CRM GROUP

Annual Report | 2015

Production

Recycling Applications

CLOSING THE VALUE CHAIN OF METALS

D/2015/0124/1

Contents

Foreword

CRM Group provides R&D, technology and innovation solutions in the field of metal production and recycling, transformation, coatings and surface functionalisation, development of new products, applications and construction solutions, process engineering solutions and renewable energy production. Closing the gap between science and market, turning inventions into products and value creation are the main missions of CRM Group.

In 2015 the total income of CRM Group reached 35.7 Mio EUR with 244 people. Activities are jointly supported by the steel industry (through the 2 active members ArcelorMittal and Tata Steel) and by 43 industrial members. 75% of the activities are financed by the steel industry. CRM Group is also supported by the Walloon Government for the development of activities and innovation in the field of circular economy, recycling, valorisation of by-products, energy and manufacturing.

Health and safety remains our first priority. Thanks to training, internal and external audits, combined with daily presence of management on the floor, meaningful progress has been achieved in safety management during the last 5 years. Despite the development of good practices throughout the CRM Group, one accident with loss time occurred in 2015. This is why risk analysis, training and audits will continue to be the top priority for 2016, in order to achieve “Zero accident”.

The present annual report highlights the main achievements obtained this year in the steel collective program, shared between ArcelorMittal and Tata Steel, and in the regional R&D program with our industrial partners.

A selection of relevant activities and results gained during the year 2015 is illustrated in 4 thematic sections:

- Recycling and circular economy: Closing the loop of metals and turning by-products and end-of-life products into valuable materials and energy sources. CRM Group is more particularly involved in the coordination of the industrial axis focused on the development of pyro-metallurgical recycling routes, including preconditioning of wastes;
- Innovative manufacturing and processing technologies: From raw materials to final shaped products; the continuous improvement of existing production routes remains a major target for the industrial members in terms of higher efficiency, lower production cost, prime product quality and short time delivery;
- Developing new advanced metallic materials with tailor-made properties, combining a process-product approach;
- Valorisation, dissemination, technical support to industry and regional economy. CRM Group continues to implement its own developments not only in Belgium but also in Europe and in the world for the benefit of its members.

Since several decades, CRM Group is actively participating to associations, organisations and networking aiming to exchange and share experience at the national and international level, where its expertise and competence in the manufacturing and processing of metallic materials are largely recognised. Since 2015, CRM Group is a core member of the EIT-KIC Raw Materials. This EIT-KIC is an EU body that enhances Europe's ability to innovate by supporting new ideas through the Knowledge and Innovation Communities (KICs).

These significant achievements are the result of trust and open relation between CRM Group organisation and its industrial members. CRM Group leadership warmly thanks them for their continuous and strong support.

Paul PERDANG
President CRM

Jean-Claude HERMAN
General Manager CRM

Company members

Active Members of CRM

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

And each of their subsidiary companies in the iron and steel industry.

The main affiliated companies in the Benelux countries are:

ARCELORMITTAL BELVAL & DIFFERDANGE S.A.	G.D. Luxembourg
ARCELORMITTAL DUDELANGE 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
ARCELORMITTAL STEEL BELGIUM N.V.	Belgium
INDUSTEEL BELGIUM S.A., ARCELORMITTAL Group	Belgium
SEGAL S.A., TATA STEEL EUROPE Ltd	Belgium
TATA STEEL IJMUIDEN B.V., TATA STEEL EUROPE Ltd	The Netherlands

On April 20, 2016

Associated Members of CRM

AIR LIQUIDE INDUSTRIES BELGIUM S.A.	Belgium
AMEPA GmbH	Germany
APERAM Stainless France S.A.S.	France
AURUBIS BELGIUM N.V.	Belgium
BEKAERT S.A.*	Belgium
BIOCARBON INDUSTRIES Sàrl	Luxembourg
CARMEUSE S.A.	Belgium
CMI S.A.	Belgium
COMET TRAITEMENTS S.A.	Belgium
DE LEUZE S.A.	Belgium
DREVER INTERNATIONAL S.A.	Belgium
EMG Automation GmbH	Germany
EURAGGLO S.A.S	France
FONDERIES MARICHAL, KETIN & Cie S.A.	Belgium
GONTERMANN-PEIPERS GmbH	Germany
HARSCO BELGIUM bvba	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
ISISS bvba*	Belgium
LHOIST Recherche & Développement S.A.	Belgium
MAGOTTEAUX INTERNATIONAL S.A.	Belgium
NDC TECHNOLOGIES S.A.	Belgium
NLMK CLABECQ S.A. – Plates	Belgium
NLMK LA LOUVIÈRE S.A. – Strips	Belgium
PHARMA TECHNOLOGY S.A.*	Belgium
PAUL WURTH S.A. G.D.	Luxembourg
PRAYON S.A.	Belgium
PRIMETALS TECHNOLOGIES AUSTRIA GmbH	Austria
PRÜFTECHNIK DIETER BUSCH A.G.	Germany
RECOVAL BELGIUM SPRL	Belgium
RECYDEL S.A.*	The Netherlands
R-TECH S.A.	Belgium
TECHSPACE AERO S.A.	Belgium
THY-MARCINELLE S.A.	Belgium
TI GROUP AUTOMOTIVE SYSTEMS S.A.	Belgium
TMT sarl	Luxembourg
UMICORE S.A.	Belgium
WINOA S.A.	France
WOW TECHNOLOGY S.A.	Belgium
ZincOx Resources plc	United Kingdom

* Approved by the General Meeting of April 20, 2016

Organisation

Board of Directors of CRM

President
Paul PERDANG, Member of the leadership team of Global R&D, ARCELORMITTAL

Vice-Presidents
Pinakin CHAUBAL, Head of Process R&D and Americas labs, ARCELORMITTAL
Debashish BHATTACHARJEE, Group Director R&D, TATA STEEL GROUP

Directors
Martin BRUNNOCK, Technical Director, TATA STEEL Strip Products UK
Vincent CHOLET, CTO, ARCELORMITTAL Europe – Long Products
Renaud COLLETTE, Conseiller, SPF Economie, PME, Classes moyennes et Energie
Nico CUE, Secrétaire Général, MWB
Mark DENYS, Director Technical Strip Products, TATA STEEL Mainland Europe
Marc FISETTE, Head of Performance Optimisation, ArcelorMittal Europe Flat Products
Bruno GAY, Senior Project Leader Building Products, UMICORE
Matthieu JEHL*, CEO ArcelorMittal Belgium
Robert JOOS, Directeur Général, Groupement de la Sidérurgie (GSV)
Herwig JORISSEN, Voorzitter, Centrale der Metaalbewerkers van België
Leo KESTENS, Professor, Universiteit Gent
Vincent LECOMTE, Directeur Général, S.A. des Fonderies Marichal, Ketin & Cie
Greg LUDKOVSKY, Vice-President of Global R&D, ARCELORMITTAL
Gabriel SMAL, Secrétaire Général, ACV-CSC METEA
Sven VANDEPUTTE, Managing Director, OCAS N.V.
Wim VAN DER MEER, Director R&D Programmes, TATA STEEL RD&T
Olivier VASSART, Long Products Portfolio and Research Centres Leader, ARCELORMITTAL
Pierre VILLERS, Inspecteur Général, Direction Générale des Technologies, de la Recherche et de l'Energie de la Région Wallonne
Pierre WOLPER*, Professeur, Doyen de la Faculté des Sciences Appliquées, ULg

Observers
Jean-Claude HERMAN, Directeur Général, CRM
Yvon MASYN, Adviseur, Agentschap Innoveren en Ondernemen

Auditor
Dominique JACQUET-HERMANS

* Approved by the General Meeting of April 20, 2016

On April 20, 2016

Iron and Steel Committee of CRM

Members

ARCELORMITTAL
J.P. ALLEMAND
M. BABBIT
P. CHAUBAL
M. DI FANT
S. VANDEPUTTE
O. VASSART

TATA STEEL
M. DENYS
A. DUNSMORE
L. JANSEN
W. VAN DER MEER

CRM
J.C. HERMAN
Ch. MARIQUE
G. LANNOO

CERTIFICAT DU SYSTEME DE MANAGEMENT DE LA QUALITE

ISO 9001 : 2008

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

CRM GROUP

dont les sièges des sociétés sont établis
Avenue du Bois Saint-Jean, 21 – 4000 Liège et Technologiepark 903c – 9052 Zwijnaarde – Belgique pour
CRM asbl *– Centre for Research in Metallurgy asbl*
et Allée de l'Innovation, 1 – 4000 Liège et Rue Sompré, 1 – 4400 Ivoz-Ramet – Belgique pour
AC&CS scrl *– Advanced Coatings and Construction Solutions scrl*
a été examiné le 02-11-2015 et a été jugé conforme à la norme ISO 9001, édition 2008 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 le BQA sa conformément à son manuel de qualité relatif à la certification de système et après conclusion du contrat de certification N° CER_AJ_QMS_02-11-2015_336_F aux termes duquel la firme accepte un contrôle régulier de son système de management.

