CRM GROUP

ANNUAL REPORT 2018

CLOSING THE VALUE CHAIN OF METALS

D/2018/0124/1

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 2018 CRM delivered also various services to more than 250 non-member customers.

At CRM Group, health and safety still remain the first priority. In 2018, safety-improvement actions continued to be implemented on the shop-floor and a culture of involvement of all staff has been fostered. Although 1 accident with lost time was registered in 2018, the overall yearly safety results continue to show a strong improvement compared with the past. A robust action plan, aiming at a VCA-certification, has been defined for 2019 in order to anchor safety awareness into the daily operations.

To fulfil its mission, the CRM Group is organised around 5 research units that are backed-up by a world class material characterisation laboratory:

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

2 | Metal processing and metallurgy: including casting & solidification, rolling & thermal treatment, product metallurgy

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

4 | Innovative designs and assembly solutions in the fields of Civil engineering, Construction, Assembly & Testing and Hybrid manufacturing

5 | Industrial solutions: embracing in-house Engineering, finishing & metallic coating processes, organic coating and sandwich panels products, process control & measurement & continuous annealing and/or coating pilot lines

Furthermore, in line with its strategic plan, CRM has structured during the last 4 years transversal activities within the organisation to tackle key societal challenges efficiently and to transform main new technological trends into industrial reality for our customers and stakeholders. These so-called technological platforms on circular economy & recycling, energy & environment, hybrid manufacturing and digitalisation mobilise all necessary competencies within CRM Group and cross-sectorial innovation and implementation.

As an independent collective research centre, CRM has continued to benefit from financial support from the Belgian and Regional authorities, as well as from the European Commission. This support has been devoted particularly to our technological platforms.

At a European or regional level, CRM has continued to invest in partnerships with others research organisations. Numerous research projects, financed by the European Commission, have led to many opportunities of co-operation with specialised European partners. CRM is to-day active in more than 20 European projects.

The end of the year 2018 was also landmarked by the retirement of CRM's CEO J.C. Herman and CTO C. Marique. We wish to express all our gratitude towards both of them for their vision and relentless efforts that led to numerous success-stories of CRM as well as to the substantial growth CRM has known during the 5 last years.

The present annual report highlights the main achievements of the year 2018.

Paul PERDANG
President CRM

Joeri NEUTJENS
General Manager CRM

Company members

On April 17, 2019

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 RODANGE et 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
APERAM Stainless France S.A.S. ..... France
ARCEO Engineering ..... Belgium
AURUBIS BELGIUM N.V. ..... Belgium
BEKAERT S.A. ..... Belgium
BIOCARBON INDUSTRIES Sàrl ..... G.D. Luxembourg
CARMEUSE S.A. ..... Belgium
CBR S.A. ..... Belgium
CMI S.A. ..... Belgium
COMET TRAITEMENTS S.A. ..... Belgium

DE LEUZE S.A.	Belgium
DELEUZE GROUP-EMUREF S.A.	Belgium
DREVER INTERNATIONAL S.A.	Belgium
EMG Automation GmbH	Germany
ENSIVAL-MORET BELGIUM S.A. (SULZER)	Belgium
E.S.W.	Austria
EVERZINC	Belgium
FONDERIES MARICHAL, KETIN & Cie S.A.	Belgium
HERAEUS ELECTRO-NITE INTERNATIONAL N.V.	Belgium
HERSTAL S.A.	Belgium
INDUCTOTHERM S.A.	Belgium
INSTITUT BELGE DE LA SOUDURE asbl	Belgium
INTERNATIONAL MANGANESE INSTITUTE	France
LHOIST Recherche & Développement S.A.	Belgium
LIEGE STEEL INDUSTRY	Belgium
MAGOTTEAUX INTERNATIONAL S.A.	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
R-TECH S.A.	Belgium
SAFRAN AERO BOOSTERS S.A.	Belgium
SARCLAD Ltd	United Kingdom
THY-MARCINELLE S.A.	Belgium
TI GROUP AUTOMOTIVE SYSTEMS S.A.	Belgium
TMT sarl	G.D. Luxembourg
VM BUILDING SOLUTIONS S.A.S.	France
WESTINGHOUSE ELECTRIC BELGIUM S.A.	Belgium

Organisation

On April 17, 2019

Board of Directors of CRM

President

Paul PERDANG, Head of Capex and IAC secretary, ARCELORMITTAL

Vice-Presidents

Pinakin CHAUBAL, Head of Process R&D and Americas labs, ARCELORMITTAL
Ernst HOOGENES, Director R&D Europe and Director Business Excellence, TATA STEEL

Directors

Ivan AERTS, Adviseur, Centrale der Metaalbewerkers van België
Vincent CHOLET, CTO, ARCELORMITTAL Europe – Long Products
Philippe COIGNE, Directeur Général, Groupement de la Sidérurgie (GSV)
Renaud COLLETTE, Conseiller, SPF Economie, PME, Classes moyennes et Energie
Mark DENYS, Director Technical Strip Products, TATA STEEL Mainland Europe
Joao FELIX DA SILVA, Directeur Général, CMI Industry
Marc FISETTE, Head of Performance Optimisation, ARCELORMITTAL Europe Flat Products
Leo KESTENS, Professor, Universiteit Gent
Greg LUDKOVSKY, Vice-President of Global R&D, ARCELORMITTAL
Anne MERTENS*, Associate professor, ULiège
Stéphane PIRON, Secrétaire Fédéral – SETCa Fédéral
Nicoleta POPA, Head of Construction applications, Infrastructures and Long Products, ARCELORMITTAL Global R&D
Vincent RITMAN, Director R&D Europe, TATA STEEL EUROPE
Mario SINNAEVE, R&D - Quality Control Manager, S.A. des Fonderies Marichal, Ketin & Cie
Gabriel SMAL, Secrétaire Général, ACV-CSC METEA
Sven VANDEPUTTE, Managing Director, OCAS N.V.
Manfred VAN VLIERBERGHE, CEO ARCELORMITTAL Belgium
Simone VOOIJS, Director Technical Tata Steel Downstream Operations, TATA STEEL

Observers

Rose DETAILLE, Inspectrice Générale, Département de la Recherche et du développement technologique, Service Public de Wallonie
Joeri NEUTJENS, Directeur Général, CRM
Yvon MASYN, Adviseur, Vlaams Agentschap Innoveren en Ondernemen

Auditor

Dominique JACQUET-HERMANS

Iron and Steel Committee of CRM

Members

ARCELORMITTAL
Jean-Paul ALLEMAND
Michel BABBIT
Pinakin CHAUBAL
Marc DI FANT
Eric HESS
Mayte RODRIGUEZ
Sven VANDEPUTTE

TATA STEEL
Mark DENYS
Loes JANSEN
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.

QUALITY MANAGEMENT SYSTEM CERTIFICATE

ISO 9001 : 2015

BQA we hereby declares that the management system of CRM Group

CRM GROUP

located at Avenue du Bois Saint-Jean, 21 B27 – Quartier Polytech 4 - 4000 Liège and Rue du Bois Saint Jean, 8 – 4102 Ougrée and Rue du Chêne, 200 – 4000 Liège and Technologiepark 903e – 9032 Zwijnaarde – Belgium,
for **CRM asbl** *– Centre for Research in MetalLurgy asbl, and by*
Allée de l'Innovation, 1 B 37 – Quartier Polytech 3 – 4000 Liège and Rue Sompré, 1 – 4400 Flemalle – Belgium
for **ACACS scrl** *– Advanced Coatings and Construction Solutions scrl,*
has been examined on 2018-05-28 and found in conformity with the ISO 9001, edition 2015, standard for the following application field:

Industrial research and associatid activities such as testing, calibration and expertise.

This certificate has been issued by BQA in according to its quality manual concerning the certification of systems, and after concluding the contract of certification N° CER_SI_QMS2015_31-05-2018_558_F under which the company accepts a regular control of its management system.

Certificate N° BQA_QMS_C_2006338
Valid until 2021-05-27

BELAC 9/9-QMS

D. SIMOENS
Director

BQA

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

BELAC

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

BELAC

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,

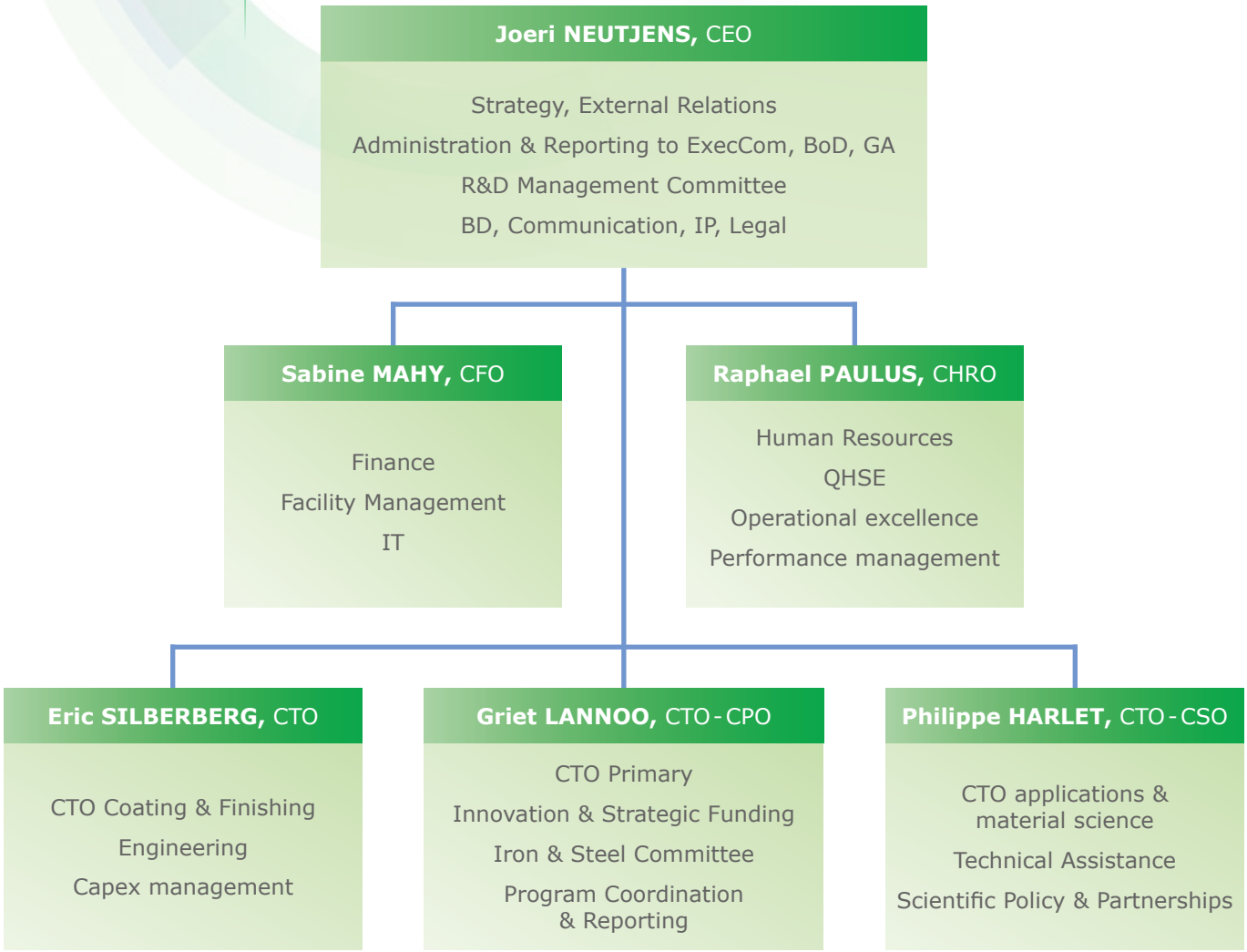
Issue date : **2017-12-07**
Validity date : **2022-10-27**

Nicole MEURÉE-VANLAETHEM

Original version of this certificate is in French.

