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Project Deliverable Report

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Technical Group:	**TGA2**

VALorisation and dissemination of RFCS projects results and experience in steel surface quality issues: on as-cast CRAcks formation

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Cover sheet of 50 subsequent pages

1. INTRODUCTION

The objective of the dissemination project is to revisit the most important European projects related to the formation of cracks in continuous casting carried out in the last two and a half decades. This document presents the assessment of the ECSC projects under concern (see list in D2.1.) together with the classification and ranking criteria.

A brief discussion on the findings, as well as the assessment forms for each of the projects, complete this deliverable.

2. CLASSIFICATION AND RANKING CRITERIA

Classification. As outcome of Task T2.2 the participants defined the list of topics and subtopics (see Deliverable D2.2 formerly released), shown below.

Topic 1 - Basic knowledge	
T1.1 Chemistry	Understanding how steel chemistry effects the susceptibility of the product to cracking through solidification
T1.2 Microstructure	Understanding of how solidification, phase change and subsequent microstructure effect cracking in the final product
T1.3 Hot ductility	Understanding how segregation and grain boundary effects, including precipitation and micro alloying, influence hot ductility and tearing at the grain boundaries.
Topic 2 – Modelling	
T2.1 Mould modelling	Modelling of heat transfer from liquid steel through to cooling water within the mould and heat transfer and solidification in the steel strand
T2.2 Secondary cooling modelling	Modelling of the effect of online secondary water cooling
T2.3 Thermodynamic & microstructural modelling	Modelling phase stability and microstructure evolution during solidification and cooling
Topic 3 – Process Optimisation	
T3.1 Layout design	Modifications to the caster design to improve cracking performance

T3.2 Operating conditions	Definition of operating windows which reduce potential for cracking. Definition of rules for downgrading due to potential crack generation.
T3.3 Injection techniques	Identification of specific techniques for inoculant addition to liquid steel to modify solidification.
T3.4 Improved steel compositions	Definition of steel chemical compositions for improving castability, to reduce defect occurrence
Topic 4 - Mould powders	
T4.1 Mould powder properties	Study of the effect of mould powder properties such as heat transfer and lubrication relative to cracking performance. Study of the evolution of mould slag properties during casting, also by slag film characterisation. Development of new powders to facilitate increased casting speeds and improve quality.
T4.2 Mould powder feeding strategies	Control of rate, location and method of mould powder application to the mould
Topic 5 – Process control & sensoring	
T5.1 Measuring systems	Instrumentation directly measuring casting parameters and other process features relevant to surface and internal quality. On-line and off-line crack detection systems
T5.2 Online Control Systems	Online caster control systems used to improve caster and process stability and thus reduce cracking, including mould level, process parameter and secondary cooling control
Topic 6 - New Casting Technology/Demonstration projects	
T6.1 Near Net shape castings	Reduction of cracking in non-standard continuously cast sections such as thin slabs, beam blanks, etc.
T6.2 Magnetohydrodynamics	Use of Magnetohydrodynamics such as electromagnetic stirring and braking. Unconventional application of Magnetohydrodynamics

The assignment of one or more topics to each partner for the execution of Task 2.3 (project analysis and ranking) has been agreed at a conference call on the 26th of September 2019: 6 or 7 projects were assigned to each partner by their main topic, where possible. In the case of

MPI and CSM, the assigned projects cover different topics and were grouped by subtopic, when possible. In this case, the involvement of CSM and MPI in the various projects was taken as distribution criterion. In fact, this was the way agreed to ensure an equal workload among the partners.

Sidenor: Topic 1 - Basic knowledge

SWERIM: Topic 2 – Modelling

MPI: Topic 3 - Process Optimisation, Topic 5 - Process control & sensoring and Topic 6 - New Casting Technology/Demonstration projects

CSM: Topic 2 - Modelling, Topic 4 - Mould powders, Topic 5 - Process control & sensoring, Topic 1 - Basic knowledge.

BFI: Topic 5 - Process control & sensoring

The overview of the project arrangement per topic, sub-topics and partner is shown in Table 1.

Table 1 Arrangement of projects by topics and partners

Title	Acronym	Main Relevant Topic	Further topics	Relevant sub-topics	
Precipitation behaviour of microalloyed steels during solidification and cooling.	PRECIPITATION	1	2,3,4	T2.2, T3.2, T4.1	SIDENOR
Grain size control in steel by means of dispersed nonmetallic inclusions	GRAINCONT	1	2, 3	T1.2, T2.3, T3.3	
Intercolumnar cracking and its relationship to chemistry and applied strain.	ICCRACK	1	2, 3	T1.1, T2.1, T3.2	
Kinetics of precipitation during continuous casting of plate steels.	KINPCC	1	2	T1.3, T2.3	
Influence of composition and continuous casting parameters on the precipitation of microalloyed particles of B microalloyed steel grades and Mn alloyed steel grades.	PMAP	1	2, 3	T1.1, T2.2, T2.3, T3.2	
Improvement of internal quality by controlling the microstructure of microalloyed cast steel	-	1	2	T1.2, T2.3	
Determination of high temperature surface crack formation criteria in continuous casting and thin slab casting	-	1	3	T1.1, T1.2,T1.3,T3.2	
Control of liquid slag carry away and entrapment in the CC mold for a better surface and subsurface quality: numerical and experimental study.	-	2	5	T2.1, T5.1	SWERIM
New secondary cooling patterns for peritectic and micro alloyed steels.	-	2	5	T2.1, T5.1	
Enhanced as-cast product quality by optimised mould taper design.	SOLIMOULD	2	3	T2.1, T3.1	
Investigation of innovative methods for solidification control of liquid steel in the mould.	INNOSOLID	2	3, 5	T2.1, T3.1, T5.1	
Optimisation of the straightening process in continuous casting.		2	5	T2.2, T5.1	
Control of the dendritic structure of the initial frozen shell in continuous casting	-	2	3	T2.1, T3.1	
Integrated models for defect free casting.	DEFFREE	2	3	T2.1, T2.3, T3.2	
Castability & surface quality of steels microalloyed with Ti or TiNb in continuous casting of slabs, thin slabs and beam blanks	-	3	5	T3.4, T5.2	MPI
Development of a toolbox for direct defect prediction and reduction through the characterisation of the meniscus slag bed behaviour and initial shell solidification in CC.	DIRECT DEFECT TOOLBOX-DDT	3	2	T3.1, T2.1	
Improvement, control & prediction of cast & rolled products through development & application of novel engineering monitoring techniques.	CASTDESMON	5	3	T5.1, T2.1	
Development of an integrative plant, process and quality supervisory system at CC by the intelligent combination of sensors, data analysis and decision support techniques.	SUPSYSCC	5	3	T5.2, T3.2	