Certificat N° BQA_QMS019_C_2006336
Valable jusqu'au 14-09-2018

BELAC
BQA N° 019-QMS

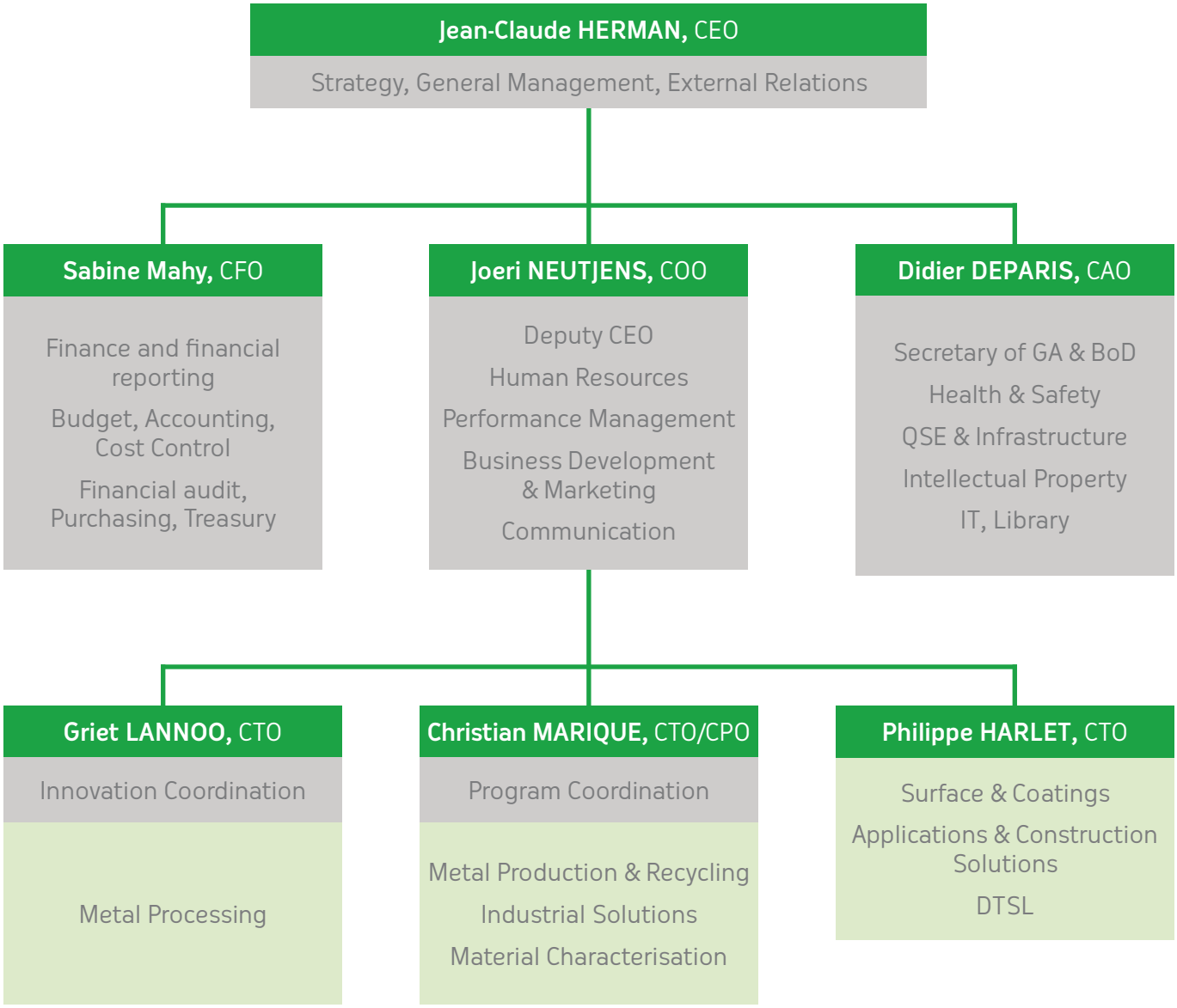
D. SIMOENS
Directeur

BQA

Toute personne ayant connaissance de l'emploi abusif de ce certificat doit en avertir le BQA sa. Ce certificat ne peut être divulgué que dans son intégralité.

BQA sa - rue Montoyer 24 (b9) - 1000 Bruxelles.

DS/AJ/C/02-11-2015



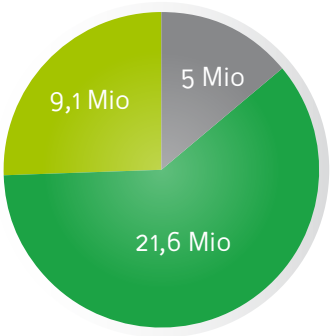
CEO : Chief Executive Officer
COO : Chief Operational Officer
CTO : Chief Technical Officer
CFO : Chief Financial Officer
CPO : Chief Programme Officer
CAO : Chief Administration Officer

CRM Group management functions
R&D operational functions

Key figures

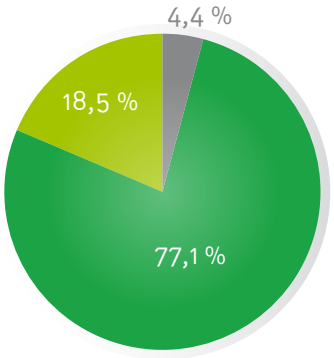
Total Income: 35.7 Mio. Euros

Income by program



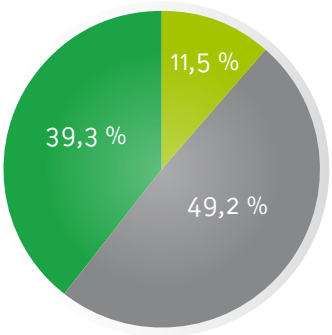
- Steel Collective
- Steel Private
- Other

Income by financing



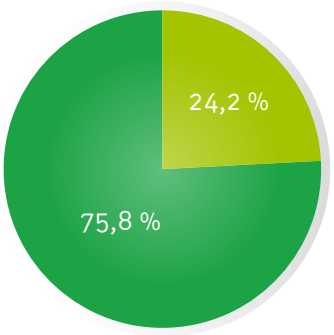
- Private
- National & Regional Grants
- European Grants

CRM Group: 244 people



- Researchers
- Technicians
- Administrative staff

Gender balance



- Female
- Male

Report on R&D activities

CRM Group, as Belgian research centre for the Steel and Metal industries, provides its industrial members and customers with solutions in terms of R&D, process technology, product development and applications. Its 45 industrial members, present in Europe and in the World, are active in a broad range of market segments and technical/commercial domains linked to the metallic materials.

During the recent years, the CRM organisation has continued to grow (244 people active in 2015) thanks to the support of its members and the enlargement of several of its activities. Moreover, CRM is present to implement its own development not only in Belgium but also in Europe and in the World for the benefit of its members.

The CRM expertise extends from upstream to downstream operations with strong competences and experimental/pilot tools in sintering, blast furnace, melting/refining & casting, rolling & thermal treatment, annealing & coating, product characterisation, metal transformation & shaping, ...

A large part of the R&D activities remains devoted to improve the capabilities and to enhance the performances of existing production routes by integrating novel technologies and adapted operating practices as well as to enlarge the product mix through the development of new grades or new functionalities.

However, new initiatives have been recently launched with the support of Regional Public Authorities to promote new economic and industrial concepts favouring a better valorisation of local material resources and a larger cross-sectorial partnership. It is notably the case for the recycling of by-products, wastes and end-of-life products containing metallic residues and metal components.

The CRM Group is structured into five operational units supported by a fully integrated characterisation laboratory:

- Metal production and recycling (Raw material processing, melting & refining, by-products treatment & valorisation);
- Metal processing (Casting & solidification, process technology, product metallurgy);
- Metal surface & coating (Metallic & organic coating, surface functionalisation);
- Metal applications & construction solutions (Building & structure, civil engineering, metal working & assembly, solutions and in-use properties);
- Industrial solutions (Engineering & thermal technologies, industrial measurement & process control, pilot facilities).

The CRM Group is entirely certified ISO 9001 whilst several measurement, calibration and analytical techniques are also certified ISO 17025.

A selection of relevant activities and results gained during the year 2015 is illustrated in 4 thematic sections:

- Recycling: Closing the loop of metals and turning by-products and end-of-life products into valuable materials and energy sources;
- Innovative manufacturing and processing technologies: From raw materials to final shaped products;
- Developing new advanced metallic materials with tailor-made properties;
- Valorisation, dissemination, technical support to industry and regional economy.

Recycling:
Closing the loop of metals and turning by-products and end-of-life products into valuable materials and energy sources

The industrial activities, especially in Europe, are more than ever confronted to major challenges such as the price and scarcity of raw materials, the need to compress production cost, the respect of strict environmental rules whilst continuing to offer to the market new and high quality products. This implies to adapt the processing technologies and to prepare and valorise new production routes based on regional or local resources and on the recycling of valuable secondary materials.

Initiated in 2013 and officially launched in 2014 by the Walloon Government, an ambitious program named "Reverse Metallurgy" aims to promote and develop new valorisation approaches for the metallic residues and other manufacturing and urban wastes. It associates several industrial and research partners with a financial support of the Walloon region for a period of 5 years.

CRM is more particularly charged to coordinate the industrial axis focused on the development of pyro-metallurgical recycling routes in cooperation with foundries, the manufacturing industry and recycling organisations.

In line with the priority topics identified when starting the project, the most outstanding progress achieved in 2015 can be summarised as follows:

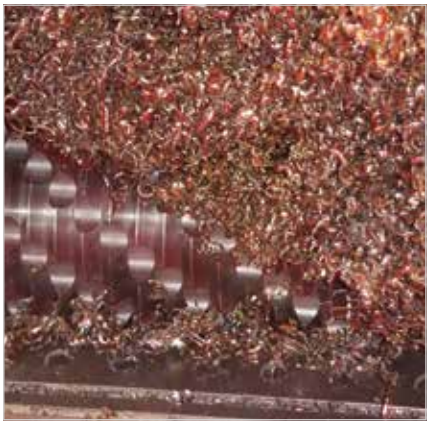
- The recovery of high value alloying elements (Cr, V, Mo, Ni, ...)

New equipment have been acquired for the pre-conditioning before melting of metallic by-products such as grinding wastes, mechanical chips/turnings and swarfs:

- one mobile shredder system for reducing the size of the turnings and giving them an adequate shape before compaction whilst avoiding the presence of massive bodies.

Mobile shredder unit

Turnings before shredding



Shredding of turnings

Oil removal press

- two compaction presses with one devoted to treat grinding sludge to remove oil and other lubricants and the second dedicated to produce dense briquettes, better suited for the handling of recycled materials and their charging in melting furnace.

Compaction press for turnings

Materials collected in several foundries and mechanical workshops have been successfully processed with these equipment including carbon and stainless steel, aluminium, special alloyed steel grades. Next steps will include melting campaigns, a full characterisation of the recovered metals and of their in-use properties as well as the collection of new materials adequately sorted and selected.

Compaction press for turnings

- The production of quality secondary aluminium

  - various secondary aluminium sources have been identified through numerous contacts with recycling organisations, foundries and mechanical workshops as well as through a dedicated campaign launched inside CRM with the contribution of the personnel families in order to collect packaging aluminium products today not part as such of the usual collection circuits.

