by additive manufacturing. The welding technology studied was the Friction Rotation Welding process. Based on a complete campaign of welding tests, the suitable welding parameters have been identified and the quality of the welds has been validated by non-destructive testing (penetrant die testing and computed tomography) and

functional testing (leak tightness and pressure testing), also illustrating our capabilities in terms of characterisation and testing in a large range of extreme and/or combined conditions such as temperature, pressure, corrosive environment, ...

Functional testing (leak tightness and pressure testing up to 150bar) after assembling by friction rotation welding.

In the field of **surface finishing** for reducing the roughness of the 3D printed parts, we select and optimise the best suited surface finishing technique depending on the parts' chemical composition, geometry and application to match the properties requirements at best cost and lowest environmental impact:

- for a stainless steel part produced by selective laser melting and studied for Anyshape in a project supported by the Walloon region; an optimised chemical polishing has been developed to achieve a final roughness of 1µm Ra.



316L part before and after chemical polishing.

- for the pump rotor already mentioned before and printed by laser metal deposition in 17-4PH stainless steel, a combination of tribo-finishing and electropolishing allowed to reduce the roughness down to ~4µm Ra. Thanks to the combination of both techniques the post-processing time to obtain a shiny surface could be reduced by 50 to 75%.

Shiny surface of pump rotor printed by LMD after surface finishing.

For the **coating of 3D components**; CRM Group has developed competence and unique tools around the thermal spray and electrostatic spraying technologies.

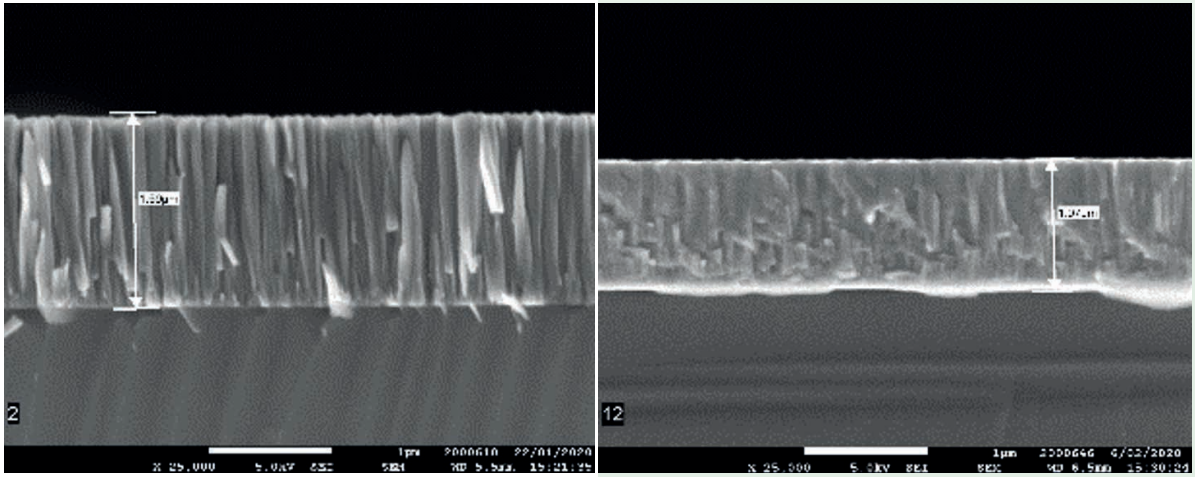
Thermal spray is a powerful technology for applying on components strong protective coatings such as **wear resistant coatings based on molybdenum** or metal carbides, thermal barrier layers or corrosion resistant treatments based on Zn or Al based alloys. The range of available materials in combination with the different spray torches available in our thermal spray system opens a great potential for future application in various industrial sectors. Indeed, besides the protection of metallic parts, a growing interest appears for the protection of temperature and wear sensitive materials such as fibre reinforced polymer composites. This research topic offers new challenges for the combination of polymers and metal based materials. Promising results of polymer metallisation with twin arc spray have been obtained and will be further investigated in the frame of the WINGS project dedicated to aeronautics.

The **electrostatic rotating bell spray technology** combines productivity and high quality application. The versatility of technology allows applying a large panel of liquid coating chemistries. Thanks to the knowledge gained on the potential and capabilities of the technology in the EFRD projects 3D Coater and HybritimeSurf, we are able to

Molybdenum coating deposited by atmospheric plasma spray to reduce friction and increase wear resistance.

advice customers regarding spray process versus chemical formulation adaptation and to realise prototypes with classical or very innovant coatings for a large panel of applications.

In the field of **3D vacuum coating, the High Power Impulsed Magnetron Sputtering** (HiPIMS) set-up, implemented in the vacuum deposition lab, extends our finishing capabilities on the advanced manufacturing technological platform which includes the conventional plasma assisted processes (magnetron sputtering, plasma assisted CVD), thermal spray and electrostatic spray of liquid products. This plasma based HiPIMS technology enables to obtain thin films with high densities and is especially suitable to elaborate hard, anti-wear, anti-corrosion layers as well as to reach specific optical properties. Our activities are more specifically focused on the elaboration of combined anti-wear and anti-corrosion layers for the protection of 3D complex surfaces (complex geometries or high roughness).



Densification of the chromium coating obtained by the HiPIMS process: Porous columnar coatings obtained by standard DC magnetron sputtering (left) and dense coating obtained by HiPIMS (right).

DIGITALISATION

SMART **PRODUCTION** AND **PRODUCTS**

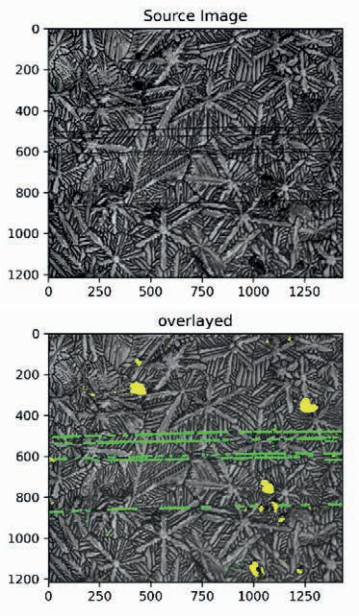
The unique skills developed by CRM Group meet the multi-sectorial needs of a growing number of applications to integrate sensors, connectivity, artificial intelligence and smart and active functions into their processes and products unlocking the full potential of digitalisation for the metals related industry.