Direct casting of small sections beam-blanks thanks to meniscus free casting technology.	Beam-blank MFC	6	2	T6.1, T2.1	
Improvement to steel cleanness, castability and surface quality through the application of magnetohydrodynamics during pouring and solidification.	MAGNETOHYDRO	6		T6.2	
Identification of optimal mould lubrication conditions through an innovative hot and cold simulation method.	LUBRIMOULD	2	4	T2.1, T4.1	CSM
Optimising slag film properties and determination of operational windows for lubrication, mould heat transfer and shell formation.	SLAGFILMOWL	4	3	T4.1, T3.2	
Optimisation of mould powder performance in casting long products	-	4		T4.1	
Effect of transients on quality of continuously cast product.	TRANSIENT	5	2, 4	T5.1, T2.1, T4.2	
Enhanced steel product quality & productivity by improved flux performance in the mould through optimising the multiphase flow conditions & special regard to melting & entrapment.	FLUXFLOW	2, 4		T2.1, T4.1	
Reduction in surface cracking in as cast low sulphur and calcium treated steels.	LSSEMIQUAL	1	2, 4	T1.1, T1.3, T4.1	
Multiplexed eddy current arrays for the detection of corner cracks on as cast products in the inspection yard & at the exit of continuous casting.	EDDYCAST	5		T5.1	BFI
Innovative non contact non destructive sensors for automatic detection of surface and internal defects in hot continuously cast products	NDTCASTING	5		T5.1	
Mastering billet casting through integration of innovative mould sensoring and on-line billet surface quality monitoring.	MASTERBILLET	5		T5.1, T5.2	
Application of fibre optical thermal monitoring at CC billet mould for improved product quality.	FOMTM	5	2, 4	T5.1, T5.2, T2.1, T4.2	
Self condition monitoring of continuous casting machines	-	5	2	T5.1,T2.1	
Innovative non-contact, non-destructive prototype system for automatic detection of surface and subsurface defects in slabs	NDTSLAB	5		T5.1	
Improvement of the continuous casting through a new system for the real-time measurement of Shell Thickness in several locations of the casting strand	SHELL-THICK	5		T5.1	

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Criteria. The criteria identified are industry-oriented. As a matter of fact, they are focused on assessing the impact of the research results on the manufacturing practices and applied technologies. To strengthen this aspect, they also include for sake of completeness an assessment of the Technology Readiness Level (TRL) at the beginning and at the end of the project. In some cases, different TRLs for different project are achieved, and this can be found in some assessment forms annexed.

A template was prepared by the coordinator for the assessment of the projects, where open questions are proposed reflecting the identified criteria, and requesting some text and a quantitative scoring (in numbers). The questions are:

1. success/failure of the proposed solution
2. practical application of the results
3. spread of results among the steelmaking community
4. TRL at the beginning of the project and at the completion
5. economic benefits
6. follow-up projects

An overall scoring is also requested as index of the project success. The scoring criterion chosen, already used in other dissemination projects (e.g., VALCRA, DISSTEC) is the following:

- A project scores “zero” if “the project idea did not work at all”.
- A project scores “one” if “the project idea was in principle good, but industrial implementation was not possible at the time”.
- A project scores “two” if “the project idea is applied in at least one industrial plant”.
- A project scores “three” if “the project idea is state of the art and is applied in many plants”.

When the project involving more than one plant partner was accomplished successfully with positive application and use of the findings, a score ‘three’ was assigned if the same item would have been object of application on plants, so awarding the exploited transferability of the achieved results or developed technology.

3. ASSESSMENT – FINDINGS AND COMMENTS

3.1. Overall scoring

The overall quantitative result of the project assessment is shown in Figure 1, consisting of the score distribution percentage.

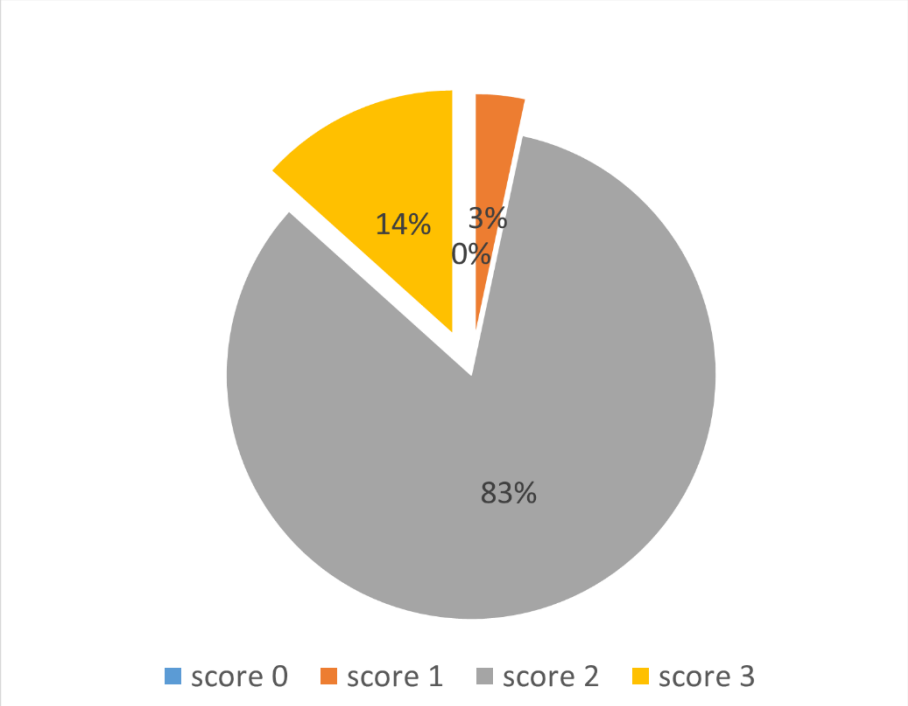


Figure 1 Score distribution (%) among projects

The most frequent score is '**2**', this meaning that the results achieved were tested successfully at least in one plant. On the other hand, this also means there is lack of transferability (or information on it) at broader scale. A possible reason for this can be found in the fact that the research period investigated can be considered for steelmaking/casting steps a 'transition' from focusing on metallurgy and route strategy definition, to a deeper focus on process control and sensoring development tailored on specific features (e.g. mould temperature control passing from thermocouple use to optical fibre) or new products.