.be

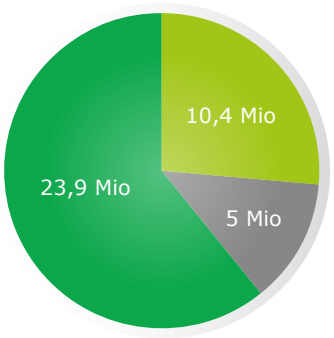
Leadership Team



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

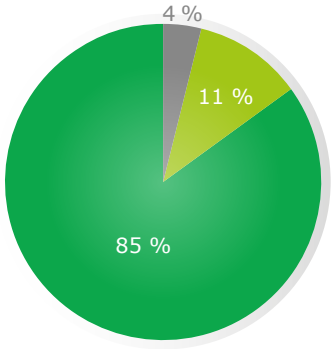
Key figures

Income by program



- Steel Collective
- Steel effective collaboration
- Other

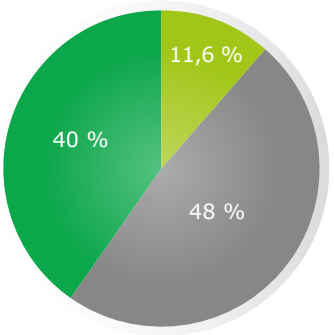
Income by financing



- Industrial collaboration
- National & Regional Grants
- European Grants

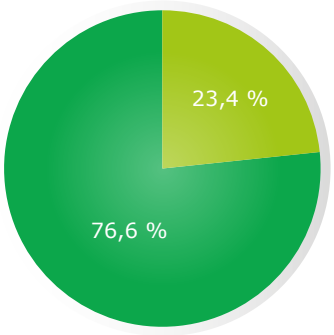
Total Income (CRM asbl): 39.3 Mio. Euros

CRM Group: 262 people



- Researchers
- Technicians
- Administrative staff

Gender balance



- Female
- Male

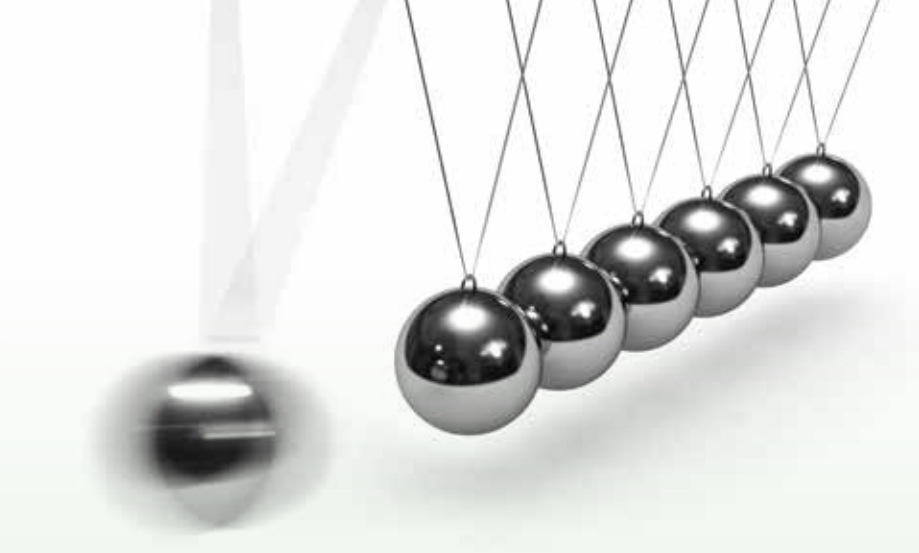
Report on R&D activities

As independent collective research centre CRM offers since decades breakthrough solutions, applied research & technical assistance aligned with the industrial and societal needs. The know-how, R&D-solutions and technical assistance are made available to members and non-members, to small, medium and large industrial companies. Besides its deep knowledge and long experience in the field of new processes, metallic products and application of metallic materials, in line with its strategic plan, CRM is also developing new competences in transversal domains like recycling, energy, new manufacturing technologies and digitalisation.

With its highly skilled staff and unique lab and pilot simulators CRM continues to build-up know-how and to propose innovative R&D and solutions in the fields:

- Metal Production, Energy & Recycling: raw material processing, melting & refining, by-products treatment & valorisation
- Metal Processing & Metallurgy: casting & solidification, rolling & thermal treatment, product metallurgy
- Advanced Surface and Smart Solutions: functional coatings, smart surfaces, surfaces for renewable energy applications
- Innovative Design & Assembly Solutions : civil engineering, building & structure, assembly & testing, hybrid & additive manufacturing
- Industrial Solutions : engineering, industrial measurement & process control, finishing and organic & metallic coatings and sandwich panels
- Material science & characterisation

To further develop CRM's attractiveness & competences in line with industrial & societal challenges the centre has continued



the development of the strategic technological platforms around the following transversal topics:

The **Circular Economy** platform dealing with recycling, closing the loop of metals, turning by-products & end-of-life products into valuable secondary raw materials

The **Energy transition** platform dealing with steels low carbon energy transition, reduction of pollutant emissions, renewable energy and the valorisation of waste into energy

The **Advanced Manufacturing** platform focussing on innovative solutions combining classic manufacturing with 3D printing

The **Digitalisation** platform focussing on intelligent integrated manufacturing and the development of smart products.

Key success factors of those strategic platforms are the fact that they are extremely well equipped with world-class and unique lab and pilot equipment and staffed with people from different disciplines for a full transversal and holistic approach.

This annual report highlights in particular the further development - in terms of extraordinary pilot equipment and activities - of those strategic technological platforms at CRM and presents furthermore a selection of noteworthy activities and results obtained at lab, pilot and industrial scale for the development of new processes, products & solutions and technical support.

The 2018 activities and realisations are illustrated into 5 thematic sections:

- Circular economy and energy preservation: Resource efficiency as main driver towards a sustainable metals industry
- Industry 4.0 and digitalisation: Smart production and smart products
- Advanced and hybrid manufacturing: The new products of the future
- From breakthrough process developments at lab scale to industrial implementations: Turning applied research into value creation
- New products & solutions and their dissemination to industry & regional economy

Circular economy and energy preservation

Resource efficiency as main driver towards a sustainable metals industry

Increasing resource efficiency and protecting the environment & climate represent major transversal challenges for the metal's industry. Within its technological platforms 'Circular Economy' and 'Energy & Environment' CRM combines remarkable and unique equipment with deep knowledge of metals & processes to respond to the needs of the industry in terms of responsible resource management.

Metals and their by-products are central elements in the now well-established concept of circular economy. Therefore a transversal technology platform on 'Circular economy' has been developed, in line with the strategic plan, to further support the industry in addressing the challenges on securing cost-efficient and sustainable access to raw materials and increasing resource efficiency.

A crucial step in the conversion of a 'waste' into a 'secondary raw material' is its pre-conditioning. In order to evaluate and optimise the pre-conditioning methods of metals and their by-products CRM is continuing, thanks to the support of regional funded projects, such as 'Reverse Metallurgy' and European Initiatives (EIT RawMaterials, Manunet, ...) to set-up a unique test and innovation platform in the processing of fine materials.

For the **cold processing**, the wide set of tools for intensive mixing, pelletizing and agglomeration has been further upgraded and completed, notably with a ploughshare mixer and two pelletizing disks, allowing to produce the best suited agglomerates for a wide range of applications, as for example :

- The production of micro-pellets (< 1 mm) of convertor sludge that were specially designed for pneumatic injection in the cyclone of the HIsarna pilot plant in Tata Steel IJmuiden within the frame of the Reclamet EIT Raw Materials project.

Micro-pellets of convertor sludge

Mixing Drums Lab and pilot scale	**Vertical Intensive Mixers** 5 – 40 – 400 litres	**Ploughshare Mixer**	**Pelletizings disks** Ø 0.4 – 1 – 1.4 m
			
			
			

Mix preparation tools available at CRM

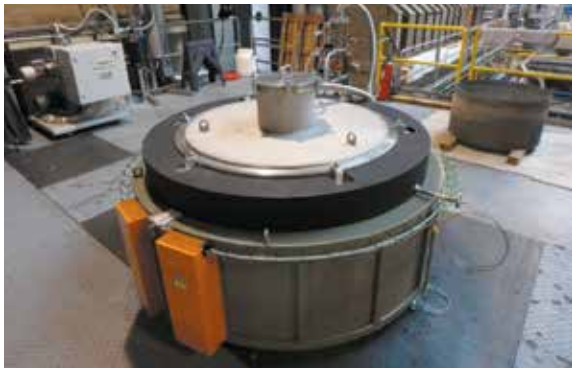
- The production of dual material pellets with a special outer layer to optimise the reactivity of the pellets.

Dual material pellets

- The assessment of different pre-processing and selective granulation strategies for the improvement of by-products recycling in the conventional sintering processing while improving the sinter quality and productivity and also reducing the emissions (RFCS SinByOse project).

- The agglomeration of by-products for recycling in foundries, in the frame of the EIT RawMaterials project CarSiFer, in partnership with Suez.