Building on its many years of expertise in developing process models and sensors for monitoring and optimising process & product quality in continuous production processes such as the steel industry, CRM Group is now bringing these developments to the next level by the integration of artificial intelligence, connectivity, sensor fusion and miniaturisation as can be illustrated by following examples:

- In the sinter plant the increasing use of a higher variability of input materials, lower quality ores and recycled materials impact the sinter productivity. **An on-line measurement of the cold permeability of the sinter** will allow the optimisation of the productivity by acting in real-time on the mix moisture content, mixer/granulation parameters and mix composition. Therefore an on-line permeameter has been developed and industrially tested on the sinter strand of ArcelorMittal Fos Sur Mer. The system is based on a high speed camera coupled with deep learning data treatment.

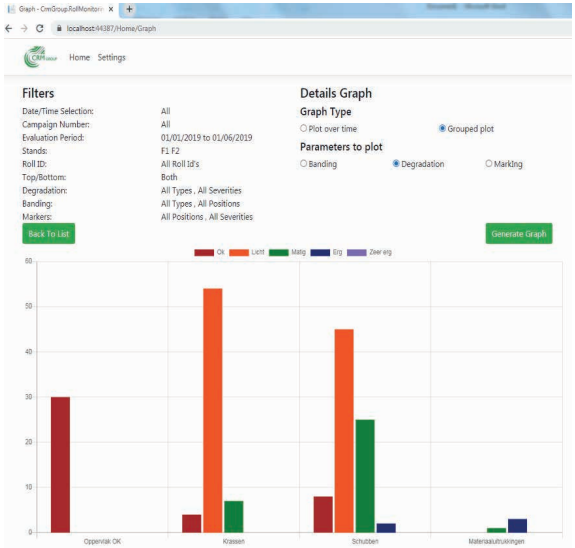
On-line and real-time cold permeability measurement installed on industrial sinter strand combining high speed camera with deep-learning.

- The low-cost and compact On-Line Microscope (OLM) that we have developed for **the characterisation of any surface at microscopic level** has also been further expanded with **machine learning algorithms** opening up new perspectives. The real-time analysis of images and identification of artefacts allows to correct the process parameters instantly, such as illustrated by the automatic identification of micro-defect like zinc holes due to adhesion problems or scratches on a galvanized surface during an industrial measuring campaign at Tata Steel Segal.



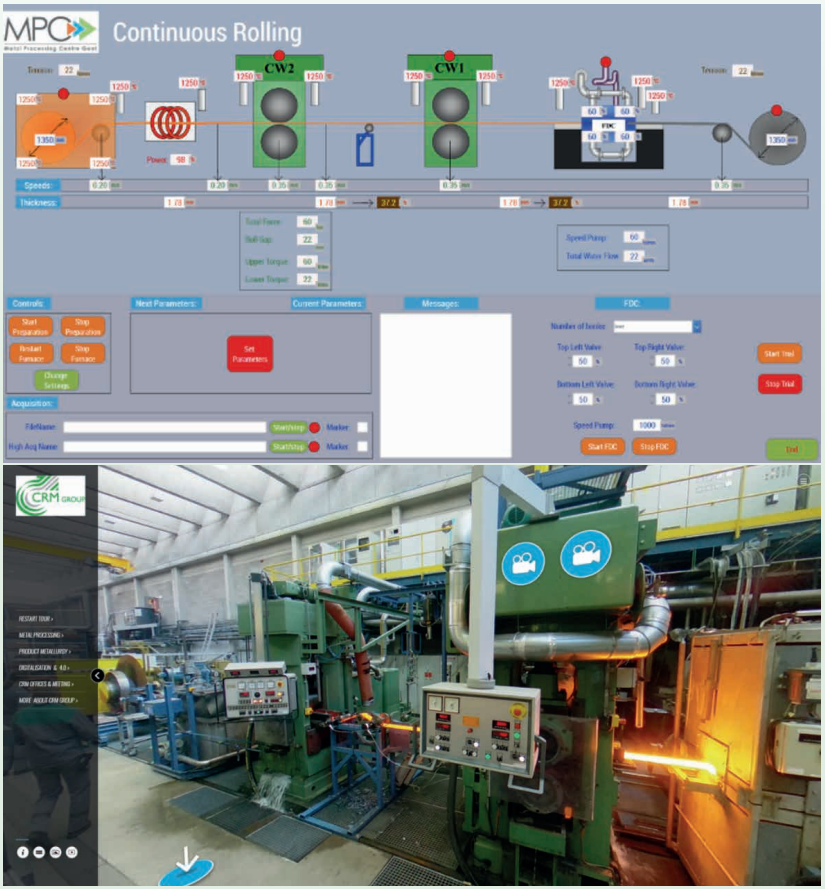
Automatic segmentation and machine learning for real time detection of micro defects during industrial measurement campaign with the OLM: scratches (green) and zinc holes (yellow).

For the monitoring of the work roll surface after a rolling campaign in a hot strip mill, a dedicated software for tablet was developed. During the last years this application has been integrated in several plants of ArcelorMittal and Tata Steel. In the course of 2020 a web-based interface has been developed to further assist mill people to make quick statistical analysis and track irregularities in the degradation of the work rolls.



Screenshot illustrating the functionalities of data storage, analysis & export of the web-based interface of the smart work roll evaluation tool

The continuous hot rolling pilot line installed in our Gent facilities has undergone, with the support of MPC the joint venture between CRM and OCAS, a full electrical revamping. The revamping includes new control cabinets as well as smart sensors and all features to use the line as an industry 4.0 demonstrator. Thanks to the web-based interface the control or supervision of the line can not only be done from the central PC but also from portable devices such as tablet or smartphone.