To transform packaging into pure aluminium ingot

Melting of aluminium grindings

- melting of these products in a furnace acquired by CRM and dedicated to melt aluminium products has indicated the possibility to produce ingot with a well-defined composition including high purity aluminium when processing recycled packaging products. Optimisation of the melting and pyrolysis treatment of these aluminium products will be pursued to better master the off-gases post-combustion and eliminate organic components whilst drastically reducing the energy required for melting.

Furnace for the melting of aluminium products

- The processing of complex end-of-life (EoL) products

End-of-life boilers have been selectively dismantled to separate the enamelled steel components from the other parts (electric heating, insulating layers,...). The melting of the recovered steel pieces in an induction furnace has confirmed the very good quality of this type of steel with no tramp elements (Cu, P, S, ...) present in the final ingot.

Casting of molten aluminium

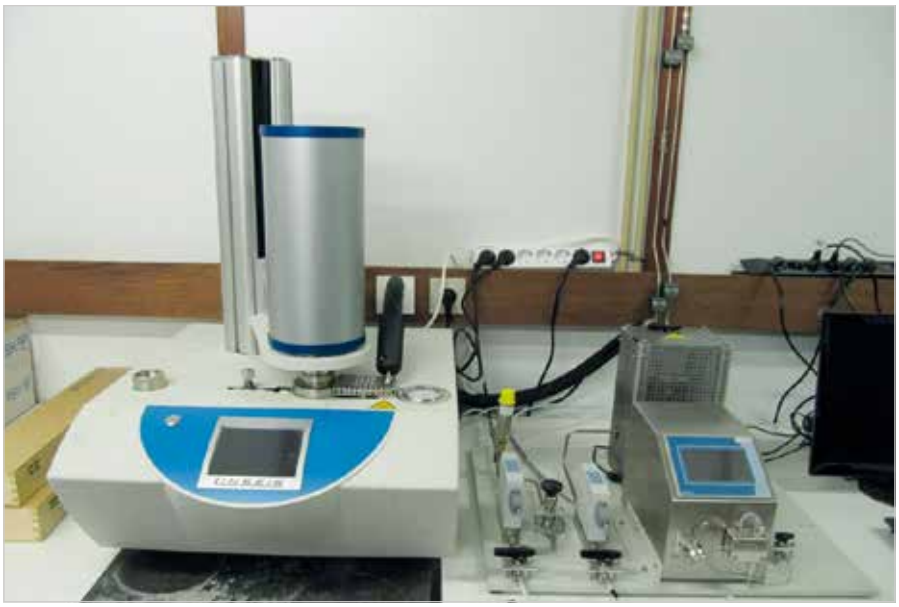
Steel parts of the boiler

Selective dismantling of boiler

Melting of boiler steel parts

■ The valorisation of sludge, dust, scale, slag, ...

- residues containing Fe, Zn, C or organic compounds can originate from old deposits or from fresh production (biomass, urban and industrial waste). Their conversion in heat (energy) or synthetic gas (syngas) and the recovery of valuable solid materials through a thermo-conversion process at high temperature is one of the explored recycling routes. A new thermo-gravimeter analyser (TGA) has been acquired for defining on small scale sample the operating windows to be applied (processing up to 1600°C under different gas atmospheres).



Thermo-gravimeter analyser (TGA)

Large scale experiments are also conducted on the “gasification” pilot unit that has been adapted to process these recycled materials. A first set of trials have been conducted with oily sludge coming from controlled landfill and from industrial site such as NLMK La Louvière to check the feasibility of an original process able to transform these waste in solid agglomerates rich in iron oxides, valorised as secondary raw materials for the Steel Industry.

The thermo-convection reactor

The new Anton Paar viscometer

- the selection of the most adapted post-treatment of metallurgical slag imposes to well know their main characteristics and behaviour at the liquid state.A new apparatus able to measure the viscosity of slag at high temperature (>1600°C) has been ordered and will be operational in the first part of 2016.

The new Anton Paar viscometer

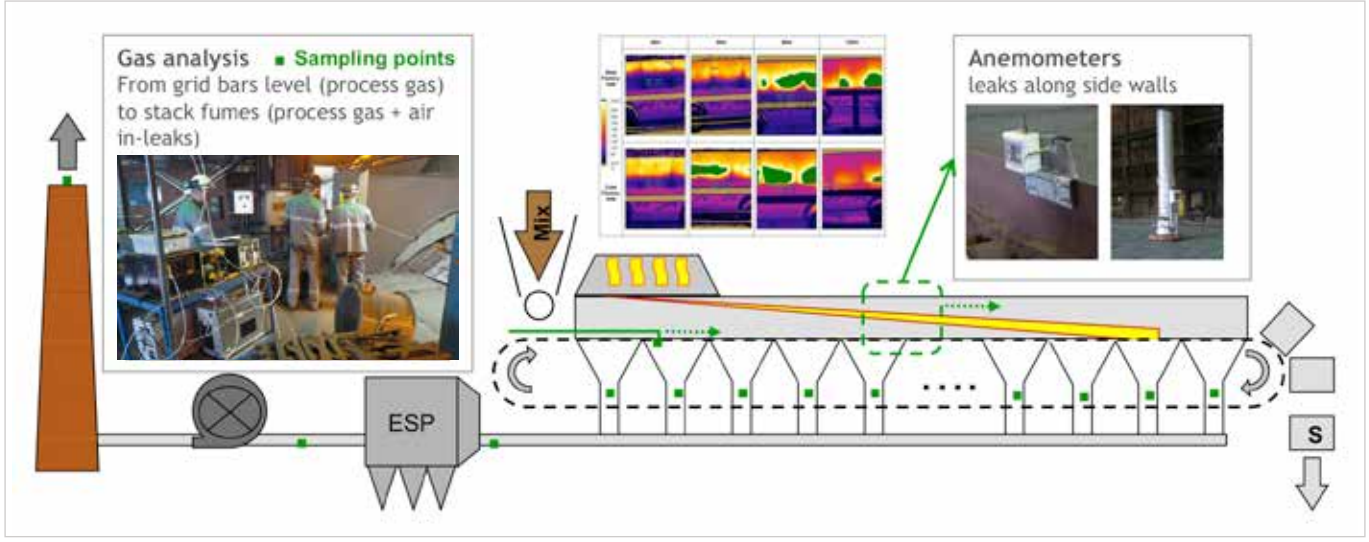
Innovative manufacturing and processing technologies: From raw materials to final shaped products

Besides the incentive placed on the development of new alternative manufacturing routes based on the recycling of metallic materials, the continuous improvement of existing production routes remains a major target for the industrial members of CRM in terms of higher efficiency, lower production cost, prime product quality and short delivery time.

The CRM activities in the **metal production** field cover a large scope extending from the raw material conditioning and processing through various successive thermo-chemical steps until the refining at the molten stage and the solidification of semi-products.

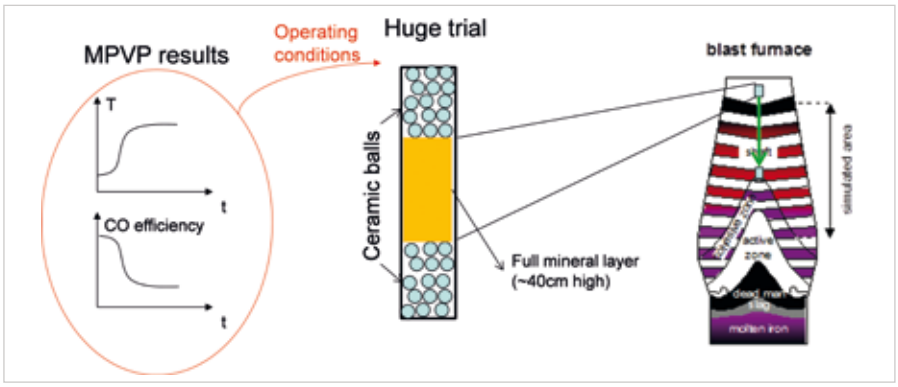
For the upstream operations and more particularly the sintering of iron ores, one of the main challenges for the Steel Industry is to incorporate in the production route variable sources of iron ores containing more and more fine particles, while keeping or even boosting productivity. CRM has developed a specific competence focused on the granulation process, a mandatory step before charging the mix in the sinter plant. A laboratory is dedicated to simulate the granulation with rotative drums of different diameters (from 4 to 60 cm) allowing to accurately calibrate the model predicting the granule size growth and to reach an up-scaled prediction close to the industrial situation. Another way to boost sinter plant productivity is to reduce air in-leaks in order to recover maximal useful fan capacity, with additional gains in terms of electricity consumption and possibly ESP's efficiency. CRM has developed a very specific expertise and dedicated tools (model and on site measurements) in order to deliver a quite accurate air in-leaks diagnosis, identifying air in-leaks locations and their relative importance, in order to help defining where to start with corrective actions showing the highest benefit/cost ratio.

Granulation equipment



Air in-leaks detection at sinter plant

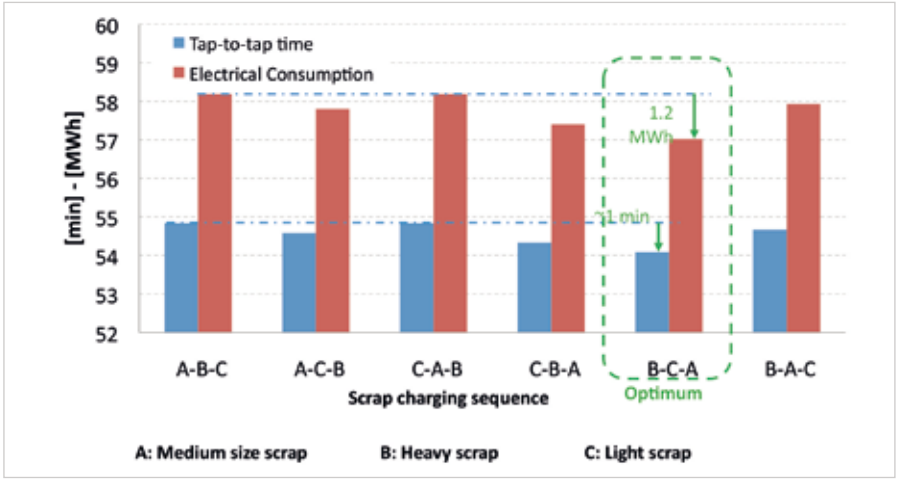
Huge reactor



BF simulation test with the Huge reactor

In the blast furnace area, it is worthwhile to mention the trials conducted with the "Huge" reactor managed by CRM at the EcoTechnoPôle (ETP). With this thermo-conversion pilot unit, it is possible to simulate the evolution of temperature, pressure, gas flow & composition down to the blast furnace cohesive zone and to assess the behaviour of the burden at a full grain size similar to the industrial situation. The mixes to be tested can include sinter, pellets and nut cokes. Specific descent path in the blast furnace can be simulated using actual gas composition and flow. A more realistic prediction of the burden degradation influencing the blast furnace performances can hence be derived allowing a better mastering of the process.