The **hot processing** platform has also been further expanded and includes now a complete set of extraordinary pilots: a Rotary Hearth Furnace, the so-called "pyrolysis platform" (presented later on) and a new thermal conditioning furnace. The latter is an exclusive pilot, designed by CRM in the frame of the 'Reverse Metallurgy' project, that allows the treatment of materials under controlled atmosphere

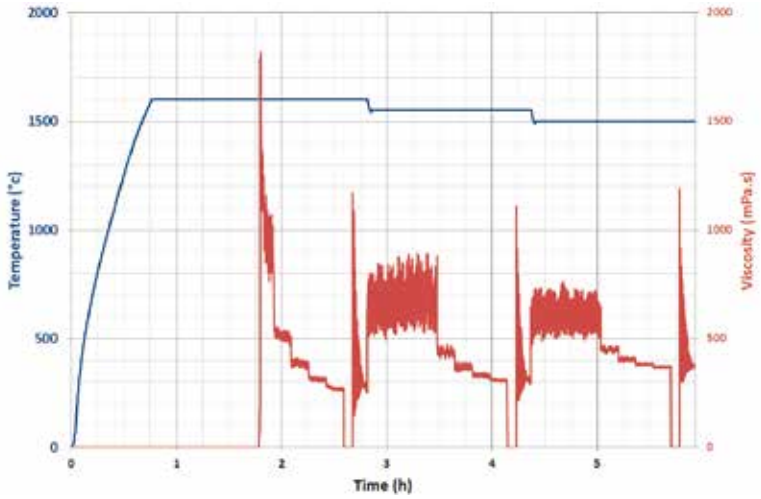


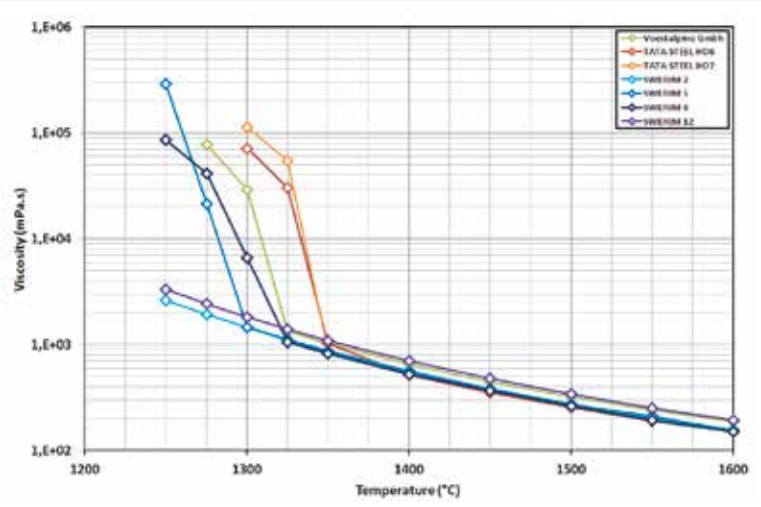
New thermal preconditioning furnace

or vacuum. With a volume capacity of 200l and its precise control of temperature up to 850°C, this furnace is designed for the processing of a large variety of materials such as zinc-coated scraps, electronic waste and hazardous materials.

The valorisation and re-use of **slags** is another key topic in the quest for sustainable metal production. For studying new slag processing routes, a good knowledge of the rheological properties is mandatory. Thanks to the unique high temperature rheometer available at CRM, the slag properties from liquid phase (up to 1650°C) down to solidified and cooled phase can be determined in a very accurate and efficient way for a wide viscosity range. As an example, blast furnace slag viscosity was recently successfully measured using this rheometer in the frame of the RFCS funded project 'OptiBlaFInS'. As a bad blast furnace (BF) hearth drainage results in increased energy consumption and operational instabilities, while also impacting the hot metal quality, as well as productivity and the life time of refractories, a better knowledge of the hearth inner conditions (a.o. slag fluidity) will allow significant operational improvements and related savings.

For the treatment of slag and other by-products coming from a variety of industrial sectors, CRM is finalising the design of a pilot DC plasma furnace. With a power of 700kW and volume capacity of 125l, this versatile furnace will allow slag treatment,





TOP: Blast furnace slag viscosity measurment (3 temperatures and 5 shear rates) - BOTTOM: Viscosity vs Temp

smelting reduction, fuming and melting of scrap and other waste materials with melting temperatures up to 1800°C.

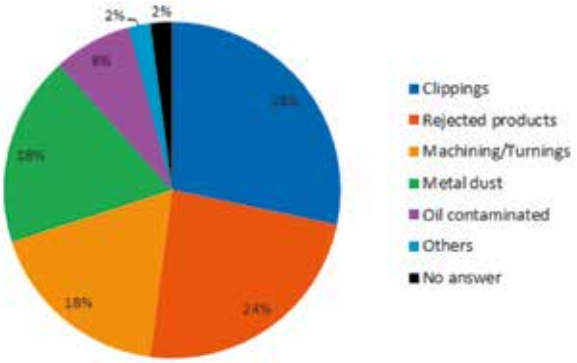
Metals are already seen as the most recycled and recyclable materials and are today massively collected and recycled into the material loop. However there's still room for further **improving the collection, sorting & recycling processes**, in particular by developing more selective and specific treatments in order to valorise at maximum

their value. Different studies are running at CRM to deal with those topics for various metals and applications:

- In the foundry sector, steel scrap is one of the most important raw materials for cast iron production. With the development of new high strength steels with better properties and addition of alloying elements, alloying elements and tramp elements in scrap will evolve with time. In the CORNET project SMARTSCRAP, funded by VLAIO (Flemish agency for entrepreneurship and innovation) CRM will identify those changes and analyse their impact, either harmful or beneficial, on standard mechanical properties of final cast iron parts.

- In the SIM-VLAIO project Cleanscrap, CRM in partnership with Clusta and Sirris work together with a great diversity of metal and steel processing companies, scrap processors & recycling parks to make the ferro-recycling landscape aware of the potential benefits of a smarter treatment and use of scrap. At the launch of the project a survey allowed to map specific scrap streams. Next steps will be to improve sorting & analysing techniques and to work on technology to pre-treat painted and coated scraps in order to minimise VOC and other emissions of volatile elements during recycling.

Which types of internal flows of ferrous scrap are present during your production precess?



Different types of ferrous waste produced during metal transformation processes

Al briquettes

- In the frame of the 'Reverse Metallurgy project' secondary aluminium waste from different sources have been collected. A first step in the innovative recycling & valorisation route concerns the compaction into briquettes with an accurate management of the proportion of different waste resources in order to manage the briquettes properties like density, shape, organic content

Al rotary tilting furnace

and chemical composition. In a second step, the briquettes are melted in a rotary tilting furnace where the purification of the Al is achieved thanks to the use of a protective salt-flux. The whole process, including the use of energy and the treatment of by-products, has been further optimised in order to minimise its environmental & climate impact. A complete pre-design of a plant operating according to this concept has been achieved during the year 2018 with the target to process 20 000 tons of aluminium wastes per year. The next step is the industrial implementation of the concept.

In order to respond to the need of highly skilled professionals with expertise in recycling of various types of materials, the EIT RawMaterials supports the Advanced Materials Innovative Recycling Master Program (AMIR). CRM contributes to this education program by taking in charge a significant part of the pyro-metallurgy course module, in cooperation with the University of Liège.

Training in the University of Liège in the frame of the AMIR initiative

The steel industry has a vital role to play in the EU's low carbon energy transition. In this perspective, the further **reduction of CO_2** emissions at sinter plants will be investigated in the RFCS funded project TACOS. Different solutions will be tested for CO_2 mitigation, like high bed heights operations, waste gas recirculation and alternative heat inputs, but also breakthrough solutions which could bring up to 50% reduction of solid fuel consumption. CRM's mathematical model of the sintering process will be combined with lab & pilot sintering trials and industrial measurement campaigns. In this context, the CRM mathematical model of sintering process is continuously improved to meet industrial needs. Last modification consisted in improving the simulation of air in-leaks at each stage of the process and in allowing the simulation of any waste gas recirculation lay-out. Concerning the industrial measuring campaigns, to easily ship all measuring tools to the industrial plant for an air in-leaks diagnosis, a boat container has been fully equipped with all necessary measuring tools.

Boat container fully equipped for on-site measuring campaigns.

To further pave the way towards a "Low Carbon Future" CRM participates to the generation of roadmaps that will state the further research needs, requirements, boundary conditions and timeline to implement CO_2-lean breakthrough technologies in the EU steel industry. The so-called LowCarbonFuture project is funded by the Research Fund for Coal and Steel.

Among the specific ways to reduce CO_2 emissions, CRM is particularly active in the **valorisation of waste biomass or other waste organic**

compounds (e.g. plastics) by their thermal conversion into valuable alternative energy sources suitable for the process industries. In 2018, many related activities were dealing with pyrolysis.

The versatile and extraordinary **pyrolysis platform** operated by CRM in collaboration with CMI is composed of several pilot plants. A multiple hearths furnace (MHF) of 36'' diameter, a batch furnace with rabbling arms (18'' diameter) and a rotary kiln (3.3 m long and 0.5 m inner diameter).

Pyrolysis platform : Batch MHF 36" furnace

The MHF and batch furnaces were relocated in ETP in 2016 and have meanwhile already been exploited for many different pilot trials.

These pilot trials are intended to demonstrate the feasibility and to identify the optimal operating conditions for the treatment of a targeted (primary or secondary) raw material, before application in an existing industrial plant or to define specifications for a new plant project. In 2018, the activities

Pyrolysis platform : Batch 18" furnace

concerned torrefaction of biomass and household waste, carbonisation and activation of peat or coal, carbonisation of wood residues, combustion of bio-sludge, but also some "non energy" applications like pre-reduction of metallic waste oxides, regeneration of spent catalysts and calcination of magnesium carbonate.

The revamping of the rotary kiln already started in 2017 was pursued in 2018 with the implementation a new natural gas line, an adjustable tilting structure and the design of the fumes exhaust and cooling pipe, the continuous feeding and unloading of the kiln as well as the cooling of the treated materials. The intended uses of the rotary kiln are mainly the pre-reduction of metallic oxides, the pyrolysis of wood and societal waste, and ore calcination.

Pyrolysis platform : rotary kiln

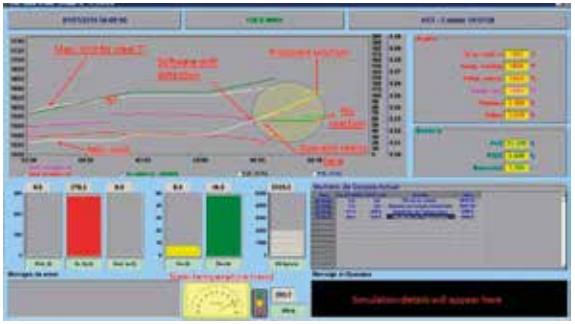
Industry 4.0 and digitalisation

Smart production and smart products

Industry 4.0 and digitalisation are rapidly finding their place in the production & manufacturing processes to improve process flexibility, reliability as well as product quality control. By coupling and combining its advanced modelling & simulation tools as well as measuring systems with data learning and complex communication protocols CRM's strategy is to develop solutions in line with the industry 4.0 concept.

CRM has been for many years active in the development of on-line models and sensors. The evolution of those tools towards smart and intelligent solutions has been realised and resulted already in some industrial applications of solutions fully in line with the industry 4.0 needs:

- The application of a **Digital Twin** by the implementation of CRM's dynamic model of the Electric Arc Furnace (EAF) in the control room of 4 furnaces for on-line simulation of the process at ArcelorMittal Lazaro de Cardenas. A guidance tool allows running in parallel additional simulations once a drift is detected during a heat in order to find and propose to the operators better process parameters.



Digital twin EAF

- The **smart monitoring** of the work roll degradation in the hot strip mill thanks to the development of a dedicated software for tablet technology. The evaluation tool has been implemented in the daily operation of ArcelorMittal Gent. Thanks to the full integration of the system in the mill network, all data is centrally stored and directly shared with the roll shop & quality management system following the new industry 4.0 trend. The application is also under implementation in the Tata Steel hot strip mill and direct strip rolling line and in other ArcelorMittal hot strip mills. A next generation of this smart evaluation tool is being further developed within the

Smart work roll surface evaluation under implementation at Tata Steel

European RFCS project Mastering work roll degradation II with for example the integration of an RFID chip for quick identification of the work rolls as well as the automatic image analysis of the pictures taken from the work roll surface.