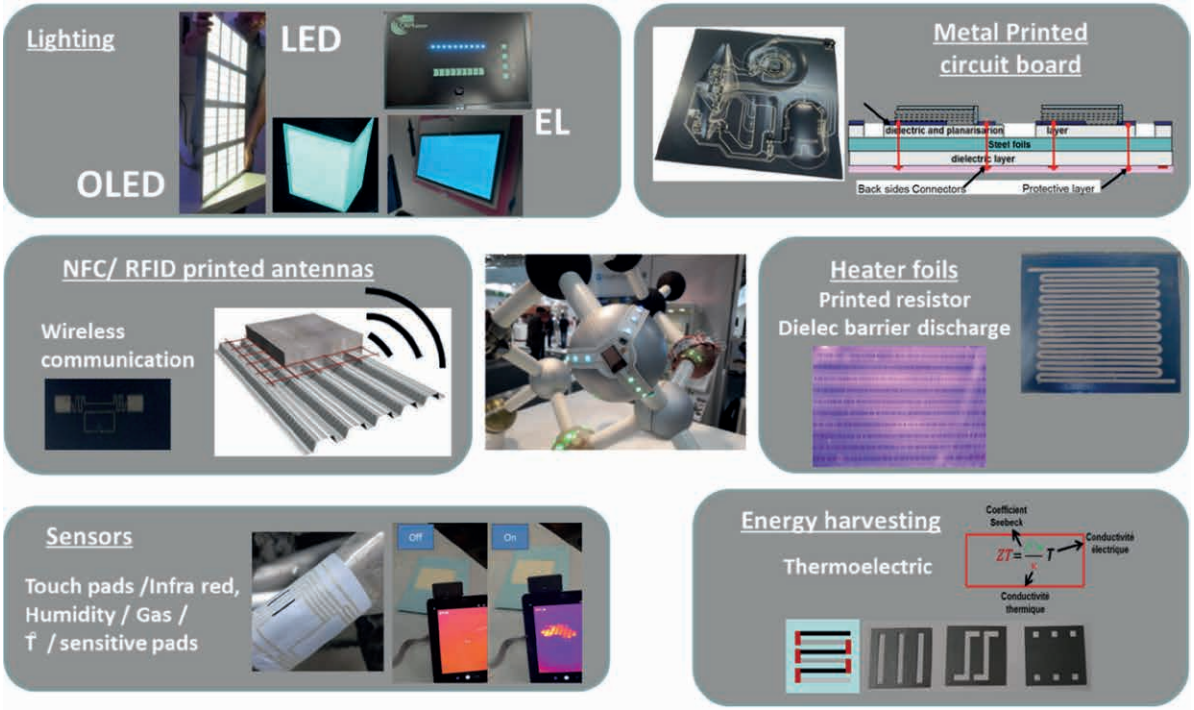
Application of industry 4.0 and virtual visit at the pilot continuous hot rolling line.

Augmented reality.

Another illustration is related to the virtual visits. Driven by safety and sanitary measures a virtual visit to our lab and pilot facilities was created with 360° cameras. The digital walkthrough can furthermore assist new operators for training, in particular when using virtual reality glasses.

The integration of Augmented and Virtual Reality to assess and demonstrate this new technologies in semi-industrial conditions on our pilot lines for remote assistance and digital instruction is also underway.

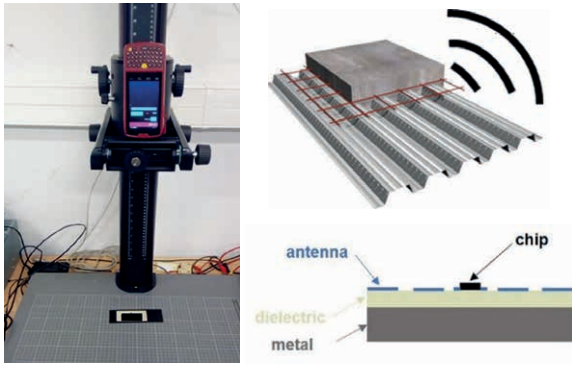
Since a decade, we are developing an unique expertise to embed smart functions in metal solutions by printed and structural electronics technologies for the production of new electronic devices and sensors.



Applications with printed and structural electronics at CRM Group.

The architecture of smart coatings is a real revolution in the design of the connected, IoT or interactive products. The unique skills developed by CRM Group on metallic and associated materials meet multi-sectorial needs for a growing number of applications to integrate connectivity, sensors or other smart and active functions as can be illustrated by some remarkable realisations in 2020:

- The development of **connected steel objects** through the integration of steel antenna; a challenging development because of the interaction between the electromagnetic field signal and the metal which strongly affects or even damages the antenna signal. To deal with this issue, we have applied several strategies for developing specific Radio Frequency IDentification (RFID) antenna designs which would fit with metal environment combined with a careful selection of dielectrics and its thickness applied on metal to uncouple antenna from it. The efforts have resulted, thanks to the support of the Walloon region and ArcelorMittal through the 'e-metal project', in an ultra-thin tag for a metal surface with a read range of 2.5 m which is a significantly better performance compared to many RFID tags available on the market. The final target is the demonstration in a connected steel panel for construction market.



Antenna sketch devices on metal and connected steel products.

- The deposition of a complex set of multi-layer thin coatings to achieve electroluminescent lighting of the object. The recent development of 2020 has mainly been focused on the development of a new process for **multi-layer coating deposition on 3D objects**.