Four projects scored '**3**', i.e.:

1. Integrated models for defect free casting. (DEFFREE)
2. Castability & surface quality of steels microalloyed with Ti or TiNb in continuous casting of slabs, thin slabs and beam blanks
3. Effect of transients on quality of continuously cast product.

4. Improvement to steel cleanness, castability and surface quality through the application of magnetohydrodynamics during pouring and solidification. (MAGNETO-HYDRO)

They are related to systems being state of the art in several plants (magnetohydrodynamics tools) and/or findings in form of process rules implemented in off- and on-line process control systems currently used in several plants (software tools tuned in DEFFREE project).

Two projects scored 1: the project idea was in principle good, but industrial implementation was not possible at the time. There are many reasons why a technically good technique is not applied during the course of a project.

It is common for a technique to not reach the plant implementation stage purely because of time constraints i.e. the project ended before trials could be performed.

Installation on plant may require a follow up project to develop and ruggedize technology for installation. Techniques in this position do not always get support to continue either within the developing company of through a European project.

3.2. Technology Readiness Level (TRL)

The evaluation of the TRL was conducted considering the TRL at the beginning of the project and the final TRL, thus having an assessment of the progress achieved thanks to the work done. The values were assigned according to the known definitions [1] and considering the main technological aspect of the project.

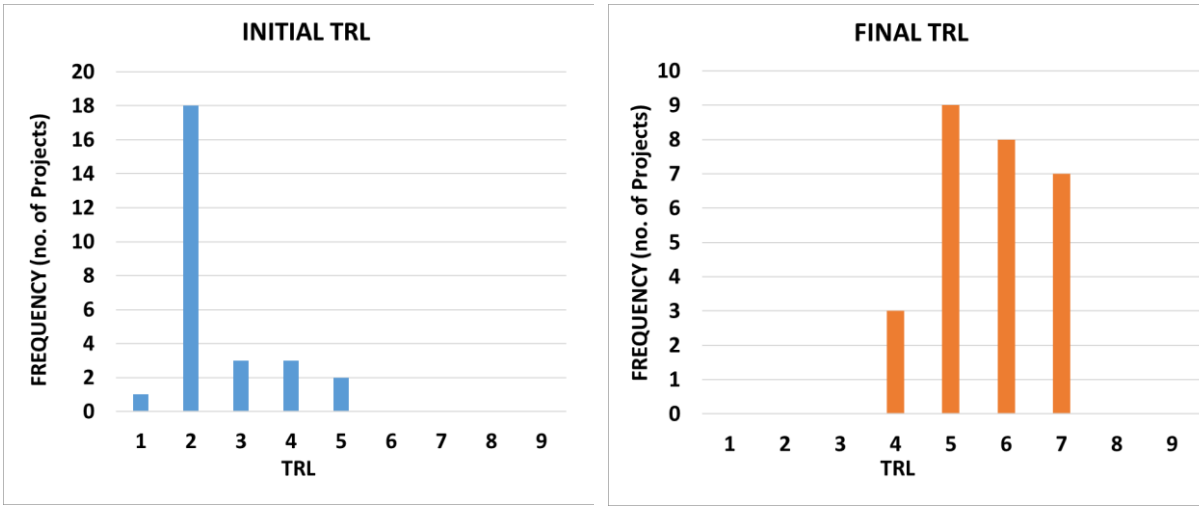
The outcome of this analysis in shown in the graphs in Figure 1, below. 1a shows that most projects started from TRL=2, i.e. from a technology concept, which was then in most cases validated in relevant environment (TRL=5). Many projects permitted to demonstrate a technology in relevant environment (TRL=6) and even to take it to a level of prototype (TRL=7) demonstrated in the operational environment.

From the point of view of the H2020 criteria, most of the examined RFCS projects are positioned as RIA (Research and Innovation Actions), whereas a few of them (TRL>6) are configured as IA (Innovation Actions).

Looking at the TRL positioning by project main topic (Table 1), the most frequent initial TRL is 2 for topics from 1 to 4: i.e. the most “traditional” research fields in continuous casting. In all

[1] https://ec.europa.eu/research/participants/data/ref/h2020/other/wp/2018-2020/annexes/h2020-wp1820-annex-g-trl_en.pdf

these four topics, the most frequent final TRL level is 5: in fact, in most cases the findings were validated at the industrial level. Higher TRL levels are found in the topic of process control & sensoring, which is intrinsically intended to be demonstrated and applied in the plant.



a) b)

Figure 2 Overall distribution of TRL of the examined projects: a) initial, b) final.

Table 2 Most frequent TRLs by project topic

PROJECT MAIN TOPIC	TRL	
	Initial	Final
Topic 1. Basic knowledge	2	6
Topic 2. Modelling	2	7
Topic 3. Process Optimisation	2	7
Topic 4. Mould powders	2	5
Topic 5. Process control & sensoring	3/4	6/7
Topic 6. New Casting Technology/Demonstration projects (only two projects)	3/8	4/9

3.3. Comments

As a general comment, the assessment showed that new measurement techniques led to improved productivity and product quality, saving of energy, material and working time, reduced production costs in several plants.

As a final comment, it can be guessed that the increasingly relevant role of the technology (defect monitoring, process parameters control via process engineering measurements linked with on-line instrumentation) will increase the number of projects developed in the RFCS frame with broader impact on the current state of the art of the steel downstream production. This also because the integrated process control systems tend to integrate as much as possible the route steps (e.g. steelmaking and casting, casting and rolling…).