The development of smart and integrated measurements continues, in line with the strategic plan, with a special focus on:

- The miniaturisation of the systems, the sensor fusion and the integration of micro-processors to acquire and to process data
- The use of wireless communication and energy harvesting adapted to industry for autonomous systems
- The adaptation and application of machine-learning to industrial processes

An example of on-going development in the field of **sensor fusion** is the combination of 3 innovative measurement systems for the instrumentation of blast furnace tuyeres: a high speed camera for following the coke particles, a camera for measuring the raceway depth together with a gas sensor developed in "SPARERIB", a RFCS funded project. The target is to support the operator in the blast furnace process control to reach lower coke rate and increased coal injection rate with maximum replacement ratio. The measurement tools have been designed for the tuyeres particularly severe environment and have been validated at lab and industrial scale to characterize raceway behaviour.

Blast furnace tuyeres instrumentation

Sensor fusion will be combined with the development of image pre-processing algorithms and statistical processing of data for fast transfer to the machine learning and sensor fusion algorithms for the in-line monitoring solutions that will be developed in the IQZeProd Cornet project supported by the Walloon region. Quality control is facing ever increasing challenges in the need for high quality control of complex and varying parts that are often, thanks to for example 3D-printing technologies, individualised in unique pieces. CRM will focus on

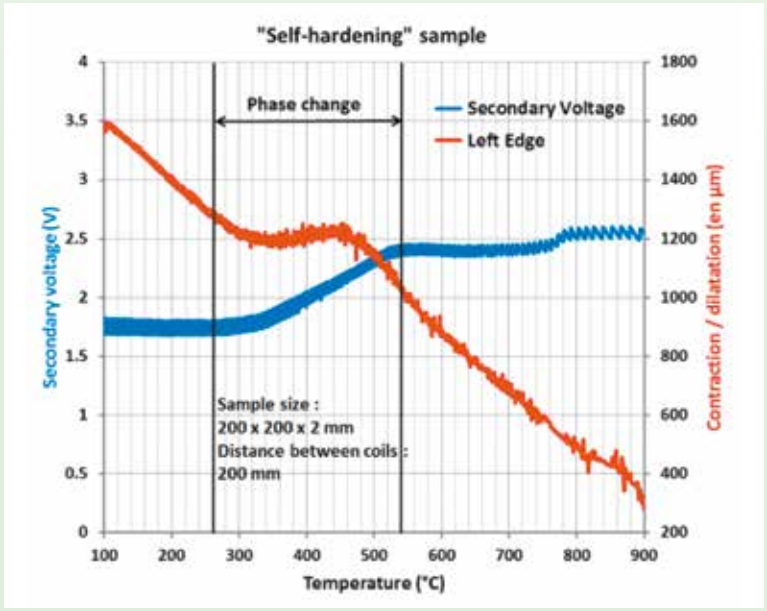
the quality monitoring of functional coatings on 3D printed parts by the combination of sensors like thermography for coating adherence, online non-contact roughness measurement, macroscopic camera inspection and on-line microscopy.

Miniaturisation has been integrated in the development of a low cost compact microscopic tool implemented at the galvanising line in order to collect surface characteristics at microscopic level. The new on-line microscope is 3 times more compact that the previous version and moreover, thanks to the use of micro-processors, the electrical control cabinet is more than 20 times smaller. The sensor has been tested in an industrial galvanising line and proved to be easy and quick to install, mechanically stable and able to grab high quality microscopic images of the Zn-coating at lines speeds of 3m/s.

On-line microscope to characterise the surface at microscopic level in galvanising lines

Surface aspects observed with the on-line microscope on GI products

With the production of new advanced high strengths steels, the accurate control of (residual) austenite fraction is of prime importance for the control of mechanical properties. For the on-line measurement of the austenite fraction in steel during annealing, a measurement concept based on magnetic measurement has been validated in lab. It has been confirmed that the sensor can follow the austenite fraction at elevated temperatures both above and below the Curie temperature, that it is robust and not sensitive to the distance between the sensor and the strip. The next phase consists in carrying out trials in industrial production line.



Correspondence between austenite evolutions measured with the lab prototype (blue curve) during natural cooling from 1000°C and the reference dilatation measurement (red curve)

Regarding **wireless communication**, it is important to develop systems adapted to the industrial requirements: namely the compatibility with metals and the large distances to be covered. Therefore in a pre-study a small electronic processor combined with LoRa circuit and antenna has been tested. The feasability to work at several km, in environments with metallic structures and coils, under a reduced electrical consumption has been demonstrated.

LORA: test of range vs signal intensity (red: low / green: high)

Smart systems, sensors and active functional surfaces become an integrated part of the internet of thinks (IoT). Today most of these printed devices are currently integrated on plastic foils, papers or textiles. Metallic substrates appear however promising alternatives because of their improved durability, moisture barrier and heat dissipation properties. In this field of innovative **printed electronics technologies** CRM has developed several new applications dedicated to organic and more generally flexible or conformable coatings on metallic substrates for the development of electronic devices such as:

- Solid state and surface lighting:
  OLED, Electroluminescent, LED-foils, …
- e-surfaces (NFC/RFID) for wireless communication
- Energy harvesting:
  Thermo-electric, piezoelectric…
- Flexible and stretchable printed circuit boards
- Printed sensors

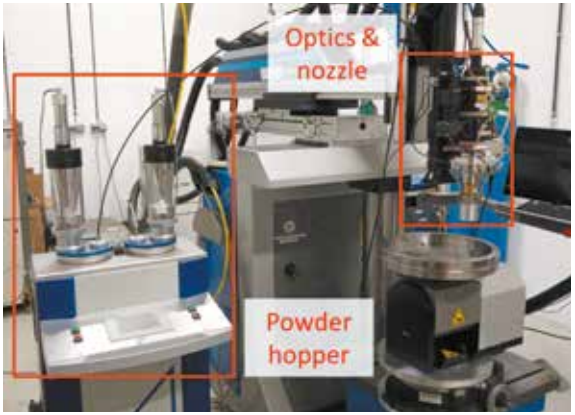
***1**- LEDs starlighted on printed circuit metal board*
***2** - Flexible hybrid printed circuit metal board*
***3** - Large scale electroluminescent panel display on steel*

Advanced and hybrid manufacturing

The new products of the future

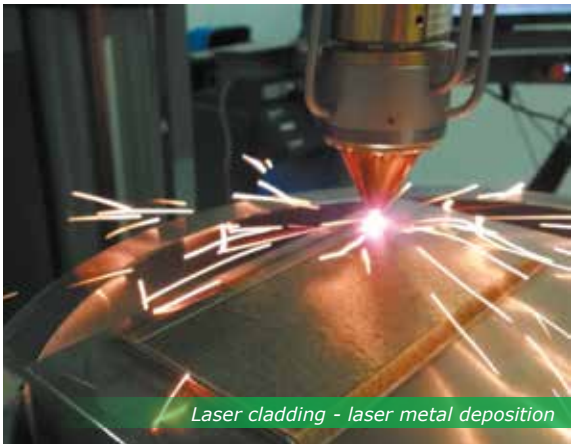
Additive manufacturing is steadily finding its place as new manufacturing technology and offers many opportunities for the metals industry for the production of parts with new functionalities. The technology should however not necessarily be considered as a substitute for conventional production and manufacturing technologies. It can, in particular for large parts, be combined with conventional subtractive or assembling technologies, in the so-called 'Hybrid Manufacturing' concept.

In order to respond to the expectations of the industry in this field and to further promote the industrial application of these advanced manufacturing technologies, CRM has combined its knowledge on metals, processing and surface treatment in a new transversal strategic technological platform named 'Advanced Manufacturing' and is continuing with the development of its remarkable **pilot facilities for manufacturing of as well as for the deposition of functional coatings on 3D parts**. In this frame several outstanding new equipment have been acquired:



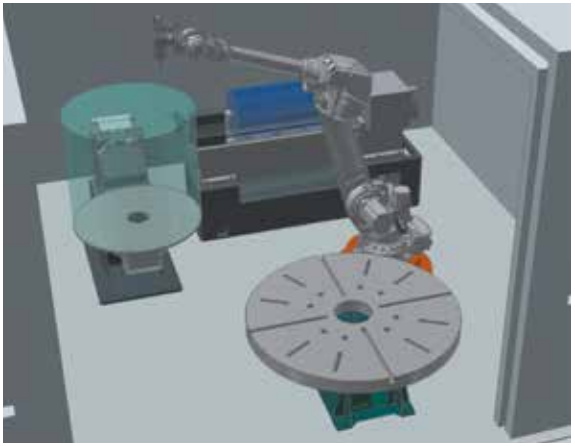
The 2kW laser cladding / laser metal deposition system

- A fully integrated laser cladding/laser metal deposition unit with a 2kW laser that can be used for the layer-by-layer building of parts, to coat surfaces, to repair parts or even for surface re-processing (eg re-melting). The system is further equipped with 2 powder hoppers allowing to work with 2 different materials simultaneously to create gradients in composition. The equipment has already been used to provide our industrial members, such as Westinghouse, with solutions to repair parts and to investigate the impact of process parameters on the properties of the printed parts.



Laser cladding - laser metal deposition

- A flexible multi-technique equipment for **direct metal deposition specially for large metallic parts**, acquired thanks to the support of the Walloon region in the frame of the IAWATHA EFRD project. The unique device combines three different building technologies operated by robots: the conventional Laser Metal Deposition with powder, the Wire Arc Additive Manufacturing and the Wire Laser Additive Manufacturing. Moreover, three handling systems are implemented allowing working on parts ranging from several kg up to 2 tons.



Flexible multi-technique equipment with laser cladding, wire arc additive manufacturing and wire laser metal depositions

- A remarkable **electrostatic spray system** mounted on a 6-axis robot arm and located in a dedicated paint cabin for the application of a large panel of liquid products, including organic (paint, varnish), hybrid and sol-gel products on complex parts up to around 1m³ and 100kg. The selected technology ensures a good coverage, control of homogeneity and a high spraying yield on 3D parts.

Paint cabin for applying liquid coatings on 3D parts

- An extraordinary **thermal spray** cabin equipped with a six axis robot arm on which three kind of torches can be mounted: a HVOF (High Velocity Oxy Fuel) gun using ethanol as fuel and two different plasma torches. This panel of tools allows the deposition of various thick coatings (typically 10-1000 µm) from powders, including metal carbides, alloys and ceramics. The cabin can receive parts up to one ton weight on a turning and tilting table.

www.enmieux.be
FEDER
Wallonie
LE FONDS EUROPÉEN DE DÉVELOPPEMENT RÉGIONAL ET LA WALLONIE INVESTISSENT DANS VOTRE AVENIR

Thermal spray booth for application of thick coatings on 3D parts

CRM also owns a vacuum heat treatment furnace that is particularly suited for the heat treatment of 3D-printed parts. The chamber can receive parts with effective dimensions of 400mm height and 400mm diameter. Heat treatments under vacuum (5.10-5mbar) or non-oxidising atmosphere can be performed up to 1600°C.