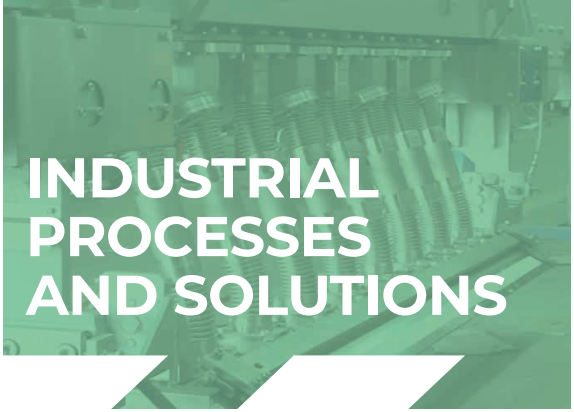
Electroluminescent stack on 3D-preformed steel plate.

All those developments will be pursued in 2021 as well as new application for:

- A **high temperature sensor** to monitor the temperature of a furnace for hot stamping in the frame of the H2020 project HIPERMAT: the thermal spray technology has been chosen since it is not only well adapted for the manufacturing of the insulating and encapsulation layers of the thermocouple but also to print the metallic junction of the thermocouple.

- A new generation of **pressure sensor** in the frame of a Win2Wall project supported by the Walloon region. The first aimed industrial application is for air flow turbines for the company Tiapro.

- A new generation of **low cost camouflage solutions** to provide an object with an adaptive thermal signature in the frame of a project supported by 'Pole Mecatech' and John Cockerill.



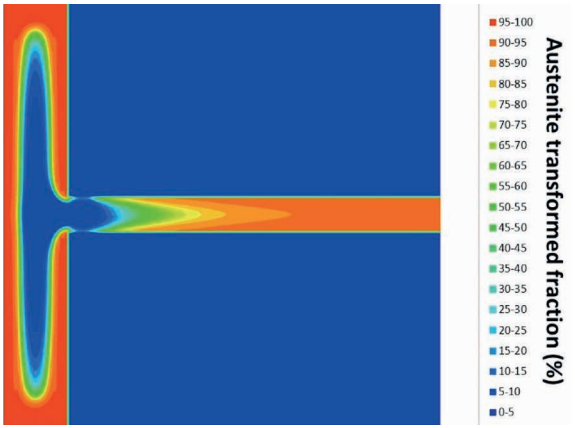
INDUSTRIAL PROCESSES AND SOLUTIONS

INNOVATION
THAT CREATES VALUE

The development and implementation of new and improved processes and solutions in combination with their process control & quality monitoring has been for decades and still remains our core business in the support to the industry. Thanks to the unique combination of profound and renowned knowledge of the industrial reality, the (in house developed) simulation tools and lab simulators, our unique pilot lines and engineering capabilities we provide the industry innovative solutions creating value.

CRM Group continues to develop industrial processes and solutions for and in collaboration with its industrial partners along the value chain of the metals industry. In complement to the many examples that already have been mentioned in the previous section, we can point out other examples of innovations that reached the industrialisation phase.

In the frame of ArcelorMittal Differdange's recent investment dedicated to the revamping of the QST (Quench and Self-Tempering) water quenching installation for H-beams we brought in our **industrial experience of implementation of cooling systems together with our modelling capabilities**. We have developed a QST thermal regulation model (ProfileCam) on one hand and contributed with technical assistance related to the engineering of the hydraulic and cooling system on the other hand. The model calculates in real-time the thermal and metallurgical phenomena occurring during both hot rolling and cooling stages. The model was specifically adapted to ArcelorMittal's QST cooling process for controlling the speed of the product in the water quenching installation to reach the targeted cooling rate and provides the metallurgical properties through the H-beam section.



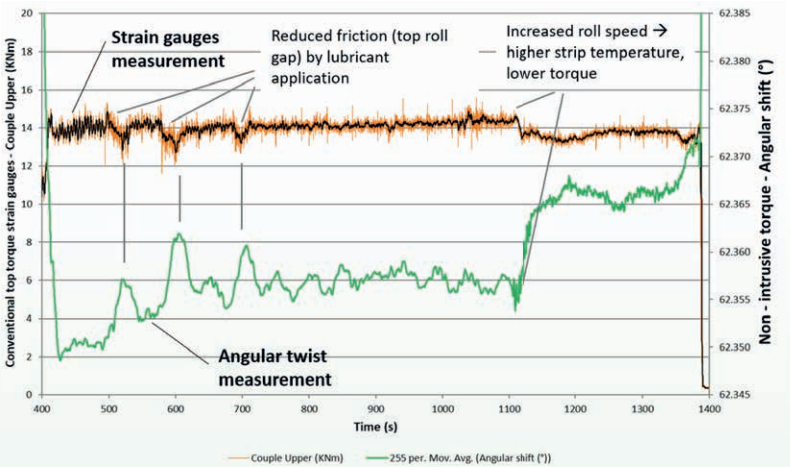
On-line metallurgical phase transformation profile in ½ section of the H-beam.

IN THE FIELD OF ROLLING:

- It is well known that an efficient and good performing lubrication system reduces friction and thereby decreases rolling forces, reduces surface defects and increases rolling campaign lengths. In order to continue to support our industrial members in **the field of lubrication technology** our lubrication lab has been fully renewed and updated. Besides the evaluation of different oils, all individual parts (mixers, nozzles, flow/pressure, lubricants) of a lubrication system can be designed according to the industrial requirements and tested to provide recommendations for a better performance. Full scale headers and lubrication supply systems can also be developed and after full evaluation and de-risking in the lab, the systems can be integrated in the industrial line at minimal technical risk.