4. ASSESSMENT FORMS

PROJECT: EDDYCAST (RFSR-CT-2004-00009)

Multiplexed eddy-current arrays for the detection of corner cracks on as-cast products in the inspection yard and at the exit of continuous casting

Questions	Information
success/failure of the proposed solution	Success in several plants for billets, but for crack detection at continuously cast slabs at Dillinger the proposed and tested method did not work properly since a) The slab temperature at exit of caster was in a critical range for a good in-line eddy current measurement application (i.e. around Curie temperature). In slab yard at lower slab temperatures the system worked better. b) The cracks in the investigated area of the slab corners were mainly closed at the slab surface due to rolling forces in the caster (soft reduction and driving rolls). This caused a bridging of steel that enabled “normal” eddy current flow, i.e. the cracks could not be detected.
practical application of the results	Technique adopted as operating practice to cast some steel grades. At Dillinger conditions the method is not applicable without a prior surface treatment.
spread of results among the steelmaking community	Mainly the final report; non notice of further exploitation/dissemination
TRL at the beginning of the project and at the completion	From TRL4 to TRL5 (besides major progress in the mechanics and cooling of system in field).
economic benefits	For billets, 6-strand equipment would require capital expenses of over 2 M€, which provides insufficient payback. The valorisation prospects appear limited to slab casters which feature much higher yield per strand. Spending € 800 000 for a 2-strand caster could prove benefits, as the caster could then be dedicated to the corner cracking sensitive grades.
follow-up projects	No information
Overall assessment	2

PROJECT: **NDTCASTING (RFSR-CT-2007-00013)**

Innovative non-contact, non-destructive sensors for automatic detection of surface and internal defects in hot continuously cast products

Questions	Information
success/failure of the proposed solution	The project NDTCASTING has shown the possibility of the EMAT system on hot surfaces with oscillation marks and scale. The project demonstrated that sensitive flaw detection under these difficult conditions is possible - defects with a length less than 10% of the chosen wavelength (λ = 14.9 mm) can be repeatedly detected. EMAT-EMAT – A prototype was developed capable of detecting surface and subsurface defects on-line at high temperatures (below the Curie temperature of steel) Laser – EMAT - A prototype Laser-EMAT system has been developed. The system has been proved in the laboratory on cold samples. Hot trials have been of limited success with surface defects being detected in some samples. Conoscopic holography – The existing plant system has extended for detecting other defects in addition to the longitudinal crack already in operation such as very thin and zigzag cracks can now be reliably detected. Overdetection has been decreased.
practical application of the results	CH-System (conoscopic holography) at ArcelorMittal – used to dictate scarfing online for cast product Pilot scale laser-EMAT and EMAT-EMAT have been tested
spread of results among the steelmaking community	As far as I know, mainly the final report; non notice of further exploitation/dissemination
TRL at the beginning of the project and at the completion	Laser – EMAT from TRL3 to TRL5 EMAT-EMAT from TRL3 to TRL5 Conoscopic holography from TRL5 to TRL7
economic benefits	Improved productivity, improved product quality, saving of energy, material and working time, reduced production costs.
follow-up projects	NDTSlab EMAT based defect detection development research continues at University level
Overall assessment	2

PROJECT: **MASTERBILLET (RFSR-CT-2008-00005)**

Mastering billet casting though integration of innovative mould sensoring and on line billet surface quality monitoring.

Questions	Information
success/failure of the proposed solution	Project turned out very successfully. The Fibre Optical System Technology is a very reliable and industrially environment proofed technology. During the measurement campaigns at Gerdau-Sidenor and at ORI Martin the FOS system and RF sensor were operated without problems.
practical application of the results	The main benefit of the FOS temperature measurement is the very easy handling in the production plant compared to the use of several thermocouples. The FOS is not influenced by electromagnetic fields like stirring systems or brakes. Another benefit is the high measurement frequency which enables the operator to monitor the mould condition in real time. Monitoring the mould wall temperature in the meniscus region by FOS has the potential to indicate the meniscus level position. Moreover, the results indicate that other effects like lubrication of the casting gap or rim formation could also be observed.
spread of results among the steelmaking community	7th ECCC, 2011 in Düsseldorf: "Lamp T., Köchner H., Unamuno Iriondo, J., Rodríguez Duran T, Optical Monitoring of Initial Solidification in a Billet Continuous Casting Mould". The second is the presentation at the AISTech 2012 Conference, 7-10 May: 'Radio-frequency sensor for liquid steel level and flux powder thickness measurements in continuous casting mould'.
TRL at the beginning of the project and at the completion	From TRL3 to TRL6/7
economic benefits	• More detailed measurement of heat dissipation in the meniscus area. • More sensitivity at the moment of early identification of troubles based on strand shell growth. • Continuous online information on casting gap lubrication and rim formation
follow-up projects	• Innosolid • Transient • FOMTM • RealTimeCastSupport • ConSolCast • OpConDigiCast
Overall assessment	2

PROJECT: **FOMTM (RFSP-CT-2012-00007)**

Application of innovative fibre optical thermal monitoring at CC-billet mould for improved control.

Questions	Information
success/failure of the proposed solution	Project turned out successfully. After overcoming some initial difficulties, the FOS system was operating successfully at Gerdau-Sidenor. Two billet-moulds were equipped, each with 40 fibre-optical-sensors and about 340 heats are measured. No significant indications of wear caused on the harsh environment at the caster could be observed. Some of the sensors were still working after the revamping procedure. The usefulness of this technology could be demonstrated for comparisons of both mould powders and strategies of addition.
practical application of the results	Monitoring the mould wall temperature by FOS indicates for example the current thermal profile, the position of the meniscus level and the influence of electromagnetic fields like stirring systems or brakes. Use of FOTS data to show the dependence of temperature behaviour and longitudinal crack formation and further surface defects. Operators are enabled to react on malfunctions at an early stage also by generated alarm values. Development of strategies for optimized casting powder additions.
spread of results among the steelmaking community	BFI website and BFI annual report/factsheets 2014-2018. Results were also presented to a working group of European steel producers.
TRL at the beginning of the project and at the completion	From TRL5 to TRL6/7
economic benefits	More detailed measurement of heat dissipation in the meniscus area. More sensitivity of early identification of troubles based on strand shell growth. Improved monitoring and optimization of the casting process
follow-up projects	Innosolid, ConSolCast, RealTimeCastSupport, OpConDigiCast
Overall assessment	2

PROJECT: **NDTSLAB (RFSP-CT-2013-00004)**

Innovative non-contact, non-destructive prototype system for automatic detection of surface and subsurface defects in slabs