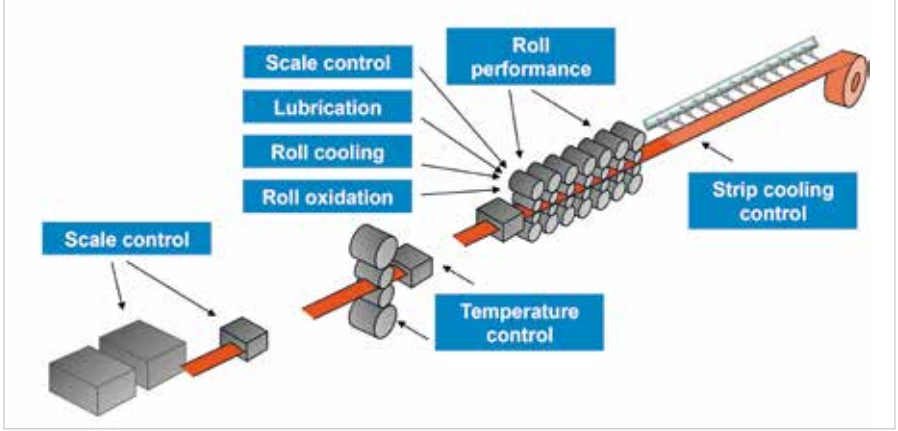
In the field of the Electric Arc Furnace (EAF) steelmaking, let us recall the dynamic metallurgical model built by CRM: for any type of furnace, it continuously solves mass and thermal balances for scrap, molten steel, slag, gas and refractories. It calculates on-line the scrap melting evolution, the melt composition and the end-point of the heat. One important ongoing development concerns optimisation tools regarding scrap management (scrap layering, optimal time for second basket charging, and adaptation of furnace operating patterns to changing scrap mixes), resulting a.o. in energy savings and 'tap to tap time' reduction).



Imput of the scrap charging sequence on the EAF performances

The **metal processing** is another area where the CRM competences have been developed within the years and are largely recognised for their technological input in the hot and cold rolling operations as well as in the thermal treatment of metallic products. In line with the hot rolling process, 4 main axes of development have to be mentioned:

- To master the lubrication for product consistency and economic gains;
- Maximising the work roll performance to increase the productivity and to reduce the operating cost;
- To assure a scale defect free product with a prime surface quality;
- To control the cooling of hot products for optimised properties.



Main development items in hot strip mill

An efficient lubrication of the contact between the strip and the work rolls is a key aspect of the hot strip mill operations to master the product quality, to reduce the energy and effort required to deform the product and to minimise the roll wear and abrasion. With the support of the RFCS program, a project called "Intelligent hot rolling lubrication" aims at proposing new approaches for improving the oil application at the Gent hot strip mill of ArcelorMittal and at assessing its impact on the work roll behaviour. Based on a model developed by CRM, the friction coefficient at the top and bottom roll of the stand can be calculated in real time and the oil input needed for reaching a correct lubrication regulated on-line accordingly. Another new tool, relying on the "tablet" technology, allows the mill team to assess the work roll degradation directly at the end of each rolling campaign by taking pictures of the roll surface and comparing them with reference images. These images can also be delivered by a small portable microscope connected to the tablet.

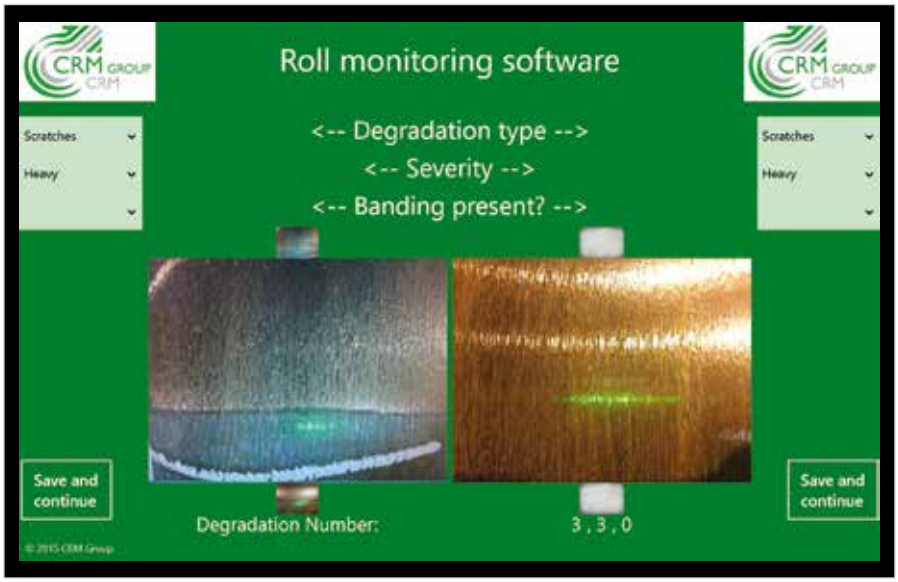
The "tablet" technology for work roll inspection

This analysis being performed rapidly at the end of a campaign is not affected by the formation of a rust layer such as currently observed at the roll shop. A better information is hence delivered to the roll shop for the re-conditioning and grinding of the roll based on the observed degradation type and its severity index determined with the tablet inspection.

The WPC cooling technology at Tata Steel IJmuiden

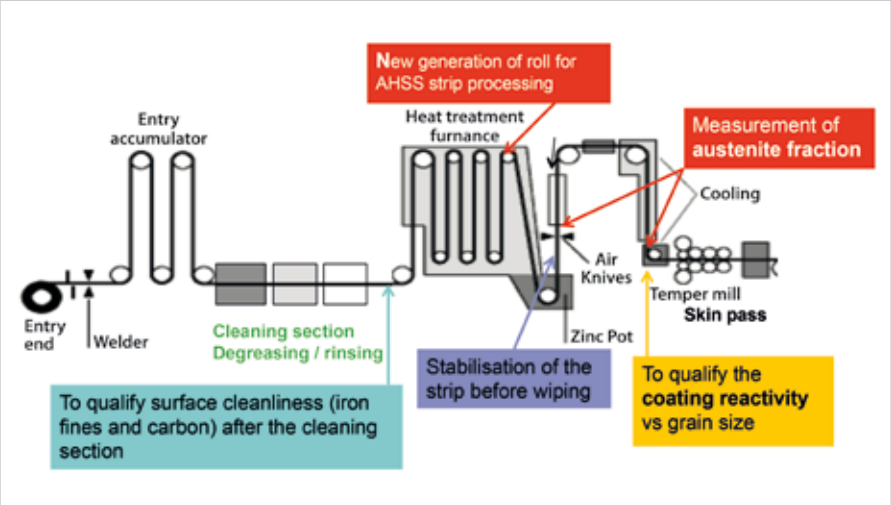
An efficient descaling operation is of prime importance for achieving the good surface quality and therefore, a new high pressure descaler has been designed and constructed by CRM. It is equipped with a translation system able to move samples at a speed up to 2 m/sec. The system can work with pressure up to 250 bar and a flow rate of more than 40 l/min.

In the cold rolling area, the successive implementation in 2013 and 2015 of an original cooling concept in two interstands of the 4-stands tin plate mill at Tata Steel IJmuiden are recalled. Based on the "Water Pillow Cushion" (WPC) design, this intense strip cooling technology has been validated after more than 3 years of industrial use as a very robust solution with no maintenance problems and with proven advantages such as a significant increase of the line speed (up to 5% when using one cooling device and up to 14% when using 2 cooling devices), a lower strip temperature and with a much better