Heat treatment furnace

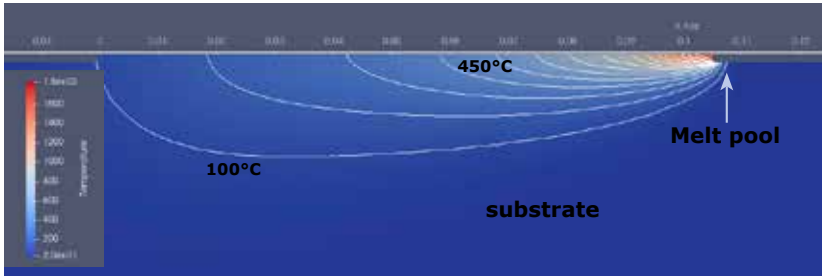
Another example of **hybrid manufacturing** is the combination of milling and friction stir welding (FSW). CRM participated in partnership with RWTH Aachen to a CORNET project financed by the Walloon Region aiming at supporting the implementation of FSW on milling machines, well known in industry, by the use of an empirical approach. Measurements on different FSW and milling machines were performed to compare their static and dynamic characteristics. Their influence on the FSW process was quantified. Several demonstrators have been realised to facilitate access to innovative assembling technology to the companies.

Friction Stir Welding on milling machines

The **additive manufacturing** as part of Key Enabling Technologies offers many opportunities, but still faces, in particular for metals many challenges related to the properties of deposited material, deformations, residual stresses and the surface finish state. With different **research activities** CRM supports its industrial partners in acquiring additional knowledge to address those challenges:

- The operational parameters and the strategy of deposition are crucial factors for good quality and properties, but their adjustment is quite complex and very expensive. **Numerical modelling** can help to predict the characteristics and to optimise the deposition strategy in order to decrease final cost and achieve 'first-time-right' production. The calculation of the thermal field is extensively used in the frame of the project lasercladding of work rolls in order to define the location of phase transformations and

appropriate location of pre- and post- heating. CRM in partnership with Open Engineering also started a CWality project financed by the Walloon region in this field for Al-alloys. The objective of this project is to develop a numerical model for the WAAM (Wire Arc Additive Manufacturing) technology applied to aluminium alloys.



Numerical modelling of laser metal deposition

- In order to further promote the use and application of 3D printing for industrial applications, CRM launched in partnership with BIL and SIRRIS a project called 'INSIDE Metal AM' supported by VLAIO and integrated in the SIM-cluster (Strategisch Initiatief Materialen). The project focusses on **3D printing** with high strength and stainless steels. CRM investigates the impact of process parameters for Laser Metal Deposition and WAAM. First trials have been performed with WAAM for the assessment of the impact of wire feeding speed and interpass time on wall thickness, surface state and properties.

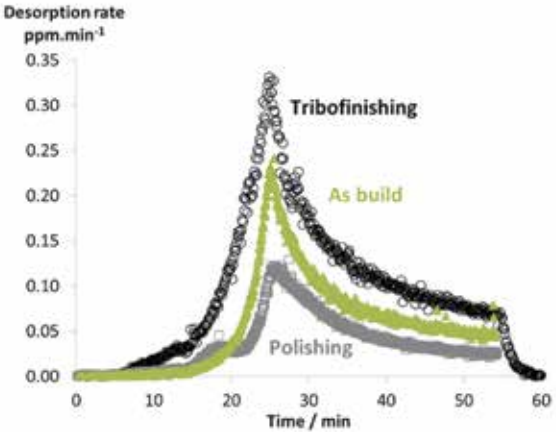
WAAM Samples

- Contamination of powders by or uptake during printing of elements like hydrogen and oxygen can have a detrimental effect on the final properties of the part. The quantification of the amounts present is thus of prime importance and therefore CRM has acquired thanks to the support of the EFRD funds in the frame of the IAWATHA project remarkable **analysis tools**, especially for the analysis of light elements. The ONH analyser allows quantification of Oxygen, Nitrogen and Hydrogen in most compounds. Excellent results have been obtained on samples in steel, Al and Ti, notably in the frame of the VAMETAM project. The CS analyser quantifies Carbon and Sulphur.

OHN analyser

www.enmieux.be
FEDER
Wallonie
LE FONDS EUROPÉEN DE DÉVELOPPEMENT RÉGIONAL ET LA WALLONIE INVESTISSENT DANS VOTRE AVENIR

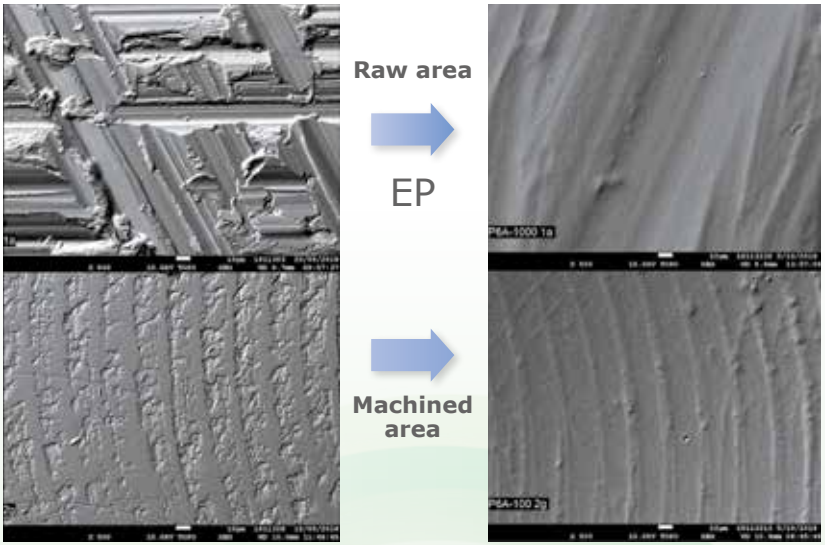
- The impact of H-uptake has been studied for 3D-printed AlSi-parts in collaboration with the Catholic University of Louvain. Aluminium alloys present a large hydrogen solubility in liquid stage while this solubility drops drastically in solid Al, leading to supposed hydrogen porosities. Thanks to thermal desorption analysis, developed by CRM initially for hydrogen studies on steel, the hydrogen in AlSi parts produced by SLM has been quantified and the importance of the surface finishing condition on the hydrogen content has been shown: after polishing the hydrogen content is lower than in the as-build part; the highest hydrogen content has been measured in parts after tribo-finishing.



Impact of surface finishing on hydrogen desorption curves of AlSi 3D-printed part

The **surface finishing of 3D parts** in general and of 3D parts produced by additive manufacturing in particular is a key point for producing parts with the required surface state and properties. In this domain CRM is looking to different technologies to reduce the roughness of such complex parts: tribo-finishing, electro-polishing and electro-plating.

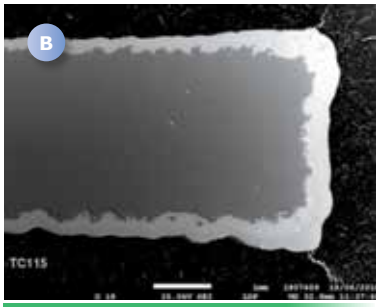
- Advanced electro-polishing techniques on both 2D- and 3D-components are studied with the support of the DGO6 and the CORNET program in the AdEPT project. A long term objective is the partial substitution of manual polishing by electro-polishing that could help to save significant labour time. Appropriate selection of the electrolyte and the electro-polishing parameters was already developed for the improvement of the surface quality of various tool steel grades. The understanding of electro-polishing mechanisms is under investigation in collaboration with UNamur.



Improvement of the surface quality by electro-polishing, respectively on raw and machined areas

Samples with varnish and ceramic coating applied after electropolishing

A - *INVAR surface of 3D-printed part before (left) and after application of a Ni-levelling coating (right)*



B - *Microscopic cross section illustrating the levelling effect of the Ni-layer*

- In the frame of the funded ERANET project TCAM the combination of different surface finishing techniques has been studied on additive manufactured metal parts, notably the combination of surface material removal techniques with the deposition of coatings in order to master both roughness and improved/ innovative surface functionalities. Titanium, Aluminium and Invar alloys have been studied and different surface functionalisation techniques (sol gel, electro-deposition and PVD) have been tested with success. It has, for example, been demonstrated on 3D-printed parts in INVAR that by combining electrochemical polishing, already providing a surface roughness of 2µm Ra, with a levelling Ni-coating applied by electroplating a roughness as low as 0.6µm can be obtained. A workshop was organized end of December to present the results of the project to a large panel of Additive Manufacturing & finishing companies.

- VICIA is another ERANET – Cornet research project, related to 3D coating but focuses more specifically on the **vacuum coatings** developments, like TiO2-coatings on 3D and complex shapes. The objective being to increase the knowledge and the understanding of thin film deposition in vacuum dry processes, such as magnetron sputtering, Plasma Assisted CVD or evaporation, and more particularly, vacuum thin film deposition on 3D complex parts.

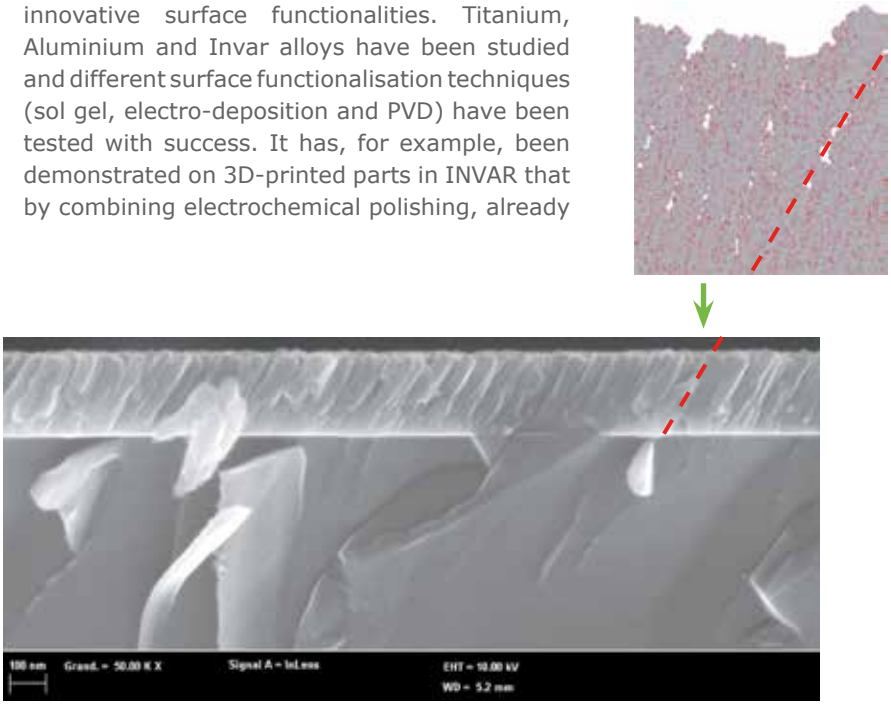


Illustration of the correlation between the simulated morphology of TiO_2 coating (top) and experimental observation by SEM (bottom).