Questions	**Information**
success/failure of the proposed solution	The EMAT system has been demonstrated to be capable of finding defects in as-cast steel slabs that cannot be found visually with grinding or scarfing of the surface. With tuning of the signal to noise ratio in the surface scan image defects as small as 5 mm^2 can be detected. Defects smaller than this are not readily detected by the EMAT system.
practical application of the results	The inspection results will be sent to the overall quality & tracking system. In the event of slabs being defective, there are several possible options: - Remedial descaling (HIPERSCALE project) - Product downgrade to less critical application - Rejected before charging to the furnace
spread of results among the steelmaking community	As far as I know, mainly the final report; non notice of further exploitation/dissemination
TRL at the beginning of the project and at the completion	From TRL4 to TRL6
economic benefits	Improved productivity and product quality, saving of energy, material and working time, reduced production costs
follow-up projects	2 proposals for a follow-up project failed
Overall assessment	2

PROJECT: SHELL-THICK

Improvement of the continuous casting through new system for the real-time measurement of Shell Thickness in several locations of the casting strand

Questions	Information
success/failure of the proposed solution	FENO/
practical application of the results	A tool providing the operators with real-time information on the billet solidification process as cross-section shell thickness where is the device and metallurgical length (if installed two devices) A tool providing the operators with real-time information about surface defects (bulging, depressions & rhomboidity) on the billet Solidification process optimisation tool: this tool (based on the output of the previous tools) would allow the operators and/or managers to define the optimal continuous casting process parameters to improve quality (minimising the generation of surface defects) and productivity Direct exploitation by ERGOLINES according to the provisions established in the SHELL-THICK Consortium Agreement with the developer partners (UBATH and TECNALIA) and future agreements of upcoming projects
spread of results among the steelmaking community	Maintenance of the public website (www.shell-thick.eu) with information about the development of the project. Poster in the 9th World Congr. in Ind. Proc. Tomography: Odedo V., Soleimani M. and Spagnul S. “Magnetic Induction Tomography for imaging defects and deformations on external surfaces”. Proc. of the 9th World Congr. in Ind. Process Tomography, WCIPT9, Bath, UK, Sept. 2018; pp. 211–217. ; Ma L., Spagnul S. and Soleimani M. Scientific Reports 7, Article number 14502 (2017); Li F., Spagnul S., Odedo V. and Soleimani M. “Sensors 2019, 19 (13), 3005.
TRL at the beginning of the project and at the completion	From TRL4 to TRL6
economic benefits	By considering statistically indicative values for typical European steelworks, the amount of scrap steel to be remelted due to rhomboidity and corner defects is indicatively 200 to 600 t//year by steel plant. By considering an average value of 500 EUR/ ton of construction steel, estimated annual savings of more than 300.000 EUR for an average steel plant. Expected more than 0.07 t of CO_2/t steel with consequent annual reduction of the CO_2 emissions of more than 40 t of CO_2 per steelwork
follow-up projects	Just finished
Overall assessment	2 (project being finished) potentially 3

PROJECT: CASTDESMON (RFSR-CT-2003-00003)

Improvement, control and prediction of cast and rolled product quality by the development of an understanding of how the casting machine design and condition affects solidification and the development and application of novel engineering monitoring techniques

Questions	Information
success/failure of the proposed solution	Project very successful. Improved means of predicting and controlling caster condition and cast product quality delivered.
practical application of the results	New and existing engineering and operational monitoring techniques (both on- and off-line technologies) for the mould and strand support areas have been delivered including: • Mould level detection – (VUHZ) EM level detector • Mould thermocouples – Established technique • Roll gap measurement – LVDTs • Accelerometers to identity "fingerprints" of mould oscillation defects has been developed further • Current monitoring system was developed to measure friction in the mould • Mould plate wear and distortion measurement • Mould taper measurement Modelling of taper relative to thermal conditions and steel grades Slab mould end plate and round bloom model – mould distortion Identification of surface bleeds based on mould plate using temperature measurements.
spread of results among the steelmaking community	Final report. A number of these techniques have since become widely used and in some cases are state of the art
TRL at the beginning of the project and at the completion	VUHZ from TRL 4/5 to TRL7 unable to calibrate **Rating - 1** MTM TRL8/9 at start **Rating - 3** LVDT Roll gap measurement. From TRL2/end TR7 **Rating - 2** Mould oscillation measurement using accelerometers. From TRL2 to TRL 7 **Rating - 1** Mould friction Measurement. From TRL2 to TRL7 **Rating - 1** Mould plate wear and distortion measurement (offline) On-line mould taper measurement. From TRL7 to TRL8 **Rating - 2** Modelling of taper. From TRL2 to TRL8 **Rating - 3** Identification of surface bleeds. From TRL2 to TRL7 **Rating - 2**
economic benefits	Enhance machine security and product quality. Improved techniques for design of mould taper improving plant performance and product quality
follow-up projects	Many of the measurement techniques are state of the art and used on many plants
Overall assessment	2 with some techniques 1

PROJECT: Magnetohydro (RFSR-CT-2007-00012)

Improvement to steel cleanness, castability and surface quality through the application of magneto- hydrodynamics during pouring and solidification

Questions	**Information**
success/failure of the proposed solution	The project was successful and delivered optimisation of EMS settings to maximise effect in multiple casting plants. The effect of EMS in the SEN was investigated using numerical and physical modelling.
practical application of the results	The main thrust of this project has been the application of electromagnetic stirring in the mould and strand to control segregation and inclusion distribution. Optimised EMS settings were developed to improve segregation and inclusion control in cast product. VASD showed that for crack sensitive grades bloom cast the EMS gave a high amount of equiaxed structure hence small quantity of non-metallic inclusions, reducing cracking. Tata optimized the combination of EMS and dynamic soft reduction to control internal cracking of low C nonmicroalloyed and V-microalloyed steels.
spread of results among the steelmaking community	The final report
TRL at the beginning of the project and at the completion	Optimisation of EMS settings Start TRL8/9 End TRL 9 **Rating - 3** SEN EMS Start TRL2 End TRL 4 **Rating - 1**
economic benefits	Improved product quality by significant increase of central equiaxed zone. Cost savings in reduced power consumption by optimising settings. Sidenor found power consumption reduced by 18%. Tata also reduced power consumption. Arcelor Mittal reported reduction of sliver defects of up to 85% and reduction in scarfing requirement of up to 66%
follow-up projects	There is evidence that there is still ongoing academic work in the field of SEN EMS a 2018 paper by Northeastern University, Shenyang China. A patent for SEN EMS was also applied for by Arcelor Mittal in 2018
Overall assessment	3