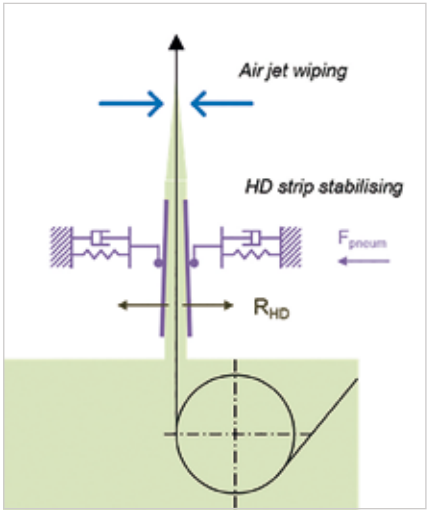


Deliverables of the roll monitoring software

New high pressure descaling unit



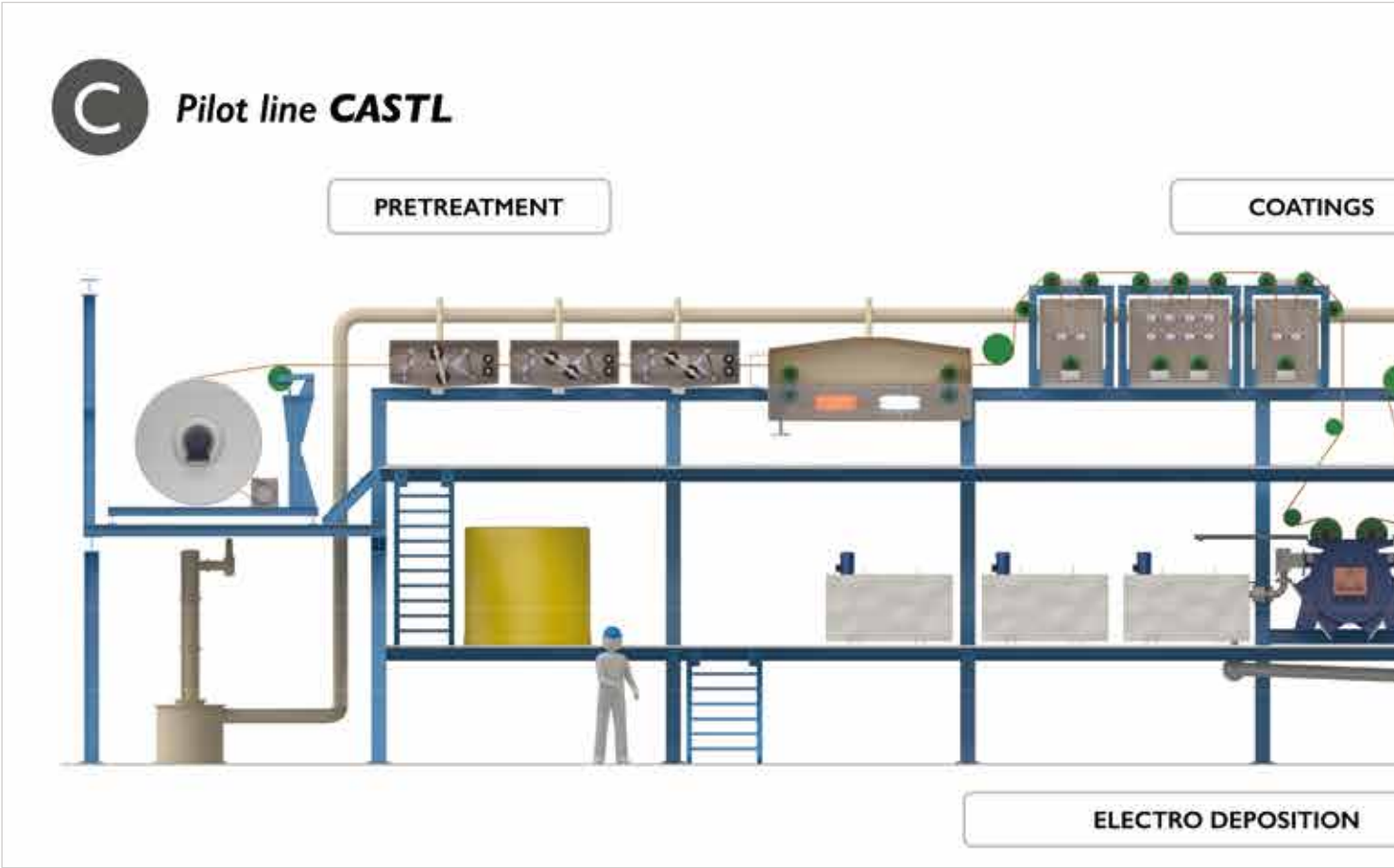
Main development items in hot dip galvanising



New concept for the strip stabilisation in hot dip galvanising

surface quality, a decrease of the rolling force and the access to harder grades. The application of the water only on the bottom side leads to a more efficient lubrication on the top face whilst the resulting homogeneous cooling assures no flatness problem.

The "finishing & coating" of metallic products is also a major part of the CRM activities and competences with the possibility to develop new concepts on unique pilot lines and laboratory simulators. Among the topics covered in this field and tested on the annealing and hot dip galvanising line let us mention the development of a sensor to qualify the strip surface state (iron fines, carbon) after the cleaning section, the selection of new roll qualities for processing high alloyed grades, the stabilisation of the strip before wiping, the on-line determination of the strip quality at the exit of the line (surface grain size, austenite fraction, ...).

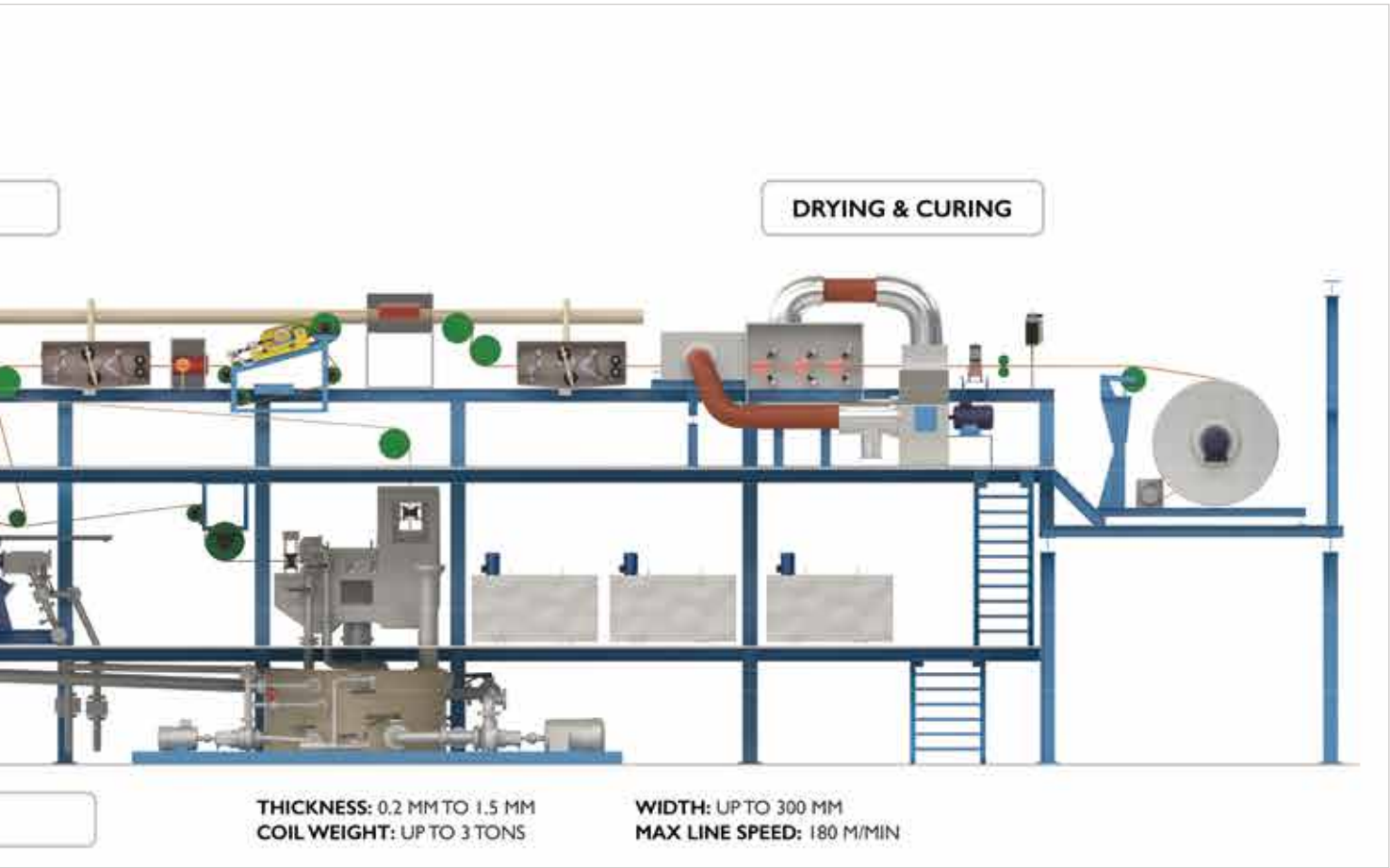


Water simulation test

Test in the pilot line

To be more especially highlighted is the progress achieved in the development of the patented device for stabilising the strip between the zinc bath and the wiping unit. The concept relies on the application of a hydrodynamic lift created at the liquid zinc interface of the moving strip and maintained by self-aligning floating pads. On both sides of the strip, the lift is balanced by air cylinders whilst the vibrations are absorbed by spring-dashpot dampers. The zinc flow coming from the wipers freely flows on the back of the pad. Initially designed through numerical simulations and water test modelling, this new device has also been tested in the pilot line confirming the possibility to drastically reduce the strip vibration during galvanisation. The development will be pursued aiming at up-scaling this technology.

One can also point out in 2015 the upgrading of a very flexible and modular multifunctional pilot line nicknamed "CASTL" for Continuous Advanced Surface treatment Line". This line implemented in 2004 with the financial support of the Walloon Region and EFRD (European Fund for the Regional Development) allows to process coils of various metallic substrates through successive or separate steps such as pickling, degreasing (brushes, electrolytic cleaning), electro-deposition or wet coating (roll coater, spray & squeeze, dip coating). It is possible to treat substrates such as carbon or stainless steel, aluminium, copper or zinc grades. To complement the existing capabilities of the line, an electro-deposition unit (radial cell or horizontal flash cell) has been integrated allowing to deposit a zinc, tin or nickel layer. This line can process coils up to 3 tons in weight (width up to 300 mm) at a speed of 180 m/min max.



The revamped CASTL pilot line

Developing new advanced metallic materials with tailor-made properties

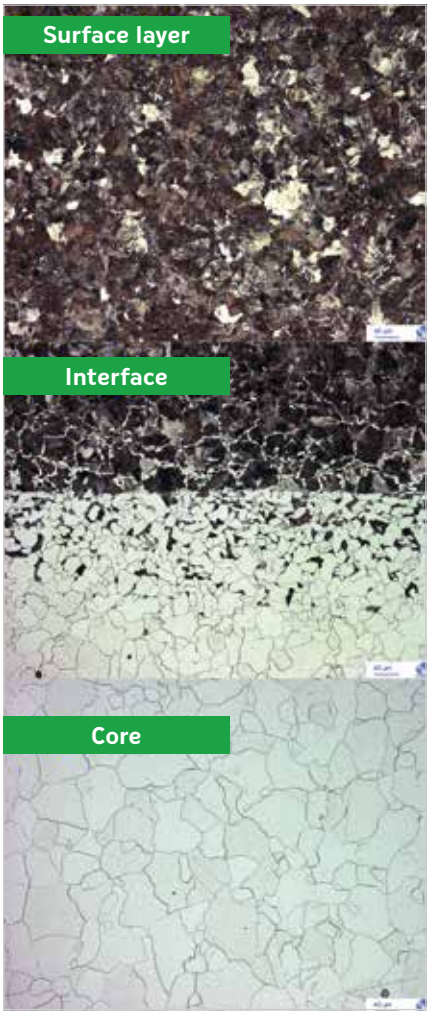
While the expertise acquired by CRM during several decades on processing technologies, physical metallurgy and process-product interactions continues to be applied for developing new concepts of advanced steel grades and associated applications, it is also valorised for promoting high-added value metallic materials in a diversified range of industrial sectors.