From breakthrough process developments at lab scale to industrial implementations

Turning applied research into value creation

CRM has a proven track record since many years in developing new process solutions for the metals industry aiming at increasing resources, energy & production efficiency, at reduction of cost & maintenance and improving products & their quality. Our unique and remarkable pilot lines are key in transferring the solution from lab to the industrial reality.

As main realisations and **industrial success stories** in the steel industry field one can mention:

- The 100th industrial implementation of the Tempcore™ process, an in-line quench and self-tempering process for the production of high quality concrete reinforced bars (so called rebars). Thanks to the use of this industrially proven technology of controlled cooling at the exit of the rolling line, costly alloying elements can be saved while producing high quality products. Over the years more than 68 Tempcore installations have been designed and commissioned by CRM all over the world and another 32 companies have received the agreement to use the Tempcore™ Trademark after having succeeded a detailed technical audit, carried out by CRM, of their operations and products.

TempCore™

Industrial implementation of Tempcore™ technology

- The High Turbulence Roll Cooling technology, called HTRC, is now implemented in 10 rolling stands of high productive hot strip mills all over the world inside ArcelorMittal and full-scale production trials are running in stand 2 of the hot strip mill nr 2 of Tata Steel IJmuiden. Thanks to the integration of this breakthrough roll cooling technology developed at CRM, the mills have a highly efficient and homogeneous cooling of the work rolls of the hot strip mill resulting in strongly improved work roll performance. The second major benefit of the technology

Industrial WPC header with width adaptable cooling

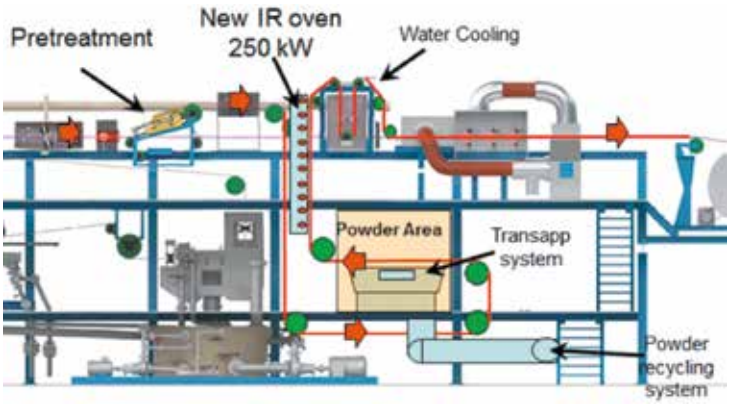
is the great potential in energy savings (up to 90%) thanks to the fact that the HTRC technology operates at low pressure and coolant flow.

- The development of the next generation of WPC (Water Pillow Cushion) intensive interstand cooling for cold rolling. Let's first recall that 2 intensive cooling headers are already successfully in operation in the tin plate mill of Tata Steel to cool the strip between the stands on the bottom side only. Thanks to the efficient and homogeneous cooling the rolling speed can be increased, the appearance of heat related strip defects is reduced and a decrease in rolling force is achieved. A next generation of the cooling technology has now been developed and is characterised by an innovative flow control concept that has been integrated to control the flow over the width. The industrial prototype has been successfully validated at the CRM lab and industrial implementation at Tata Steel will be performed beginning 2019.

The possibility to **upscale technologies by** transferring them to **pilot process lines** can be further illustrated by:

- The successful demonstration at the Continuous Advanced Surface Treatment Line (CASTL) of a new concept for continuous powder coating. Indeed, current powder coating technologies are not compatible with continuous processes due to long curing times. Thanks to the fruitful collaboration with the Fraunhofer partners in the SIMOPOLI project (funded by the Walloon region in the European CORNET program), a new technology of powder application combined with special infrared emitters for fast thermal treatment and specially tuned powder for fast curing has been successfully transferred from prototype scale to a demonstrator line on CASTL. Metallic coils (with 250mm) were successfully pre-treated, powder coated, cured and coiled. The parts formed with those strips showed a perfect final surface quality, even better than the

New continuous powder coating process tested at CASTL line

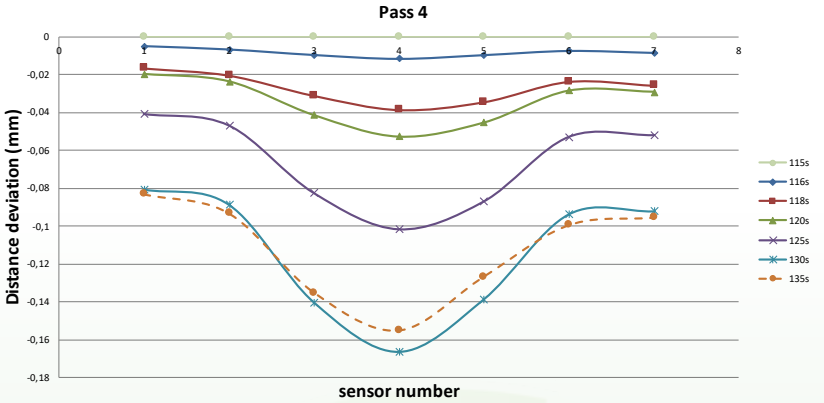


conventional batch post painted parts. In order to further increase the line speeds up to 60m/min while keeping a high coating quality a new project 'High Speed Coating Line' has been launched in partnership with Fraunhofer IPA.

- In view of the development of an alternative coating to substitute the harmful CrVI-plating of work rolls for cold rolling, CRM works on a solution that consists of the application of a 'Cermet' type coating by means of electroplating. The upscaling from small samples at lab scale up to pilot rolls has taken place. A new electroplating module, specially dedicated for 3D parts with diameter up to 150mm and height up to 1m has been designed and implemented on the CASTL line. Pilot-size rolling mill rolls have been successfully electro-plated.

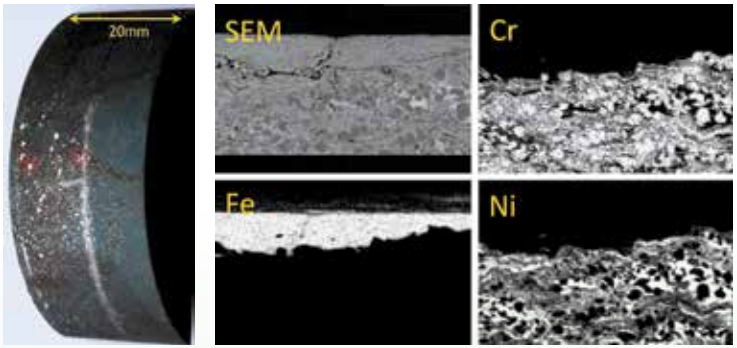
- In the field of rolling it is known that the work roll profile has a major influence on steering and flatness during rolling and that it can vary in time, so the knowledge of the evolution of the work roll profile is of high interest for the mill operators. A first roll profiler system has been developed by CRM and has proven its industrial reliability in the plate mill application in ArcelorMittal Industeel Belgium. For hot and cold strip mills however an additional difficulty has to be tackled as the measurement has to be performed during rolling operations. A high speed simultaneous acquisition system has been integrated in the design and tests have been performed on the continuous cold rolling pilot line of Tata Steel. Detailed analysis of the trial demonstrated the aptitude of the sensor for measurement during rolling.

The new electroplating module installed on CASTL pilot line and dedicated to 3D objects



Roll profile measurement during rolling operations

- In the field of annealing & galvanising, furnace rolls are critical components for the continuous lines: on the one hand their service life has a direct impact on maintenance and thus productivity; on the other hand their surface state (possible pick-up or scaling) can have heavy consequences on the quality of the final product. Simulations on a dedicated friction simulator at CRM supported the understanding of pick-up of oxides and iron fines on the coating of the rolls in the annealing furnace in the European RFCS project NoStickRoll. It has been shown that at temperatures around 500°C, typically after the rapid cooling section,



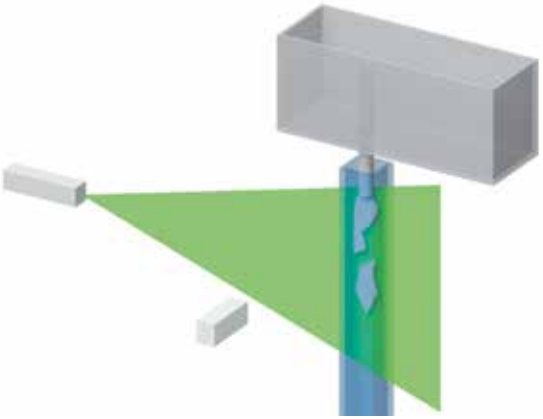
Cr_3C_2/Ni coated roll showing Fe pick-up after 3 days of friction and associated cross section and SEM mapping.

the pick-up mainly concerns iron, even if silicon-oxide pick-up can also be observed during the production of electrical steels.

Pilot lines are key elements in our developments of new process solutions as well as for the product development. CRM operates unique and remarkable pilot lines like Rotary hearth furnace, continuous casting, hot rolling, annealing & hot dip galvanising lines and different coating & surface treatment lines such as for organic coating, vacuum deposition, electro galvanising. In order to continue to respond to the needs of our customers and partners CRM continued to revamp and extend its pilot line capabilities.

- The unique pilot vertical continuous casting simulator - able to cast 3.9m of product of different sections - has been revamped concerning automation and control systems and water supply of the secondary cooling. New handling tools to facilitate and secure the job of the operators have also been integrated. The pilot line is a powerful and very flexible tool to develop new technologies as well as new products in the frame of continuous cast steel.

- The casting water model facilities at CRM have been equipped with a remarkable powerful laser system allowing the measurement of concentration and temperature in different sections. The sophisticated measurement system based on laser-induced fluorescence (LIF) and Particle Image Velocimetry (PIV) can help significantly to develop or optimise new processes including fluid dynamics, in particular for mould flow pattern in the continuous casting process.



The LIF implemented on the water model

- To evaluate new pickling or rinsing technologies as well as new pickling liquors or additives, CRM and De leuze jointly developed an extraordinary new pickling simulator, called 'Picklean', able to simulate spray and dip pickling as well as rinsing. The finalisation of the rig will enable to simulate industrial conditions to reproduce pickling and rinsing on test panels up to 300 x 200 mm².

Pickling simulator

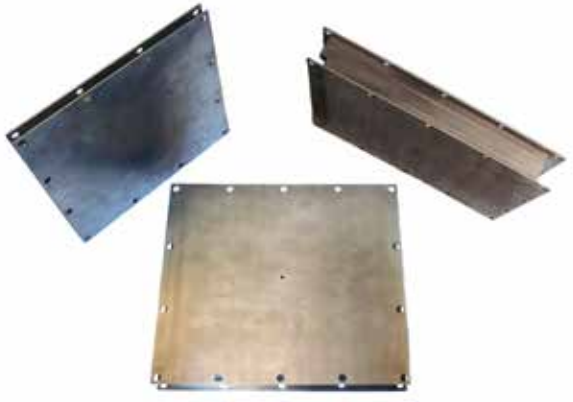
New products & solutions

And their dissemination to industry & regional economy

With its deep knowledge and years of experience in metallurgy, material science and application of metals, CRM supports large, medium and small industrial companies, who are active in various sectors like metals industry, manufacturing, construction, aeronautics and aerospace. CRM's supports goes from advice related to material choice and technical assistance over the development of new products, up to the development and design of complete solutions.