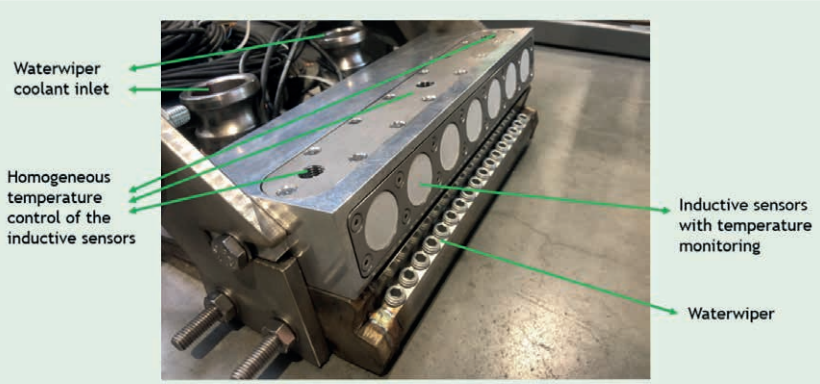
Design & test lab for lubrication

- Since asymmetry in the roll bite during hot and cold rolling induces steering problems, spindle breaks, flatness problems and chatter and vibration issues, a reliable measurement of the spindle torque is a key question not yet resolved with conventional torque measurement systems. We have therefore developed a new system based on the measurement of the angular twist of the cardan shafts. This non-intrusive low cost and robust sensor has been validated on the hot rolling pilot line in 2020 and the encoders will be implemented in the ArcelorMittal Gent hot strip mill and the Tata Steel Ijmuiden cold rolling mill in 2021.



Validation of 'RobustTorque' measurement principle during hot continuous rolling trials

- In cold rolling, a new wiper concept has been developed that ensures good wiping properties and thus avoids work roll cooling water falling on the strip and disturbing lubrication and this without the risk of scratches on the work roll due to mechanical contact between the wiper and the work roll. To do so, the conventional mechanical wiper will be replaced by a wiper based on water sprays combined with an appropriate water evacuation through a gutter. In order to have a good control on the

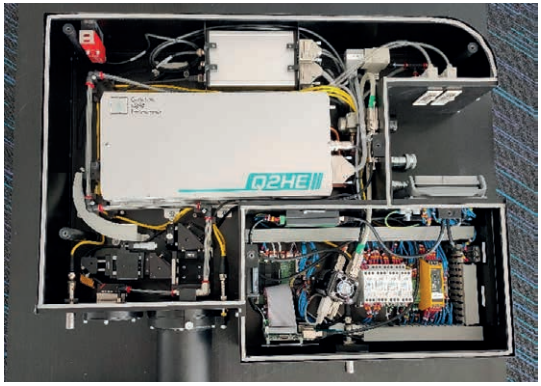


New wiper concept: waterwiper with integrated roll profile measurement sensor ready to be implemented in cold rolling pilot line.

position of the 'water-wiper' a work roll profile measurement system has been integrated. The concept has been designed, constructed and evaluated on the full scale cooling platform. No leakage towards the strip was detected and the profile sensor concept was waterproof. The next step is to integrate the combined water wiper and profile sensor in the Tata Steel cold rolling pilot line.

IN THE FIELD OF COATING:

- A **high-sensitive on-line device has been developed to evaluate surface pollution levels** at the exit of the cleaning section before galvanising. Based on the LIBS – Laser Induced Beakdown Spectroscopy – the 'Cleanex' sensor can simultaneously measure and differentiate the major pollutants : surface carbon from mill oil and iron fines. With this sensor, for which an industrial version has been built in partnership with Sarclad and will be deployed during 2021, the cleaning section can be optimised through the adjustment of the relevant parameters by quickly acting in case of a drift in the pollution level.

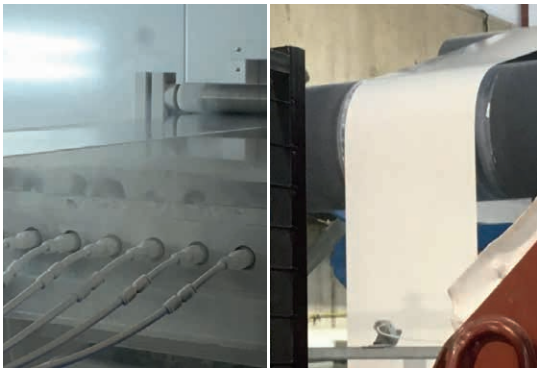


Cleanex prototype

- The **precise control of the strip profile and its vibration** between the wipers is a key factor to accurately control the Zn coating weight and its homogeneity. In partnership with John Cockerill, CRM implemented the 'CrossBowMeter' to measure in industrial galvanising lines the strip position between the wiper lips along the width with a precision of 0.1mm and its vibrations up to 50Hz.

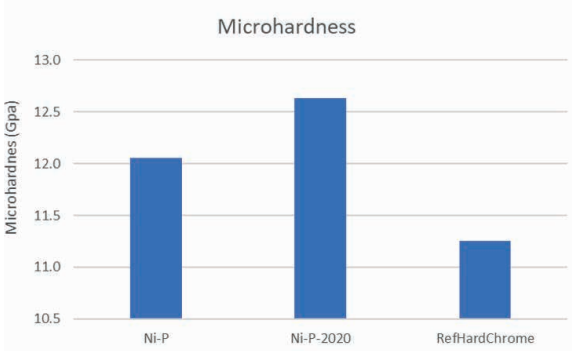
CrossBowMeter: measurement of the shape and vibrations of the strip just above the wipers in galvanising lines.

- In the field of the **continuous application of powder coatings** we continued the work **on upscaling and bringing the 'fluidised bed' technology closer to industry** in the frame of the HIPOLIN project. Thanks to trials on our CASTL pilot line we have optimised this new technology and provided guidelines for a complete industrial application. Different parameters such as voltage, distance strip-bed or air flow were studied and the importance of each one in terms of critical level for the process was determined. At the same time, the demonstration of the possibility to produce powder coatings on long coils was performed and some industrial partners involved in the project showed interest to test this technology at industrial scale.