The metallurgical design of modern steel grades and especially the UHSS (Ultra High Strength Steel) products remains a challenging task for combining the various performances and properties expected by the customers and product users. A particular difficulty is to meet the continuously increasing requirements in terms of properties, which are sometimes "contradictory" and not easy to combine in one single product (i.e. strength and energy absorption, abrasion resistance and toughness, high strength/formability and coatability).

From one side, there exist different possible strengthening mechanisms (grain refinement, solid solution strengthening, precipitation hardening and transformation hardening) that have been and are still fully exploited to tailor the mechanical properties of the bulk materials.

The development of multilayer materials can be another attractive strategy. To explore this opportunity, a dedicated program has been launched at CRM to produce experimental materials. Through hot roll bonding tests combining an appropriate surface preparation and a specific rolling schedule, multilayer steel plates showing a sound metallurgical bond have been produced. These plates were further processed into thinner sheets exhibiting a pronounced composition and microstructural gradient, combining the advantage of a hard-skin with a soft and ductile core.

A multitude of layer combinations (ferrous as well as non-ferrous) can be imagined to manufacture a new generation of architectured metal products.



Cross-section view of a multiple layer product

Another key aspect in the design of new advanced steel grades is the access to a very fine description and understanding of the microstructure changes and evolution during their processing like the auto-tempering phase after thermal treatment.

Hot rolling of multilayer material

To realise these studies, the use of sophisticated and complex characterisation equipment has to be pointed out like the measurement campaigns with a very high resolution X-ray diffraction available at the European Synchrotron Radiation Facility close to Grenoble in France.

European synchrotron facility

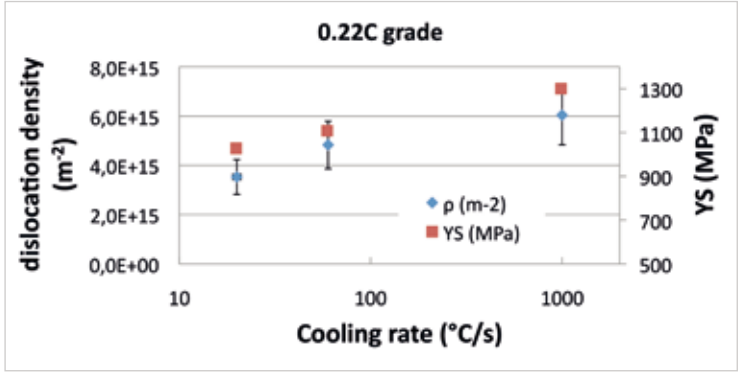
On such an installation, it is possible to determine with a great accuracy the dislocation density of complex phase microstructures illustrated with an example for a 0.22 % C martensitic steel grade: after a thermal treatment where different cooling rates were applied (from 20 to 1000°C/s), it is shown that a fast cooling rate favours the persistence of a higher dislocation density strengthening in the material and explains for a significant part the obtained higher yield strength (YS).

Another key parameter for the characterisation and development of modern metallic products concerns the impact of the diffusible hydrogen on the stability of the mechanical properties and the metal embrittlement in service. CRM has gained a deep competence and expertise notably in the design and construction of Thermal Desorption Analyser (TDA) able to finely measure the evolution of the hydrogen content with the temperature or within the time including very low level (below a few tenth of ppm). Such equipment can be coupled with a furnace operating under controlled atmosphere simulating high temperature processes to assess the impact of air, nitrogen or hydrogen-nitrogen mixed atmosphere.

Dedicated thermal treatment furnace

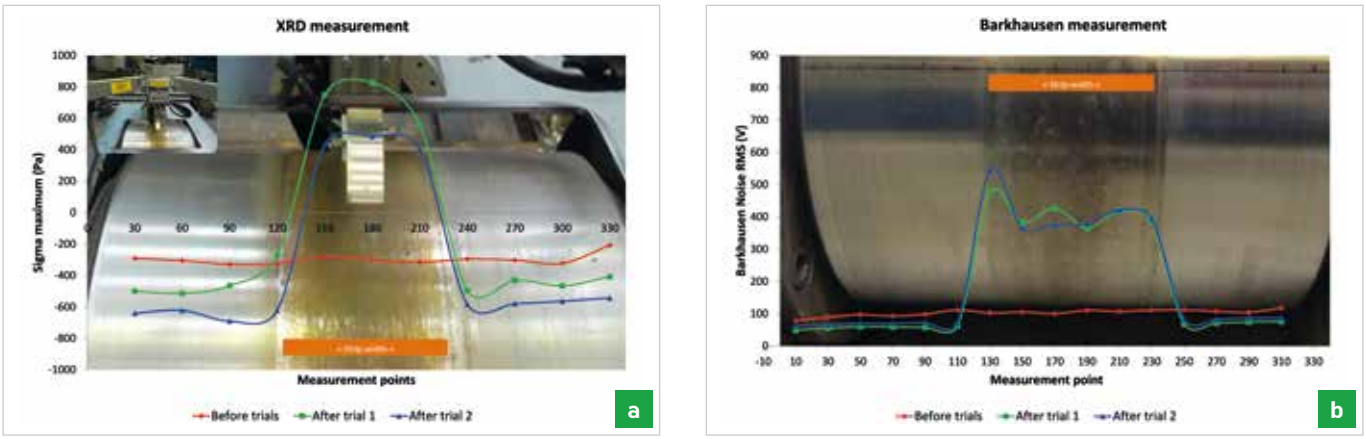
An important application field of metallic material concerns the manufacturing of rolls largely used for the thermo-mechanical processing of metals among which the steel industry consumes the largest volume.

CRM is active since more than 40 years in the study of the work roll behaviour and performances and its impact on the mill productivity, the product quality and the operating cost. It is managed through an intense collaboration with its affiliated steel companies ArcelorMittal and Tata Steel and adherent roll makers such as Marichal Ketin or Gontermann-Peipers.



Influence of the dislocation density on the yield stress

Thermal Desorption Analyser (TDA)



Stress profile on roll (a) XRD (b) Barkhausen

Innovative approaches to assess and to characterise the work roll materials in use have been developed as well as the proposal of new manufacturing ways.

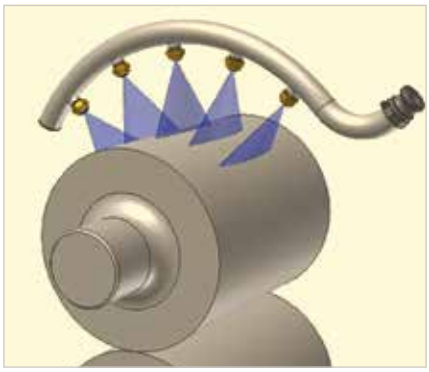
During hot rolling operations, the work rolls are submitted to a complex cycle of thermal and mechanical effort influencing their life time in terms of resistance to wear and thermal fatigue. The effort and deformation imposed to the rolls generates surface and internal stresses leading to a progressive cracking and abrasion of the material.

A dedicated study has been conducted, with the support of the RFCS program, to more deeply study the stresses influence and evolution along a rolling campaign and to identify appropriate measurement techniques and actuators able to reduce their impact on the roll cracking.

Compared to the more classical XRD measurement, it has been shown that the Barkhausen stress measurement system (application of a magnetic field to the roll and analysis of the back noise) delivers very similar results for determining the stress profile and amplitude of the residual stresses along the roll surface.

Being influenced by changes in the roll microstructure and hardness, only relative stress values are obtained through this very quick measurement however this does not at all affect its attractiveness as rapid control method of the roll quality.

The modification of the thermal roll profile by the application of a pulsated cooling leading to a lower quenching effect of the roll surface appears more promising with a smoother and more homogeneous stress profile in the vicinity of the rolled product edges delaying the crack propagation along the roll width.



Pulsated cooling device (PCD)

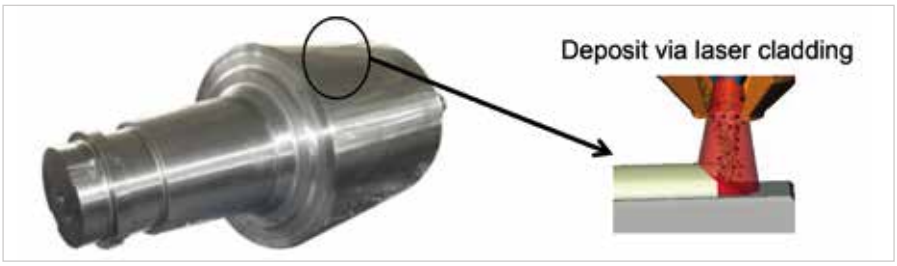
Hot rolling trials with PCD

A very innovative roll manufacturing process is explored by applying the advantages of laser cladding to overlay a re-usable steel arbor with a thick layer of tool steel material. The main objectives are to increase the length of the rolling campaigns and to allow schedule free rolling. This new concept is characterised by a very fast cooling rate and a resulting fine microstructure leading to enhanced mechanical properties of the roll. This development is commonly shared between CRM, Marichal Ketin, ArcelorMittal and Tata Steel. An experimental pilot equipment able to process large industrial rolls (up to 825 cm diameter) is under construction and hosted by Marichal Ketin with the target to start industrial trials during the second quarter of 2016.