As independent and collective research centre, certified ISO9001 and ISO17025, CRM offers to members and non-members the access to a unique set of characterisation and testing equipment and its acquired knowledge. The dissemination of this know-how and the promotion and application of its own solutions are also part of its mission.

Based on previous developments of CRM in European Space Agency (ESA) projects, CRM has been selected by the HEXAFLY (High Speed Experimental Fly Vehicles) consortium to provide **heat storage devices (HSD) based on Phase Change Materials (PCM).** The specially designed heat storage devices will ensure the thermal stability of the electronics in the rocket developed by the consortium.



Heat storage devices based on PCM

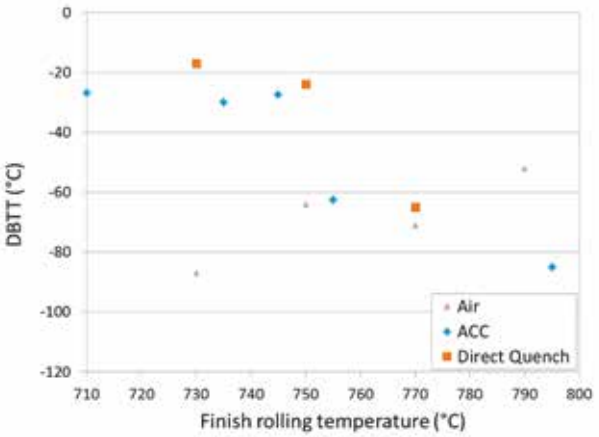
In the frame of another project, sponsored by ESA, CRM accomplished together with the Walopt company the design, assembly and testing of a **low cost solar concentrator for satellite solar arrays**. The system is based on a disruptive and patented ESA technology. Prototypes have been assembled and tests showed that the system allows reaching homogeneous reflection patterns which in turn improve the efficiency of the solar array by 80%.

A *Solar Concentrator Prototype after assembly* - **B** *Laboratory light reflection trial* - **C** *Result of light reflection trial*
D *Result of image analysis of the laboratory light reflection trial.*

Fuel cells are gaining more and more importance, their main disadvantage however remains their cost and their life time. In the INOXYPEM project, part of the EFRD portfolio 'Film Multi-Fonctionnels', CRM and the project partners are developing an alternative for an essential part of the fuel cells namely the bipolar plate, today produced in graphite. By developing innovative metal-based bipolar plates treated with specific coatings by PVD technology - that combine low interfacial contact resistance (ICR) with high corrosion resistance in the severe environment of the fuel cell - the cost and lifetime of the fuel cell can be improved. Specific testing methods are also developed, in particular for ICR and corrosion measurements. For the manufacturing of the new designed channels for bipolar plates, CRM is also being acquiring a hydroforming equipment working at high pressure. The equipment is complementary to other metal forming unique equipment of the CRM group and will allow combining very high mechanical deformation with precision in forming.

Hydrogen permeation through a membrane is a key technique to characterise hydrogen diffusion and solubility in materials. However conventional electrochemical permeation is not always representative of the industrial reality. Indeed, hydrogen uptake in materials often occurs at high temperature during manufacture and forming operations. Furthermore, gaseous sources of hydrogen are often responsible for the hydrogen uptake. Gaseous permeation therefore appears as an interesting solution. In this aim, CRM is currently developing a set-up for **hot gaseous permeation**. This set-up aims at analysing hydrogen diffusion in various metals at temperatures up to 900°C.

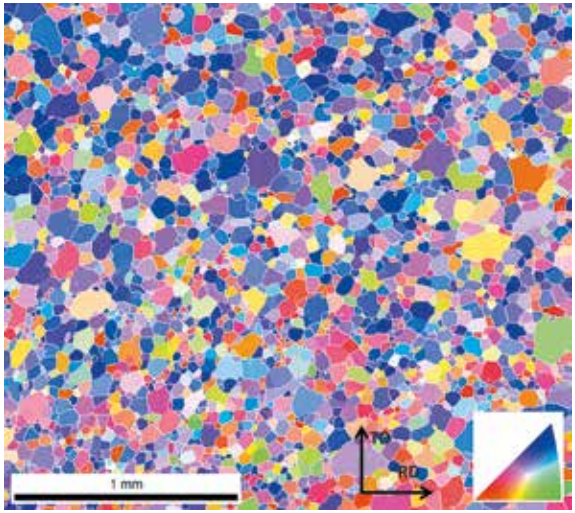
In the product development field, the achievement of a good strength-toughness balance is particularly challenging for the higher strength plates in heavy gauges since they are rolled partly in the intercritical region. In the European funded RFCS project INCROHSS the impact of the process parameters on the strength-toughness balance has been investigated. The detrimental effect of rolling in the ferrite region on ductile-brittle transition



Impact of finish rolling temperature on ductile brittle transition temperature of high strength plates

temperature is confirmed and linked to the absence of recrystallisation.

The use of **electrical steels in soft magnetic circuits**, made of stacks of electrical steel sheets separated by an insulating layer, are becoming crucial in almost all industrial sectors, as they are key elements in the industrial electrical machines. In the H2020 project ESSIAL, CRM contributes to the improvement of the performance and functionalities of laminated circuits by the use of laser surface texturing. CRM produces in the project both non-oriented and grain oriented FeSi electrical steels, provides its metallurgical knowledge, in particular in terms of texture characterisation and will apply the required coating to allow to investigate the impact of laser scribing both before and after the final coating process.



EBSD of FeSi steels

In the market of vehicle restraint systems, CRM develops **innovative solutions for road safety barriers**. CRM helps its customers in the optimisation and design of the most competitive devices relying on:

- A profound expertise of the requirements to guarantee safer roads and its active involvement in several standardisation and technical committees
- The deep knowledge of steel and its properties allowing the selection of the best suited high performance steels
- Know-how in mechanical testing and material characterisation
- A huge expertise in virtual testing with particular attention to crash dynamics. Numerical simulations allowing reproducing in detail the phenomena of crash in all their complexity

Numerical simulation of crash test for safety barrier design

For the dissemination of its results and to promote its developments, CRM has participated to different events, seminars, congresses, workshops and fairs.

On September 14th, 2018, Willy Borsus, Minister-President of the Walloon Region, and Pierre-Yves Jeholet, Vice-President and Minister of Economy, Industry, Research, Innovation, Digitalisation, Employment and Education visited CRM. At this

Visit of Ministers Borsus and Jeholet

occasion they have discovered the CRM's recent developments in the domains recycling & circular economy, 3D-metallic printing, industry 4.0 and the activities related to the photovoltaic steel panels and construction.

CRM also actively participated to seminars and workshops such as:

- An information session on 3D-printing with metallic materials on the 'Flam3D-SIM Metaal info avond' on February 19th, 2018
- A thematic day in collaboration with Promosurf on March 1st, 2018 on 'Poudrage en continu ? Oui, ça existe !" organised at CRM
- The participation to the event 'Revêtements innovants wallons : quels bénéfices pour votre entreprise ?' on the EFDR portfolio "Films Multi-Fonctionnels" (FMF) organised by Réseau LIEU on April 24th in Liège
- The 'Materials Market' on the SIM User Forum in Gent where the activities related to additive manufacturing and recycling has been presented on May 17, 2018
- The "Indentation 2018" symposium organised by CRM, ULiège, UMons and UCL on September 11-14, 2018 in Liège
- The co-organisation of a thematic day together with VOM on 'The surface finishing of metallic or plastic parts produced by additive techniques' on December 6th, 2018 in Liège

Since several decades, CRM is actively participating to associations, organisations and networking aiming at exchanging, sharing experience and looking for synergies at the national and international level where its expertise and competence in the field of manufacturing and processing of metallic materials are largely recognised.

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

UCRC (Union of Collective Research Centres): The association representing at the Federal level the Belgian collective research organisations.

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.

CReSus (Centre for Resource Efficiency and Sustainability): A common initiative of CRM and ULiège/GeMMe aiming to strengthen collaborations at regional level as well as in the European initiatives such as Horizon 2020 and EIT/KIC on (primary and secondary) raw materials.

MATERIALS RESEARCH CLUSTER GENT

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/

In the frame of EIT Raw Materials, a **European Pilot Plant Network for Extractive Metallurgy and Mineral Processing (Metnet)** has been created, offering to customers an access to pilot plants in order to bring ideas or concepts into industrial use. Besides CRM, the current members are Swerea MEFOS (Sweden), BRGM, CEA & ERAMET (France), GTK (Finland), ELKEM (Norway), IMN (Poland) and MPI (UK). More info : www.metnet.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.

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*

Award, publications & Conferences 2018

AWARD

2018 AIST Hunt-Kelly Outstanding Paper Award
Second Place for our paper entitled "Development of Tailored Roll Grade Materials for the Early Stands of Finishing Hot Mills." This award recognizes, through peer review, the active leadership and significant contributions of individuals or companies to the Association of Iron & Steel Technology (AIST) and the global iron and steel industry.

CONFERENCES 2018

B. Vanderheyden, C. Marique
Metal & Steel Industry: Key players of the circular economy. The European perspectives
Asia Steel International Conference 2018, Bhubaneswar, 6-9 February 2018

I. Tolleneer
Technieken om slijpstof te valoriseren, Agoria-workshop Workshop: Afval van verspaanprocessen en circulaire economie, een verstandshuwelijk?
Berchem, May 8th, 2018

V. Tusset, C. Marique, B. Vanderheyden
Process control of metallurgical routes adapted to new raw materials, metallic wastes & recycled end of life products
ICASI 2018 & CCATM 2018 International Conference & Exhibition on Analysis & Testing of Metallurgical Process & Materials, Beijing, 16-18 October 2018

J. Borlée
Carbon direct avoidance (CDA) via electricity and industrial clusters
EU Industry Day, EUROFER workshop "European steel industry main pathways towards the smart, low carbon industry of the future", Brussels,Belgium, 22-23 February 2018

J.-C. Pierret
Low Carbon Future Steel Industry – Process Integration pathway
Thematic workshop LowCarbonFuture @IndTech2018, Vienna, 29 October 2018

J.-C. Pierret
CRM EAF model development, enrichment and industrial implementations
3rd European Academic Symposium on EAF Steelmaking – EASES 2018, RWTH Aachen, 29-30 May 2018

B. Kleimt, R. S. Nick, M. De Santis, J.-C. Pierret, M. Jemson
EU supported research projects on secondary metallurgy technology with focus on on-line measurement and control - Evaluation of results and outlook to future developments
8th European Oxygen Steelmaking Conference, Taranto, 10-12 October 2018

D. Espinosa, G. Moreas, J. Malbrancke, H. Uijtdebroeks
New promising actuators to control the cracking behaviour of scale during hot rolling, including enhanced evaluation technologies
European Oxide Scale Conference (OXI 2018), London, 11 Dec 2018 - 12 Dec 2018