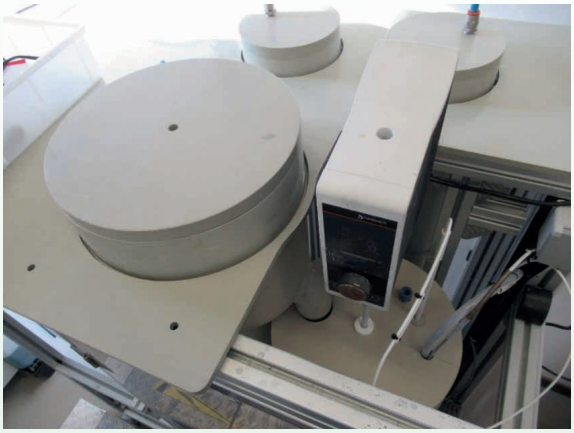
Fluidised bed technology for continuous powder coating of coils.

- In order to comply with the stringent REACH regulation, **a substitute for the hard chrome plating of the rolls in the cold rolling mills** is necessary. We have continued our development based on the Ni based coatings. To improve their mechanical resistance NiP coatings plated from a specially tuned electrolyte 'Ni P 2020' were successfully produced achieving higher hardness and equivalent Young modules as hard chrome.



Properties of the improved Ni-P-2020 coating to replace hard Cr

The search for alternatives for the harmful hard chrome plating is not only an issue for the steel industry but also for a variety of other industrial sectors. Therefore a new electro co-deposition facility was implemented in 2020. The device is dedicated to the electrodeposition of **cermet coatings** and has been used for long duration codeposition campaigns for the codeposition of carbide particles in a nickel-based matrix. Results demonstrate a very homogeneous and repeatable incorporation of the carbide particles. The wear resistance is increased thanks to this integration of hard carbides in the Ni-coating and coatings are suited as alternative coating to the harmful hard chromium coatings for **hydraulic applications**.



Codeposition pilot designed for the electro-deposition of cermet coatings

The example here above, as well as many examples already cited in the other sections, give a good illustration of the capabilities of CRM Group **to support companies to develop processes and solutions in a large variety of sectors:** metallurgical, aeronautic, energy, defence, construction, industry,.... until the pharmaceutical industry. Indeed, supported by the Walloon region, a custom-designed solution has been developed for Pharma-Technology. An **automatic non-destructive inspection and sorting of pharmaceutical products** (capsules and tablets) according to different criteria such as dimensions, mass, active ingredient content was requested. For such a real-time continuous inspection at high speed, several new technologies such as infrared spectroscopy and microwave resonance, ... have been selected and matured before integration in the full solution. The Q-control CU-120 is now commercialised by Pharma-Technology.

TECHNICAL SUPPORT, VALORISATION & DISSEMINATION

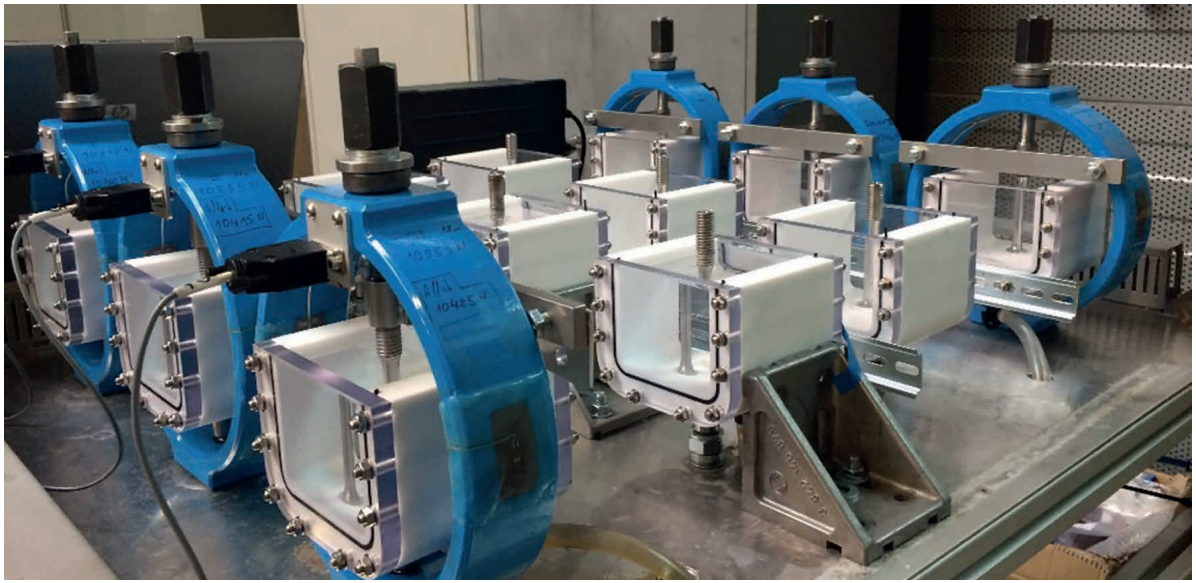
TO **INDUSTRY** AND **REGIONAL ECONOMY**

The development of new alloys, coatings, processes and solutions is enabled by the deep knowledge of metallic materials combined with the unique set of testing, characterisation and simulation tools that CRM Group holds. This expertise and facilities are at disposal of CRM Group's members and customers to solve their problems or develop their business.

By the continuous increase of our know-how combined with new state-of-the-art test set-ups, we accompany our customers to increase the performance of their process, product or application or to assess its safety, reliability or integrity. The service is offered in R&D projects, in industrial technical assistance and in support that is offered to more than 350 customers active in a variety of sectors: metallurgy, energy, industry, aeronautics, defence and construction. In particular for SME's in the Walloon region developing a new product, process or service that requires scientific validation, CRM Group is recognised as service provider with the technology voucher 'Chèques Technologiques'.

In the field of **metal forming** we combine a dual approach of experimental testing (forming presses and roll forming line) with numerical modelling. Depending on the need of the customer, our services ranges from troubleshooting, component characterisation to the development of new solutions with its industrial production process. To complete our panel of forming equipment and to allow the realisation of innovative designs for fuels cells or heat exchangers a **hydroforming equipment** will be acquired and implemented in 2021 thanks to the support of the European Fund for Regional Development.

Hydroforming principle that will be mounted in the 5000kN AP&T press



View of the stress corrosion test bench.