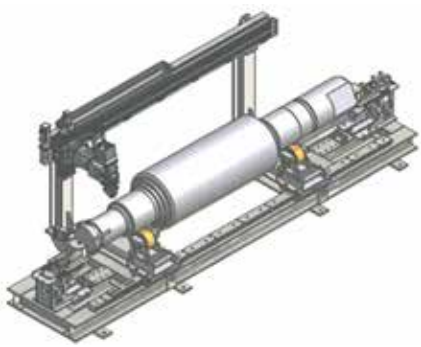
Alternative solutions for the substitution of banned elements like hard chromium or cadmium imposed by REACH continue to be the subject of investigations. With the financial support of the Walloon Region (DGO6 department), two different projects ("NoChrome & Alti2DE") conducted by CRM have led to very attractive and promising results:

- Electroplated cermet coating combining a Ni-P matrix reinforced with SiC is, after an appropriate annealing treatment, able to

Demonstration bar coated with a Ni-P-SiC cermet



The roll laser cladding concept



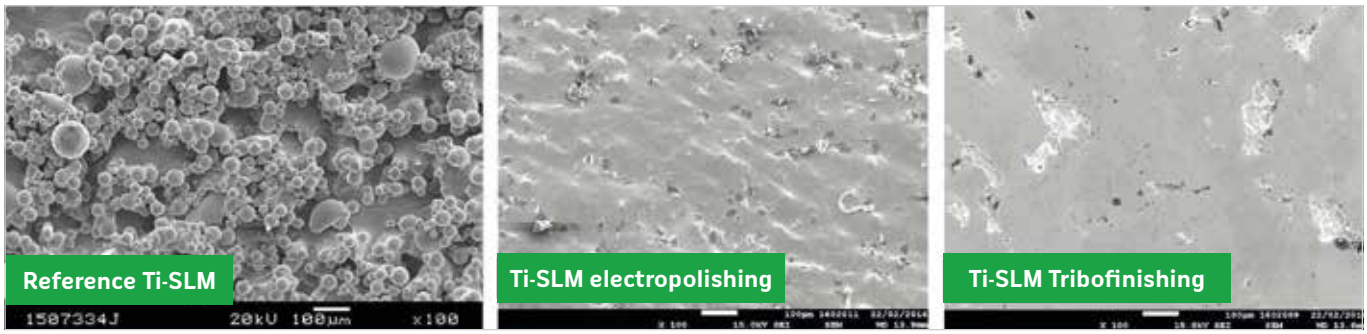
View of the roll laser cladding unit

match the performances of hard chrome coating in terms of hardness and wear resistance; its corrosion resistance being superior to that of hard chrome layers. This type of coating can be easily applied on simple piece geometry (plate or cylinder).

■ Amorphous carbon-based coating deposited by PVD technology presents another option with an even better wear resistance than hard chromium coating but with a lower friction which gives an advantage to reduce energy losses in specific applications where friction is an issue. They could be deposited on tri-dimensional pieces. As substitution of cadmium, AlMn alloys proposed by CRM show high potential even if their salt-spray-test resistance is not as high as cadmium-based coatings.

A last activity to be mentioned concerns the surface engineering and special treatment of parts made by additive manufacturing; CRM leads a study about the post-surface processing of parts manufactured for ESA (European Space Agency) in collaboration with WALOPT, SIRRIS and THALES ALENIA SPACE in France. Three metallic materials (an aluminium grade AlSi7Mg, a titanium grade Ti6Al4V and an Invar alloy) are investigated with a special focus on their surface finishing after additive manufacturing. CRM is more particularly equipped to perform tribo-finishing and electro-polishing treatments.

Tribo-finishing installation

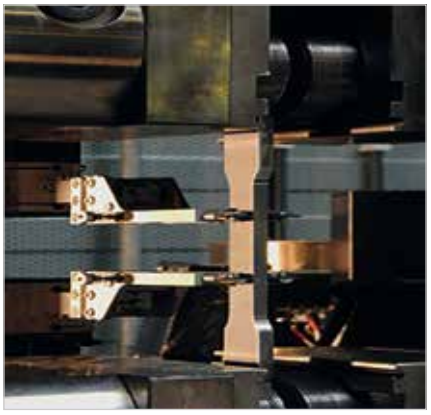


Surface aspects of pieces processed by additive manufacturing

Valorisation, dissemination, technical support to industry and regional economy

Based on the strong long-term partnership with its industrial members and the competence gained in the processing, manufacturing and applications of metallic materials, CRM offers a broad range of expertise for supporting the needs of the industry (including small & medium enterprises) at the regional and international level.

A team of highly qualified people and a large panel of equipment are at the disposal of the members and external partners or customers for solving their problem and developing their business.



Tensile test machine

Pendulum for toughness measurement

This activity relies on up-to-date characterisation & measurement tools including mechanical testing, chemical analysis, metallography study, numerical simulation, ...

In that prospect, it is helpful to recall the opportunity for the SME's in Walloon Region to be financially supported for the studies ordered to a certified research centre like CRM by the initiative named "Chèques Technologiques" that is managed by AEI (Agency for Enterprise & Innovation in Wallonia).

As far as novel equipment are concerned, one can mention that new modules able to realise bending or tensile operations on small specimen under protected atmosphere and just before their detailed analysis in a SEM-FEG unit have been acquired in 2015 with the financial support of the Walloon Region and EFRD (European Fund for the Regional Development) ("ClearZinc" project).

Bending module for SEM-FEG

The access to a documentation service and a technical library has also to be recalled as one of the services offered by CRM to its members. The use of modern search platform and the connection to numerous technical data banks allow a continuous

CRM at the CETAS exhibition

Mulpic installation in China

and comprehensive watch of the state-of-art in metallurgy and associated domains as well as the fast delivery of publications, proceedings, standards or patents.

A significant effort is also devoted to promote and disseminate the acquired knowledge and to valorise and implement own technologies or solutions worldwide.

One of the efficient ways is the organisation of seminar or workshop as well as the selective participation to international conferences, fairs or to events favouring the networking and the building of new partnership.

As relevant examples for the year 2015, let us mention:

■ The "Hannover Messe" (April 13 to 17, 2015): Inside an exhibition space reserved by the Walloon Region, CRM and SIRRIS have shared a stand devoted to the new 3D manufacturing technologies.

CRM participation at the Hannover Messe

■ On May 20, 2015, CRM has welcomed in Liège the "GRD" (Group for Research of Development) for a workshop focused on the item "Reverse Metallurgy".

■ The 2015 CETAS conference (Analytical Chemistry & Materials Characterisation in the Steel and Metal Industries) has been co-organised from May 19 to 21 in Düsseldorf by CRM & VdEh (the German Association for the Steel Industry). More than 175 participants from 20 countries have contributed to this conference aiming to review the state-of-the art in the analytical and measurement techniques.

■ CRM has actively participated to the "Salon Metamorphoses", an event organised by SPI to promote the use and development of innovative materials. (Liège-May 28 & 29, 2015) with a specific focus on the new manufacturing technologies and the promotion of novative approaches in the construction sector.

■ On Wednesday May 27, CRM Group has hold the inauguration of a continuous modular vacuum and wet coating pilot lines built and installed in a clean room environment, a world premiere. A first application, realised in partnership with ArcelorMittal and with the support of the European Commission (Program Life+) aims at the development of a PhotoVoltaic Steel roof application. Part of this development was financed by the Walloon Region ("Plan Marshall") and the support of the pole "Mecatech".

■ Around 175 people have visited the facilities of CRM in Gent-Zwijnaarde in the frame of the "Science Day" organised by the Flemish Region on November 22, 2015.

■ In the frame of the guidance mission "SUREMAT" supported by the Walloon Region, CRM has participated to the Eurofinish trade fair (June 2015) and has organised two thematic days for the SME's on the items "Replacement of the hard chromium process (July 2015) and "Surface treatments in the housing sector (November 2015).

Industrial valorisation and implementation of technologies: In line with one of the strong competences of CRM i.e. the cooling technologies applied for the thermo-mechanical processing of metallic products, a new MULPIC (Multi-Purpose Interrupted Cooling) installation has been ordered in June 2015 by Baosteel Zhanjiang near Primetals Technologies, licensee of this technology.

This latest order underlines the Mulpic position as the world's leading cooling technology and increases the number of systems installed worldwide to 22 installations.

The roll to roll vacuum coater

Valorisation, dissemination, technical support to industry and regional economy

- Since several decades, CRM Group is actively participating to associations, organisations and networking aiming to exchange and share experience at the National and International level where its expertise and competence in the 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 22 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 : common initiative of CRM and ULg/GeMMe aiming to strengthen collaborations at regional level as well as in the perspective of European initiatives such as Horizon 2020 and EIT/KIC on (primary and secondary) raw materials.

  - 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. To be highlighted for the year 2015, the investment realised by the « Metal Processing Centre (MPC)» (the joint venture between OCAS & CRM) in the installation of 2 new air casting furnaces with a respective capacity of 80 and 300 kg of metal at Zwijnaarde-Gent. These new melting furnaces will further enhance the support given to the manufacturing industry in collaboration with the partner SIRRIS.

- 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).

The RawMatTERS consortium, of which CRM is core partner with ULg and 120 other European industrial, academic and research partners, has been selected by the European Institute of Technology (EIT) to constitute a «Knowledge and Innovation Community" (KIC) on Raw Materials including several themes as exploration, mining, raw materials use in process & manufacturing industry, recycling and substitution of critical raw materials.

In the frame of this initiative, 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 present members are Swerea MEFOS-Sweden, BRGM, CEA & ERAMET –France, GTK-Finland, ELKEM-Norway and IMN-Poland. More info : www.metnet.eu

The four independent European steel research institutes (CRM, CSM, Swerea MEFOS 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

Publications & Conferences

J.-C. Herman, B. Vanderheyden, M. Dormann
Recovery of strategic metals from waste or how to transform metallic waste into raw materials
Salon Métamorphoses, Liège, 28-29 May 2015

C. Marique, J-C. Herman, B. Vanderheyden, V. Tusset
Metal Industry : a major player of the global circular economy
CETAS 2015 9th International Conference, Düsseldorf, Germany,19-21 May

C. Marique, J-C. Herman, V. Tusset, J. Crahay
La Reverse Metallurgy, germe pour l'additive manufacturing ?
Salon Métamorphoses, Liège, 28 mai 2015

M. Dormann, D. Steyls, V. Piret, B. Vanderheyden, P-F. Bareel, Q. Van Haute, C. Bodson
DRI production from Shredder Residues
2nd ESTAD, Düsseldorf, 15-19 June 2015

B. Vanderheyden, F. van Loo, C. Mathy, J.-C. Pierret
Optimised Waste Gas Recirculation Layouts for Environment-friendly and Energy Efficient Sintering of Iron Ores
AISTech2015 & ICSTI, Cleveland, 4-7 May 2015

F. van Loo, JF. Douce, E.Pirard, R. Pietruck, M. Martinez Pacheco
Improved sinter mix preparation while using challenging materials
2nd ESTAD, Düsseldorf, 15-19 June 2015