PROJECT: DIRECT DEFECT TOOLBOX-DDT (RFSR-CT-2011-00005)

Development of a toolbox for direct defect prediction and reduction through the characterisation of the meniscus-slag bed behaviour and initial shell solidification in Continuous Casting

Questions	Information
success/failure of the proposed solution	This was a complex with many approaches being developed. A number of physical and modelling tools were successfully developed to predict conditions which would lead to cracking. Combination of the results of different techniques were successfully corroborate results and tune the tune the mathematical models. Several techniques will require further development.
practical application of the results	SSAB - Change of Immersion depth of the SEN and change of peritectic starting powder for first slab after a flying tundish change. Good results (increased yield) from the plant trials. Tata - Switching off the EMBR during casting of IF steels result in an enhanced heat transfer in the meniscus area and reduce sub-surface and sliver defects.
spread of results among the steelmaking community	The final report A number of journal and conference papers including: ISIJ International, Ironmaking and Steelmaking, Acta Materialia, 10th International Conference on Computational Fluid Dynamics, 8th European Continuous Casting, 3rd International Symposium on Cutting Edge of Computer Simulation of Solidification, Casting and Refining, 9th International Conference on CFD in the Minerals and Process Industries, TMS2015 Annual Meeting and Exhibition, 4th International Conference on Advances in Solidification Processes (ICASP4), EUROMAT 2013, Solidification Workshop, Brunel University, UK, TMS2014 Annual Meeting and Exhibition, UK Space Meeting, Leeds, July 2013
TRL at the beginning of the project and at the completion	Numerical Modelling from TRL2 to TRL5 Physical Model from TRL5 to TRL6/7 Mould powder characterization from TRL2 to TRL5. Flux sampling techniques from TRL2 to TRL6/7
economic benefits	The proposed changes achieved a significant improvement in quality and process stability for the steel plants involved including reduced defects/Increased yield in cast Stainless steel slab and reduce sliver contamination in IF steels
follow-up projects	Unknown
Overall assessment	2

PROJECT: Direct casting of small section beam-blanks thanks to meniscus free casting technology - Beam-blank MFC project

Questions	**Information**
success/failure of the proposed solution	Demonstration project, 11/18 points validated
practical application of the results	Pilot casting only, no industrial trials during this project (2012) 2019: Beam blank casters now commercially available
spread of results among the steelmaking community	Final Report, no information regarding further spread found
TRL at the beginning of the project and at the completion	From TRL3 to TRL3-4
economic benefits	Project quoted substantial savings, but little data provided
follow-up projects	Nothing published found
Overall assessment	1

PROJECT: 7210-PR/141

Castability and surface quality of steels microalloyed with Ti or TiNb in continuous casting of thin slabs and beam blanks

Questions	**Information**
success/failure of the proposed solution	Changes in mould powder formulation and cooling strategies were successful.
practical application of the results	New lower viscosity mould powder developed. Changes in cooling strategies reduced faults
spread of results among the steelmaking community	Final Report
TRL at the beginning of the project and at the completion	From TRL4 to TRL6
economic benefits	Lower costs due to fewer breakouts
follow-up projects	None found
Overall assessment	2

PROJECT: **SupSysCC (RFSR-CT-2009-00033)**

Development of an integrative plant, process and quality supervisory system at continuous casting by the intelligent combination of sensors, data analysis and decision support techniques.

Questions	**Information**
success/failure of the proposed solution	More success for Slab casters than Billet. Slab mould oscillator monitoring very successful. Cleanness evaluation technique also successful.
practical application of the results	Mechanical mould oscillation monitoring highlighted issues that could be acted upon efficiently. Strand motor monitoring more difficult to apply due to caster design differences
spread of results among the steelmaking community	Final Report. Guidelines compiled as part of project
TRL at the beginning of the project and at the completion	From TRL 3 to TRL7
economic benefits	Nothing specific mentioned in project, but an accuracy of more than 80% of correct estimation of slab defect rate was quoted
follow-up projects	None found
Overall assessment	2

PROJECT: **FLUXFLOW (RFSR-CT-2003-00027)**

Enhanced steel product quality & productivity by improved flux performance in the mould through optimising the multiphase flow conditions & special regard to melting & entrapment.

Questions	**Information**
success/failure of the proposed solution	Success at Cogne Acciai Speciali plant
practical application of the results	Technique adopted as operating practice cast some steel grades
spread of results among the steelmaking community	As far as I know, mainly the final report; non notice of further exploitation/dissemination
TRL at the beginning of the project and at the completion	From TRL2 to TRL5 (assuming powder tailoring is a technology – as mixed with well definite operating conditions – and not a concept
economic benefits	Not known/available
follow-up projects	Relevant hints for LUBRIMOULD (R. 26173); SLAGFILMOWL (R.24988), DEFFREE (R. 25874)
Overall assessment	2

PROJECT: 7210-CA/905

Optimisation of mould powder performance in casting long products

Questions	**Information**
success/failure of the proposed solution	Success at lab level
practical application of the results	Technique adopted as operating practice cast some steel grades
spread of results among the steelmaking community	book The Casting Powders Book (pp.177-222)
TRL at the beginning of the project and at the completion	From TRL2 to TRL4 (assuming powder tailoring is a technology – as mixed with well definite operating conditions – and not a concept)
economic benefits	Not explicitly mentioned
follow-up projects	Some reference in SOLIMOULD
Overall assessment	2

PROJECT: **LSSEMIQUAL (RFSR-CT-2008-00008)**

Reduction in surface cracking in as cast low sulphur and calcium treated steels.

Questions	**Information**
success/failure of the proposed solution	Success at partners' (RIVA, Arcelor, Tata) plants
practical application of the results	Technique adopted as operating practice cast some steel grades
spread of results among the steelmaking community	Indications in the final report on the operating conditions followed and tailored on their own scenario
TRL at the beginning of the project and at the completion	From TRL2 to TRL5
economic benefits	Not explicitly known/available
follow-up projects	Relevant hints for ICCRACK
Overall assessment	2

PROJECT: **LUBRIMOULD (RFSR-CT-2009-00006)**

Identification of optimal mould lubrication conditions through an innovative hot and cold simulation method.