M. Caruso, U. Lorenz, T. Nguyen Minh, P. Uranga
Impact of intercritical rolling on the strength/toughness balance in heavy gauge structural steel plates
Thermec 2018, International Conference on Processing & Manufacturing of Advanced Materials, Paris – FRANCE, 8-13 July 2018

M. Caruso, U. Lorenz, T. Nguyen Minh, P. Uranga, U. Mayo, N. Isasti, R. Petrov
Key note lecture, Intercritical rolling of heavy-gauge structural plates: which compromise between strength and toughness?
Materials Science and Engineering (MSE) Congress, Darmstadt, Germany 2018, 26-8 September 2018

T. Nguyen-Minh, M. Caruso, U. Lorenz, J. Sietsma, R. Petrov
Texture evolutions in heavy gauge steel plates after inter-critical rolling at high temperatures
Materials Science and Engineering (MSE) Congress, Darmstadt, Germany, 2018, 26-28 September 2018

P. Hernaut, D. Ertzibengoa, B.C. De Cooman, A. Lebedev, G. Wierink, J. Gawad, M. Caruso, I. Tolleneer
Development of High Performance Steel Plates at NLMK Clabecq,
2nd International Symposium on the Recent Developments in Plate Steels Memphis, TN, USA, 3–6 June 2018

JF. Noville, J. Borlée, Ph. Harlet
Production and Use of Quenched & Self-Tempered (QST) Rebars
- *Department of Trade & Industry (DTI) of Philippines, Makati City – Nov. 6, 2018*
- *Association of Structural Engineers of the Philippines (ASEP), Metro Manila – Nov. 6, 2018*
- *Institute of Civil Engineering, UP Diliman, University of Manila, Philippines - Nov. 7, 2018*
- *PhilConstruct Trade Expo's – Techno Forum on Building Materials, SMX Convention Center, Pasay City, Philippines – Nov. 9, 2018*

M. Caruso, P. Huyghe, J.-L. Collet
In-situ investigation of austenite stabilization during quench and partitioning process and its mechanical stability during tensile testing
User-dedicated Microsymposium (UDM2), EPN Science Campus, Grenoble, 5-7 February, 2018

M. Mandy, C. Georges, T. Sturel, P. Drillet, P. Jacques
On the use of deuterium to characterize hydrogen uptake mechanisms in 22MnB5 bare steel
International conference on Metals and Hydrogen, SteelyHydrogen2018, 29-31 May 2018, Ghent

B. Nabi, C. Georges
Development of hydrogen characterization techniques for titanium alloys used in aerospace applications
International conference on Metals and Hydrogen, SteelyHydrogen2018, 29-31 May 2018, Ghent

O. Hubert, C. Georges, S. Cobo and P.J. Jacques
The influence of diffusible hydrogen on the mechanical behavior of advanced high strength steels with a bainitic-martensitic matrix exhibiting a TRIP effect
International conference on Metals and Hydrogen, SteelyHydrogen2018, 29-31 May 2018, Ghent

C. Georges, P. Delroisse, A. Simar, P.J. Jacques
Critical assessment of the hydrogen uptake during the powder-bed laser 3D-printing of Al-Si grade
Thermec 2018, International Conference on Processing & Manufacturing of Advanced Materials, Paris – FRANCE, 8-13 July 2018

C. Plancq, L. Bordignon, G. Monfort, G. Moreas, V. Tusset, X. Vanden Eynde
Control of galvanizing process using oxidation thickness measurement inside furnace
European Oxide Scale Conference (OXI 2018), London, 11-12 December 2018

J.-F. Van Humbeeck, D. Mercier, C. Le Pen, S. Hertel, A. Jobke
Smoothing of metallic thin films using advanced electropolishing technologies
Chemnitzer Seminar 2018

J.-F. Vanhumbeeck, D. Mercier
Mechanical characterization of electrodeposited metallic and cermet coatings by indentation and scratch experiments
Indentation 2018 Conference, Liège, 11-14 September 2018

P. Drobny, D. Mercier, V. Koula, L. Caplovic
Hard coatings characterisation using nanoindentation and acoustic emission
Indentation 2018 Conference, Liège, 11-14 September 2018

N. Nutal, J.P. Colette, F. Duminica, C. Georges, S. Le Craz, J. Magnien, C. Masse, L. Robert, J.-F. Vanhumbeeck, L. Pambaguian
Post processing of metal parts made by additive manufacturing
Metal Additive Manufacturing Conference, Vienna, 2018

N. Nutal, D. Mercier, N. Jimenez Mena
Bulk characterization of Invar 36 made by selective laser melting
Indentation 2018 Conference, Liège, 11-14 September 2018

P. Jacques, P. Delroisse, A. Simar, C. Georges
Critical assessment of the hydrogen uptake during the powder-bed laser 3D-printing of Al-Si grade
International conference on Metals and Hydrogen, SteelyHydrogen2018, 29-31 May 2018, Ghent

P. Jacques, C. van der Rest, M. Marteleur, P. Delroisse, A. Simar, C. Georges
Critical assessment of the hydrogen uptake during the powder-bed laser 3D-printing of Al-Si grade
Workshop additive Manufacturing, ULiège, Liège, 2018

N. Nutal, D. Mercier, N. Jimenez, J.-F. Van Humbeeck, C. Georges
Bulk characterization and surface processing of Invar 36 made by selective laser melting
Workshop additive Manufacturing, ULiège, Liège, 2018

D. Mercier, S. Flament, G. Walmag, G. Esser, X. Vanden Eynde, M. Sinnaeve, M. Caruso
Mechanical properties mapping of cast bimetallic work roll shell material by nanoindentation
Beware Fellowships program

D. Mercier, T. Pardoen
Indentation and fracture
Indentation 2018 Conference, Liège, 11-14 September 2018

S. Reuter, C. Georges, P. Jacques
Optimisation of the corrosion rate of iron-based alloys for bioresorbable stent applications by surface acidification
Eurocorr 2018, 9-13 September 2018, ICE Krakow, Poland

A. Lafort, L. Fourdrinier, E. Volon, C. Kempeneers
Thin film solar modules (CIGS technology) on insulated steel substrate in R2R production for their integration into roofing elements
16th International Conference on Plasma Surface Engineering, 17-21 September 2018, Garmisch-Partenkirchen Germany

A. Daniel, F. Duminica, S. Lucas
Optimisation of PVD and PECVD thin film deposition on 3D objects
16th International Conference on Plasma Surface Engineering, 17-21 September 2018, Garmisch-Partenkirchen Germany

F. Duminica, B. Gilbert, L. Libralesso, R. Belchi
AlxMn1-x coatings elaborated by PVD as alternative to cadmium for steel corrosion protection
16th International Conference on Plasma Surface Engineering, 17-21 September 2018, Garmisch-Partenkirchen Germany

R.Harzallah, M. Larnicol, C. Leclercq, A. Herbein, F. Campana
Development of high performances Solar Absorber Coatings
SolarPaces2018, Maroc, 02-05 October 2018

M. Gremling, R. Clausius
V&V results of new ArcelorMittal MASH TL-5 Steel Median Barrier
Transportation Research Board, Washington DC, USA, January 8th, 2018

V. Huet, G. Sebastian, D. Bridoux
Ondatherm® Deck: an optimized system that combines industrialized waterproof roofing with high thermal performance insulation in one prefabricated solution
ICAE 2018

C. Cofano
Dispositifs routiers de retenue: quelles nouveautés ? Durabilité des dispositifs de retenue en acier
Session de formation et d'information CRR, Janvier 2018, Namur

I. Tolleneer, C. Cofano
Afschermende constructies voor wegen: wat is er nieuw? - Duurzaamheid van metalen geleideconstructies
Session de formation et d'information CRR, Janvier 2018, Gand

PUBLICATIONS 2018

C. Kech, A. Galloy, C. Frippiat, A. Piel, D. Garot
Optimization of direct liquid-liquid extraction of lipids from wet urban sewage sludge for biodiesel production
Fuel Processing Technology 212, January 2018; pp. 132–139

M. Baniasadi, B. Peters, J.-C. Pierret, B. Vanderheyden, O. Ansseau
Experimental and Numerical Investigation into the Softening Behavior of a Packed Bed of Iron Ore Pellets
Powder Technology 339 (August 2018); pp. 863–871

S. Flament, G. Walmag, O. Lemaire, M. Sinnaeve
Development of a New Grade for Rear Finishing Stands Based on Modeling and Evaluation of Specific Degradations
Iron & Steel Technology, January 2018

G. Walmag
CRM Group: un centre de développement de solution utilisant le rechargement par laser - CRM : Een centrum voor de ontwikkeling van uw oplossing met toepassing van lasercladding
VOM Magazine maart 2018

P. Huyghe, M. Caruso, J.-L. Collet, S. Dépinoy, S. Godet
Into the quenching and partitioning of a 0.2C steel: An in-situ synchrotron study
Materials Science & Engineering A 743 (2019) 175–184

P. Huyghe, S. Depinoy, M. Caruso, D. Mercier, C. Georges, L. Malet, S. Godet
On the Effect of Q&P Processing on the Stretch-flange-formability of 0.2C Ultra-high Strength Steel Sheets
ISIJ International, June 2018

M. Mandy, C. Georges, T. Sturel, P. Drillet, P.J. Jacques
On the analysis of the simultaneous uptake and desorption of different isotopes of gaseous hydrogen by advanced high strength steels
Scripta Materialia 161 (2019) 84–87

D. Mercier, J.-F. Vanhumbeeck, M. Caruso, X. Vanden Eynde, M. Febvre
Microstructural and mechanical characterization of electroplated nickel matrix composite coatings
Surface Engineering, 2018

F. Duminica, R. Belchi, L. Libralesso, D. Mercier
Investigation of Cr(N)/DLC multilayer coatings elaborated by PVD for high wear resistance and low friction applications
Surface and Coatings Technology, March 2018

S. Kossman, A. Iost, D. Chicot, D. Mercier, I. Serrano-Munoz, F. Roudet, P. Dufrenoy, V. Magnier, A.-L. Cristol
Mechanical characterization by multiscale instrumented indentation of highly heterogeneous materials for braking applications
J Mater Sci

N. Nutal, S. Le Craz, J-F Vanhumbeeck, F. Duminica, C. Archambeau
Oppervlakte afwerking van stukken geproduceerd via additive manufacturing, Finition de surface des pièces issues de l'additive manufacturing
VOM magazine augustus 2018


CRM GROUP

CRM GROUP

- **AC&CS Sart-Tilman** > *Liège*
  Advanced Coatings & Construction Solutions
- **AC&CS Ivoz-Ramet** > *Flémalle*
  Advanced Coatings & Construction Solutions
- **CEWAC** > *Liège*
- **CRM Gent** > *Zwijnaarde*
  Centrum voor Research in Metallurgie
- **CRM Sart-Tilman** > *Liège*
  Centre de Recherches Métallurgiques
- **EcoTechnoPôle** > *Liège*
  ETP
- **PiMW Sart-Tilman** > *Liège*
  Pôle d'Ingénierie des Matériaux de Wallonie






T +32 (0)4 254 62 11
F +32 (0)4 254 64 64
info@crmgroup.be

www.crmgroup.be