R. Jaimes Contreras, F. van Loo, J.F. Douce, M. Schöngut, F. Šťpánek, M. Evrard, E. Pirard
Advanced characterisation to investigate the effect of raw material properties on the kinetics of iron ores granulation
2nd ESTAD, Düsseldorf, 15-19 June 2015

B. Vanderheyden, F. van Loo, C. Mathy, J.-C. Pierret
Optimised Waste Gas Recirculation Layouts for Environment-friendly and Energy Efficient Sintering of Iron Ores
2nd ESTAD, Düsseldorf, 15-19 June 2015

C. Ojeda, O. Ansseau, P. Nyssen, J.C. Baumert, J.C. Thibaut, M. Lowry
EAF Process Optimisation Tool Using CRM Dynamic Model
2nd ESTAD, Düsseldorf, 15-19 June 2015

V. Piret, M. Dormann, B. Vanderheyden, A. Cotton, P-F. Bareel
CRM's assets and developments for improved pre-processing in pyrometallurgy
34th IBA Conference, Scottsdale, 8-11 November 2015

P. Nyssen, G. Bister, D. Deschuyteneer, D. Hautcoeur, E. Juste, A. Mertens, J. Lecomte-Beckers, V. Lardot et F. Cambier
Production of alumina foundry moulds by additive manufacturing for low and high melting point alloys prototypes
Annual meeting of the Belgian Ceramic Society, Mons, Belgium, October 26th 2015

O. Ansseau, L. Bellavia, G. Monfort, C. Ojeda
LIBS on-line measurement of the hot metal composition in the blast furnace runners
CETAS 2015 9th International Conference, Düsseldorf, Germany, 19-21 May

H. Uijtdebroeks, Z. Koont, A. Ianos, J.J. Fitzpatrick, G. Gebara, P. Guther, P. Ceolin, M.J. Hough, P. Van Poecke
Implementation of High Turbulence Roll Cooling at ArcelorMittal Dofasco's Hot Strip Mill
METEC & 2nd ESTAD, 15 to 19 June 2015, Düsseldorf, Germany

B. Vervaet, H. Uijtdebroeks, L. Jacobs, G. Tahitu
Intensive and homogenous bottom strip cooling in the cold strip mill with the intensive high turbulent and low pressure water pillow cushion technology
METEC & 2nd ESTAD, 15 to 19 June 2015, Düsseldorf, Germany

J. Malbrancke, H. Uijtdebroeks, M. Mohammadi Tehrani,, G. Fricout, C. Vergne
Roughing mill work roll kinetic of degradation
Rolls 5 Conference 2015, 22 - 24 Apr 2015, Birmingham

J. Crahay, D. Debrabandere, J-F. Vanhumbeeck, J.J. Bertrandie, F. Bixquert, P.H. Bolt, R.G.J. Bröcking, Ch. Doeding, H. Dietsch, G. Evans, F. Jansen, J-M. Lesenne
Substitution of hard chrome plating for rolls of skin-pass and temper mills
METEC & 2nd ESTAD 2015 Proceedings

G. Monfort
On-line assessment of the surface cleanliness of steels at the cold rolling mill by Laser Induced Breakdown Spectroscopy
CETAS 2015 9th International Conference, Düsseldorf, Germany, 19-21 May

L. Bordignon, G. Monfort, P. Albart, P. Kuhn, T. Wuttke, R. Sagl, A. Jarosik, A. Vogel, S. Merzlikin, W. Melfo
Evolution and measurement of iron oxide growth during HDG annealing conditions and the impact on galvanising behavior of AHSS
10th Galvatech, Toronto, Canada, May 31st - June 4th, 2015

L. Bordignon, M. Larnicol, X. Vanden Eynde, A. Farinha, P. Gerkens, J.F. Noville, J. Smal, M. Bobadilla
Liquid Oxide Annealing for Surface Preparation of HSS
10th Galvatech, Toronto, Canada, May 31st - June 4th, 2015

G. Moréas, P. Albart, L. Bordignon, G. Monfort, V. Tusset
Control of galvanising process thanks to oxidation thickness measurement inside furnace
CETAS 2015 9th International Conference, Düsseldorf, Germany, 19-21 May

G. Monfort, G. Moreas
CRM Group Sensors developed for process control
CETAS 2015 9th International Conference, Düsseldorf, Germany, 19-21 May

EVA-PLEX : une technologie innovante de galvanisation fonctionnant à basse température
Article VOM 08/2015 « galvanoplastie »

S. Flament, G. Walmag, M. Sinnaeve
Investigation on work roll corrosion and oxidation mechanisms in a Hot Strip Mill
AISTech 2015, The Iron & Steel Technology Conference and Exposition, 4 -7 May 2015 in Cleveland, Ohio
Iron & Steel Technology, November 2015
2016 Rolls Technology Best Paper Award

J. Malbrancke, T. Reichardt, J. Schindhelm, A. Bán, A. Falck, H. Deli
Wear protective electroless nickel dispersion coatings for rolls in hot long product rolling
Rolls 5 Conference 2015, 22 - 24 Apr 2015, Birmingham

S. Flament, G. Walmag, M. Sinnaeve
Investigation on work roll corrosion and oxidation mechanisms in a Hot Strip Mill
ABM 52nd Rolling Seminar, 17th to 20th August, 2015 in Rio de Janeiro - RJ, Brazil

D. Debrabandere, J-F. Vanhumbeeck, J.J. Bertrandie, H. Dietsch, J.M. Lesenne, F. Bixquert, F. Jansen, G. Evans, R. Brocking, H. Bolt
Substitution of hard chrome plating for rolls of skin-pass and temper mills
METEC & 2nd ESTAD, 15 to 19 June 2015, Düsseldorf, Germany

J-F. Vanhumbeeck, D. Debrabandere, J. Crahay, R. Bröcking, A. Meghwal, Stefan Melzer, Tata Steel, S. Verdier, G. Evans, T. Lowbridge
Development of Electrical Discharge Coating (EDC) as Chrome-Free Alternative for Increasing Campaign Length of Temper Mill Work Rolls,
10th Galvatech, Toronto, Canada, May 31st - June 4th, 2015

J-F. Vanhumbeeck, D. Debrabandere, J. Crahay, R. Bröcking, A. Meghwal, Stefan Melzer, S. Verdier, G. Evans, T. Lowbridge
Development of Electrical Discharge Coating (EDC) as Chrome-Free Alternative for Increasing Campaign Length of Temper Mill Work Rolls
Iron & Steel Technology, November 2015, p.68.

A. I. Farinha
Determination of metallic coating weights by gravimetric methods: uncertainties and limitations
CETAS 2015 9th International Conference, Düsseldorf, Germany, 19-21 May

C. Georges, X. Vanden Eynde, M. Dubois
The diffusible hydrogen management during the annealing and overaging steps of galvanised Dual Phase steels
10th Galvatech, Toronto, Canada, May 31st - June 4th, 2015

C. Georges, X. Vanden Eynde, T. Sturel
Determination of diffusible hydrogen content in various coated high-strength steels
CETAS 2015 9th International Conference, Düsseldorf, Germany, 19-21 May

C. Georges, M. Mandy, P. Drillet, T. Sturel, P. Jacques
On the interaction mechanisms between atmospheric sources of hydrogen and Al-Si coated high strength steels during the hot stamping process
Euromat 2015, Warsaw, Poland, September 20-24, 2015

C. Georges, P. Huyghe, S. Godet
Influence of quenching and partitioning conditions on the microstructures and mechanical properties of a 0.2C steel
PTM2015, Whistler, Canada, June 28th-July 3rd, 2015

C. Georges, M. Mandy, P. Drillet, T. Sturel, P. Jacques
On the interaction mechanisms between atmospheric sources of hydrogen and bare high strength steels during the hot stamping process
Mapping the Future of Materials Science, Paris, France, September 7-9, 2015

C. Georges, M. Mandy, P. Drillet, T. Sturel, P. Jacques
Étude des mécanismes d'interaction, au cours du procédé d'emboutissage à chaud, entre les sources atmosphériques d'hydrogène et les aciers à haute résistance
Young Researchers Days, Saint Etienne, April 8-9th, 2015

C. Georges, O. Hubert, S. Cobo, P. J. Jacques
Study of the influence of diffusible hydrogen on the mechanical behavior of 3G steels with a bainite-martensite matrix exhibiting a TRIP effect
Euromat 2015, Warsaw, September 20-24, 2015

C. Georges, O. Hubert, S. Cobo, P. J. Jacques
The influence of diffusible hydrogen on the mechanical behavior of third generation steels with a bainite-martensite matrix exhibiting a TRIP effect
Mapping the Future of Materials Science, Paris, France, September 7-9, 2015

J-F. Vanhumbeeck
La substitution du chromage dur
Article VOM 08/2015 « galvanoplastie »

N. Nutal, M. Larnicol
Nouveaux revêtements composites par intégration de microparticules
Article VOM 11/2015, «Le poudrage sous toutes ses facettes »

N. Nutal, J. Crahay, M. Larnicol, J-F. Vanhumbeeck, P. Rochus, J-P. Collette, H. Jochem, C. Magnien, Masse, O. Rigo O and L. Pambaguian
Surface engineering for parts made by additive manufacturing
66th International Astronautical Congress, Jerusalem, Israel. Copyright ©2015 by the International Astronautical Federation.

J-F. Noville
TEMPCORE®, the most convenient process to produce low cost high strength rebars from 8 to 75 mm
METEC & 2nd ESTAD, 15 to 19 June 2015, Düsseldorf, Germany

AC&CS Sart-Tilman
Advanced Coatings
& Construction Solutions
› Liège

CRM Sart-Timan
Centre de Recherches
Métallurgiques
› Liège

EcoTechnoPôle
ETP
› Liège

CRM Gent
Centre de Recherches
Métallurgiques
› Zwijnaarde

AC&CS Ivoz-Ramet
Advanced Coatings
& Construction Solutions
› Flémalle

PiMW Sart-Tilman
Pôle d'Ingénierie
des Matériaux de Wallonie
› Liège

T (+32) 04 254 62 11 | F (+32) 04 254 64 64 | info@crmgroup.be






CRM GROUP

www.crmgroup.be