Questions	**Information**
success/failure of the proposed solution	Success at CAS and TATA plants
practical application of the results	Technique adopted as operating practice cast some steel grades
spread of results among the steelmaking community	Through the Final Report
TRL at the beginning of the project and at the completion	From TRL2 to TRL5 (assuming powder tailoring is a technology – as mixed with well definite operating conditions – and not a concept
economic benefits	Not explicitly mentioned/evaluated
follow-up projects	Not explicitly found
Overall assessment	2

PROJECT: **SLAGFILMOWL (RFSR-CT-2005-00012)**

Optimising slag film properties and determination of operational windows for lubrication, mould heat transfer and shell formation.

Questions	**Information**
success/failure of the proposed solution	Success at Corus Scunthorpe plant
practical application of the results	Deeper knowledge on powder –shell heat transfer mechanisms
spread of results among the steelmaking community	Via papers (see below)
TRL at the beginning of the project and at the completion	From TRL2 to TRL5 (assuming powder tailoring is a technology – as mixed with well definite operating conditions – and not a concept
economic benefits	Not mentioned
follow-up projects	Relevant hints for B. Stewart, M. McDonald, M. Hopkins, R. Burniston - Corus Research, Development & Technology, Middlesbrough, UK - Paper presented at the European Conference Continuous Casting of Steel, Riccione, 3-6 June 2008 La Metallurgia Italiana , luglio-agosto 2009 – pp.55-62
Overall assessment	2

PROJECT: **TRANSIENT (RFSR-CT-2009-00005)**

Effect of transients on quality of continuously cast products.

Questions	**Information**
success/failure of the proposed solution	Success at Gerdau- and AM Ruhrort plants. Five new caster monitoring systems were developed, of which four successfully installed on casting machines to obtain process/quality data.
practical application of the results	Several Benefits: rhomboidity reduction in microalloyed billets, strong reduction of rejection of medium carbon low sulphur microalloyed grades at the mill due to transverse cracking, and of rails rolled from ladle changeover, change of secondary cooling practice
spread of results among the steelmaking community	International Work-Conference on Artificial Neural Networks, Detection of Transients in Steel Casting through Standard and AI-Based Techniques, V. Colla et al., Development and application of a non-steady state strand solidification model, G. Stephens et al., 30th JSI,18-19 December 2012 Innovative monitoring techniques for better control of strand solidification, T. Lamp et al., 7th ECCC, Dusseldorf, 2011
TRL at the beginning of the project and at the completion	From TRL2 to TRL5
economic benefits	8% reduction in mould powder consumption, yield increase of forging grade blooms to over 90% and reduction of rejections to nearly 2% due to secondary cooling policy changes, 33% increase in yield of affected forging grade blooms by improved tundish end casting policies
follow-up projects	General reference in recent process monitoring projects
Overall assessment	3

PROJECT: EUR 19360 (no acronym)

Control of liquid slag carry-away and entrapment in the CC mould for a better surface and subsurface quality.

Questions	Information
success/failure of the proposed solution	Main project focus is on numerical and physical modelling, as well as plant trials to determine mould conditions that improve slab surface and subsurface quality. Several modelling tasks were carried out successfully including modelling of the slag-metal interface (e.g. standing wave), slag layer modelling and nozzle design effects in 3D. However, coupling of these models with heat transfer was not possible. The physical modelling was carried out successfully on liquid metal with low melting point ($ZnBr_2$) and water with different media to simulate slag (e.g. silicon oil, paraffin, etc.). The modelling work was able to successfully propose different mechanisms for slag carry-over and entrapment. These are based on vortex formation and shear rate at the interface due to flow coming from the jet and upper roll.
practical application of the results	Plant trials were carried out successfully at a slab caster in Raahe, Finland. Several modifications to nozzle design were proposed and tested based on the numerical modelling work to optimize standing wave (which was found as high as 37 mm at 1.75 m/min). Samples were taken from 1800 x 150 mm slabs to perform inclusion analysis finding mostly alumina and manganese sulphides. Slag entrapments were not detected in this analysis. Useful theoretical background and strategies for analysis of the critical velocity were presented. These are still in use today.
spread of results among the steelmaking community	No dissemination actions for the project results are described in the final report. It is unknown it the results from the research led to publications in Journals or Conferences.
TRL at the beginning of the project and at the completion	Numerical modelling: TRL2 to TRL5 Physical modelling: TRL 1 to TRL3 Plant Trials: TRL5 to TRL7 Overall: TRL1 to TRL7
economic benefits	Not available
follow-up projects	Not available
Overall assessment	2

PROJECT: EUR 19850

Optimisation of the straightening process in continuous casting

Questions	Information
success/failure of the proposed solution	Measurements of strain indicators were carried out both off- and on-line at CORUS IJmuiden. This included successful measurement of strand deflection during inter-roll bulging. Roll forces, surface speeds and trapezium shape distortion were also measured successfully. MPI successfully developed improved 3D numerical models in FEM to simulate bending. Finally, a multi-beam model was developed by CORUS R&D. All these models were used successfully to predict the evolution of stress-strain during the straightening process.
practical application of the results	The applicability of model predictions was assessed and validated in plant trials in 2 slab casters. Both models and trials confirm bulging deflections on the order of 0.3 mm. Although roll forces were accurately predicted by the models, surface speed could not be captured precisely in simulations. Trials also confirmed that the trapezoidal shape is caused by the unbending regardless of the unbending type (single point or multi roll). The dynamic Modelling provided the most comprehensive analysis of bending/unbending in slab casting at that point of time.
spread of results among the steelmaking community	No dissemination actions were taken.
TRL at the beginning of the project and at the completion	From TRL2 to TRL6
economic benefits	Not available
follow-up projects	None
Overall assessment	2

PROJECT: 7210-PR/012

Control of the dendritic structure of the initial frozen shell in continuous casting