One more service frequently offered concerns **corrosion** monitoring and study. Activities cover a wide range of industries and are supported by an important pool of analytical methods and (on-site) testing capabilities. The latest development concerns the stress corrosion cracking test bench to evaluate the susceptibility of metallic alloys to corrode under applied stress in NaCl medium to ECSS 37C (equivalent to ASTMG38). Such test is commonly applied in aerospace applications.

Another illustration is the support offered to industrial partners (Sonaca, Bekaert) for **characterisation study** and comparison of new aluminum and titanium filler wires for **welding**. The objective of these studies was to assess the weldability of the wires and compare the properties of the deposit metal with those of commercial wires.

Non-destructive and on-site analysis is a specific expertise we offer to our members and customers. In 2020 CRM was successfully audited by TÜV and T.N.I to perform non-destructive tests for the control of packaging for the transport of radioactive material at Ateliers de la Meuse.

NDT inspection of packaging for nuclear waste.

The know-how acquired is continuously updated and is put at the benefit of a number of companies and sectors as can be illustrated by the following collaborative projects and dissemination actions:

- Since end 2020 CRM Group is part of **WINGS**, the **W**alloon **IN**novations for **G**reen **S**kies. This collaborative project gathers 19 partners led by three major companies in the field : Thalès, Sonaca and Safran Aero Booster as well as numerous research centers. It aims at developing innovative technologies allowing

the design of a new generation of aircraft meeting the European environmental objectives of carbon neutrality by 2050.

- Together with 16 other innovation partners, we joined forces to stimulate growth and innovation in the Flemish industry. With the support of Vlaio integrated services through a diverse range of topics such as digitalisation, sustainability and industry4.0 will be offered to the Flemish industry.

For the dissemination of our results and to promote our developments, we have (co)organised webinars, workshops and trainings:

- In the frame of the Advanced Materials Innovative Recycling (AMIR-RIS) master programme aiming at educating students to become highly skilled professionals with expertise in recycling of various types of materials and develop a deep entrepreneurship mind-set, we have continued in 2020 to contribute to this programme in cooperation with University of Liège by giving lectures on the basic thermodynamics of pyro-metallurgy, the production and recycling of aluminium and copper, the concept of circular economy and the challenges of high pyro-metallurgical processes.

- In the frame of the RFCS project LowCarbonFuture, CRM has participated to the organisation of 2 webinars respectively in February and March 2020 to share the result of the project on CO_2 mitigation technologies.

- To disseminate the results of the Vlaio-SIM 'INSIDE metal AM' project on 3D printing of steel, a webinar was organised in October 2020 to help companies to better understand the additive manufacturing of steel components by providing them guidelines on material selection and the quality of powders, the selection of the printing technology as well as insights in possible post-treatments.

- A workshop organised in October 2020 on Improving surface quality in hot strip rolling in the frame of the RFCS project 'INFIRE'.

- To disseminate the results of the Vlaio-SIM Cleanscrap project, CRM Group illustrated, together with Clusta and Sirris, how to improve the 'value-in-use' of ferrous materials during a webinar organised in November 2020.

Our extensive network of R&D partners, associations and partnerships are at the benefit of our industrial members to identify opportunities, collaborations or funding possibilities:

- As a **collective research centre** recognised by the **Belgian** and **Regional Authorities**, CRM is member of:

Innovaders : The new identity of the UCRC (Union of Collective Research Centres), which promotes collective research, encourages cooperation and synergies and defends our common interests.

Wal-Tech: An association regrouping the 19 collective research centres certified by the Walloon Region. Several platforms have been created to share experience and coordinate activities.

VLOOT (VLaamse Overkoepelende Organisatie van Technologie- & Innovatieverstrekkers). It is a structural overall collaboration between more than 20 technological and scientific innovation actors in Flanders.

SIM (Strategic Initiative for Materials), a virtual strategic research center governed by industry and academia with the objective to contribute to the competitive position of the materials industry in Flanders by means of strengthening the scientific base and building technology platforms in relevant areas, and by generating an open innovative environment for close collaboration between industry & academia.

Flam3D is the independent platform for all stakeholders active in 3D printing and Additive Manufacturing in Belgium and The Netherlands.

A6K is a network of technological companies bringing together relevant players from Wallonia, Belgium and elsewhere in the fields of energy, communication and embedded systems or operational transformation towards Industry 4.0 to encourage the emergence of projects.

MRC (Material Research Cluster Gent) is an initiative in which seven partners (OCAS, Gent University, Sirris, BIL, Clusta, CRM, SIM and its division Flamac) share commun laboratories with a strong focus on metals. This cluster has at its disposal state-of-the-art equipment for characterisation and testing from the nanoscale to large-scale industrial components and structures and more than 200 scientists and technicians under one same roof.

- At the **European level**, CRM takes actively part to the following organisations and platforms:

The **European Steel Technology Platform (ESTEP)** brings together all the major stakeholders in the European steel industry (steel manufacturers, universities and research institutions active in steel research, major users of steel, and public bodies like the European Commission and national governments).

Together with ULiège and over 120 other European industrial, academic and research partners, CRM is since 2015 a member of the KIC (Knowledge and Innovation Community) **"EIT Raw Materials"**, covering a wide range of themes like exploration, mining, efficient use of raw materials in process manufacturing industry, recycling and substitution of critical raw materials. More info : https://eitrawmaterials.eu/

The four independent European steel research institutes (CRM, CSM, Swerim and VdEh-BFI) joined forces in 2011 to found **RIES**, a network that pools the complementary research areas of these institutes.

Legally formed in July 2012, **SPIRE (Sustainable Process Industry through Resource and Energy efficiency)** is a European Public Private Partnership (PPP), dedicated to innovation in energy and resource efficiency and created to meet and participate to the Horizon 2020 Framework Programme of the European Community.

Hybrid 3D network, a network partner of small and medium-sized companies and research institutions from all over Germany, Belgium, Swiss and Austria active in (hybrid) additive manufacturing who want to expand their range of knowledge, share their experience with other partners, generate and implement new ideas and be upfront in the emerging field and market of hybrid additive 3D manufacturing technologies and processes.

Within **PROMETIA**, an international non-profit association promoting innovation in mineral processing and extractive metallurgy for mining and recycling of raw materials, CRM is member of the METNET networking offering to customers an access to pilot plants in order to bring ideas or concepts to industrial use (https://prometia.eu/metnet-network/).

ERMA network brings together a growing number of organisations from the public and private sectors covering the entire raw materials value chain for contributing to ensure a reliable, secure and sustainable access to raw materials.

EBA250 is a platform for key stakeholders throughout the entire battery value chain.

LET US MENTION THAT CRM IS ALSO MEMBER OF:

WorldSteel: the International Institute of the Steel Industry,

EUROFER: the European Federation of the Steel Industry,

UWE: Union of the Walloon Enterprises

VOKA: the Flemish network of Enterprises.

PUBLICATIONS & CONFERENCES 2020

PUBLICATIONS & **PAPERS ON CONFERENCES** 2020

Metal Production, Recycling and Energy

J. BORLEE, J-C. PIERRET
Low Carbon Future in the Steel Industry – Process Integration Pathway
LowCarbonFuture webinar, 24 March 2020

S. BORN, A. BABICH, J. VAN DER STEL, H. THONG HO, D. SERT, O. ANSSEAU, C. PLANCQ, J-C PIERRET, R. GEYER, D. SENK, V. PRIDHIVI
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Steel research int. 2020, 2000038, pp. 1-9

L. BEIRAO DO VALLE, T. MARCON, Y. PONTIKES, P. PETRICA, M. GIELS
Low cost production of geopolymer precursors through red mud sintering
3rd International Bauxite Residue Valorisation and Best Practices Conference, 29 September & 1 October 2020, online

H. HAGE, H. THONG HO, M. OUWEHAND, C. TEERHUIS, J. VAN BOGGELEN, J. FRADET, C. ZEILSTRA, K. MEIJER, X. WANG, F. BLAFFART, M. DORMANN, B. VANDERHEYDEN
Metal recovery from secondary raw materials through the HIsarna process – the ReclaMet project
ESTEP Resi4Future Web-workshop, 13 November 2020

J-C. PIERRET, C. OJEDA, P. NYSSEN, J-C. BAUMERT, J-C. THIBAUT, M. LOWRY, F. LOPEZ, R. LULE, C. CHACON, J. MENDOZA, W. RUDIGER
Predictive EAF model for optimisation of melting at ArcelorMittal Lazaro Cardenas
Future Steel Forum, 8-9 December 2020, online

V. DECOTTIGNIES, T. MARCON
VALOMAG project: From the recovery of scrap magnets to the production of new magnets and rare earth oxides
PROMETIA 7th Scientific Seminar, 10 December 2020, online

Metal Processing & Product Metallurgy

H. UIJTDEBROEKS
Impact of roll bite actuators and oxygen depletion on strip surface quality
Infire seminar on Improving surface quality in hot strip rolling, October 2020

S. FLAMENT, O. LEMAIRE, G. WALMAG, M. SINNAEVE
Optimization of Hot Rolling Roughing Mill Rolls to Prevent Premature Contact Fatigue Damage Occurrence
Iron & Steel Technology, Nov 2020

Finishing & coating

F.-D. DUMINICA, X. VANDEN EYNDE, M. MANDY, B. NABI, C. GEORGES, T. STUREL, P. DRILLET, R. GRIGORIEVA
Investigation of PVD thin films as hydrogen barriers in aluminized press hardened steels (PHS)
Surface and Coatings Technology, Volume 397, 15 September 2020, 125940

M. ZHUKOVA, R. KOTIPALLI, O. PONCELET, L. SAMAIN, L. FOURDRINIER, D. FLANDRE
Correlation and optimization of the optoelectrical properties of DC magnetron-sputtered Cu2ZnSnS4 absorber layer as a function of the material composition
Elsevier Materials Science in Semiconductor Processing, Volume 121, January 2021, 105367

R. COQ GERMANICUS , D. MERCIER, F. AGREBI, M. FÈBVRE, D. MARIOLLE, Ph. DESCAMPS & Ph. LECLÈRE
Quantitative mapping of high modulus materials at the nanoscale: comparative study between atomic force microscopy and nanoindentation
Journal of Microscopy, Vol. 280, Issue 1 2020, pp. 51–62

M. BARREAU, C. MÉTHIVIER, T. STUREL, C. ALLELY, P. DRILLET, S. CREMEL, R. GRIGORIEVA, B. NABI, R. PODOR, J. LAUTRU, V. HUMBLOT, J. LANDOULSI, X. CARRIER
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S. DETRICHE, S. VIVEGNIS, J.-F. VANHUMBEECK, A. FELTEN, P. LOUETTE, F.U. RENNER, J. DELHALLE, Z. MEKHALIF
XPS fast depth profile of the native oxide layers on AISI 304, 316 and 430 commercial stainless steels and their evolution with time
Journal of Electron Spectroscopy and Related Phenomena 243 (2020) 146970

L. FOURDRINIER, L. SAMAIN
Correlation and optimization of the optoelectrical properties of DC magnetron-sputtered Cu2ZnSnS4 absorber layer as a function of the material composition
Materials Science in Semiconductor Processing, Volume 121, January 2021, 105367 (available online 20 September 2020)

Advanced manufacturing

N. JIMENEZ, F. HENDRICKX
Laser metal deposition onder de loep genomen basisprincipes, toepassingen en uitdagingen
Metallerie, Vakblad voor de metaalverwerkende industrie, nr. 2020-04, mei 2020

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  Advanced Coatings & Construction Solutions
- **AC&CS Ivoz-Ramet** > *Flémalle*
  Advanced Coatings & Construction Solutions
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