Questions	Information
success/failure of the proposed solution	The project developed successfully new mould geometries for better control of the dendritic structure of the initial frozen shell in the continuous casting of billets. The new moulds include an increased radius at the corners and face bulging (i.e. in-built parabolic taper). Work at Sidenor confirmed the influence of corner radius and face curvature on subsurface defects and quality of the rolled bars by means of metallurgical investigations on billets produced from trials with the new moulds. CSM successfully developed a model to describe solidification of the steel inside the mould. The 2D model included the effects of thermal field from the liquid steel and the influence of slag infiltration by means of a 1D model. Results of the simulations revealed that the risk of off-corner cracks is lower in the case of billets with large radii and concave faces. Simulations were carried out to identify the ideal taper conditions.
practical application of the results	Conclusions of the trials were that the new mould geometries improve quality of the rolled product with a decrease in scrapping of ca. 30 %. Increased radius showed a clear beneficial effect, while bulging was ineffective. Despite the improvements, significant operational investments would be required to adapt production facilities to the proposed geometries. These costs are not justified by the % of decrease of rejection rates. Furthermore, there are problems with stacking and manipulation of these billets due to their curvature which require additional measures for their storage and transportation. Nevertheless, the models could be applicable for testing other mould designs.
spread of results among the steelmaking community	No particular dissemination actions were described in the report.
TRL at the beginning of the project and at the completion	From TRL2 to TRL7
economic benefits	Despite the improvements, other modifications arising from the manipulation of the products after casting offset the possible benefits. Thus, the new mould geometries were not implemented in full production.
follow-up projects	None
Overall assessment	2

PROJECT: EUR 21445 (no acronym)

New secondary cooling patterns for peritectic and micro alloyed steels

Questions	Information
success/failure of the proposed solution	The project developed new cooling strategies based on numerical modelling of secondary cooling, laboratory studies of hot ductility and evaluation of as–cast microstructure. However, work at CORUS was greatly hindered due to internal/external factors. Work by the other 3 partners was carried out successfully with varied degrees of success. ProfilARBED decreased successfully longitudinal discontinuities and transverse defects on beam blanks. Internal discontinuities did not affect the surface quality. At CRM, metallurgical studies shown that hot ductility improvements are achievable by a grain refining treatment consisting in intense cooling followed by self-reheating. The ductility drop associated with phase transformation is suppressed for grades with and without micro-alloying elements, but not with Niobium. For #voestalpine Donawitz, the influence of the casting parameters to the crack susceptibility of peritectic and microalloyed steel grades was successfully described and a numerical model for new cooling strategies was successfully developed to calculate the possible use of a quenching box (in zone 6).
practical application of the results	Some partial trials were conducted at CORUS in US and UK, with varying degrees of success. The core of the trials could not conducted due to delays, external/internal factors not related to the project. The feasibility of the thermal path proposed by CRM after metallurgical studies was not possible as originally expected. At voestalpine, trials were carried out in a bloom caster and results were validated by measuring the diameters of the white bands that formed at the final stirrer. This shown that the calculated subsurface temperatures enable the austenitic-ferritic transformation and a positive effect on cracking.
spread of results among the steelmaking community	No particular dissemination actions were taken.
TRL at the beginning of the project and at the completion	From TRL3 to TRL6
economic benefits	Not available
follow-up projects	None
Overall assessment	2

PROJECT: RFSR-CT-2012-00011 INNOSOLID

Investigation of innovative methods for solidification control of liquid steel in the mould

Questions	Information
success/failure of the proposed solution	A correlation between increased surface crack defects and increased mould heat flux was successfully found. Numerical model enabled the development of an adjusted design for the cooling circuit in the copper mould plates. A FEM model was utilised to compute the resulting heat flux in the copper plates. Characterisation of casting powders was carried out successfully. The Fibre optic temperature measurements (FOTS) system was successfully implemented at Salzgitter slab caster providing a higher resolution in space and time for temperature measurements than thermocouples.
practical application of the results	Three measuring campaigns were successfully performed. Assessment of the pilot plant cast product has indicated that there is a significant difference in surface quality. There was a clear improvement of surface quality linked with the mould surface profiling for the peritectic casts. Microstructural examination of the oscillation marks showed no remarkable difference internally. The oscillation marks were generally of the “hook” type; however, the depth of the oscillations marks was reduced. There is little or no evidence of difference within the dendritic structures on a microstructural scale within the product surface. Small longitudinal surface marks relating to the mould grooves were apparent however these should not have any significant impact on further processing as they are likely to be removed by scale loss during reheating if the product is not scarfed
spread of results among the steelmaking community	Two conference presentations: - Schäperkötter, M.; Müller, P.; Feldmeyer, B.; Tscheuschner, C.: “Industrial investigations of fibre optical sensor instrumented thick slab caster mould.” 9th European Continuous Casting Conference - ECCC 2017, Vienna, Austria. - Tscheuschner, C.; Schäperkötter, M.; Müller, P.: “Analysis and optimisation of mould cooling conditions by application of CFD modelling and verification in industrial trials.” 9th European Continuous Casting Conference - ECCC 2017, Vienna, Austria.
TRL at the beginning of the project and at the completion	From TRL5 to TRL7
economic benefits	Not available
follow-up projects	2 RFCS projects with FOTS
Overall assessment	2

PROJECT: RFSR-CT-2005-00011 SOLIMOULD

Enhanced as-cast product quality by optimised mould taper design

Questions	Information
success/failure of the proposed solution	The project could determine how the mould taper in combination with shrinkage, operational parameters and other conditions (wear and distortion) affect the as-cast product quality of carbon and stainless steels. This was done through a combination of plant investigations in long and flat products, numerical modelling and plant trials. A full strand inter-roll bulging model was successfully developed. Calculations showed that improved taper profiles can reduce the gap between mould and shell to avoid compression and distortion (e.g. rhomboity). Laser measurements to characterize the as-cast profile below the mould were unsuccessful due to hostile environment.
practical application of the results	Trials with different oscillation settings showed the benefit of reducing oscillation stroke and frequency. Reduced mould level setpoints (i.e. fluctuation range) could also benefit medium carbon grades where shrinkage rates are low. Project found that the interaction between the square shaped solid shells formed at the meniscus with a thermally distorted mould below the meniscus is controlled by mould taper and solid shell shrinkage. So, changing mould level affects heat transfer and consequently, the taper in the mould. Low frequency mould level oscillations occur as a result of inter-roll bulging and can be reduced by adjusting the stopper. All these findings were tested in plant with positive results. However, the conclusion is that applying an ideal in-built taper is not realistic due to the variety of steel grades in production, so there must be a compromise for taper design. Recommendations for Improved mould level control, oscillation praxis, and optimised taper were given instead.
spread of results among the steelmaking community	No particular dissemination actions were taken.
TRL at the beginning of the project and at the completion	From TRL2 to TRL5
economic benefits	Not available
follow-up projects	None
Overall assessment	1

PROJECT: PMAP (RFSR-CT-2012-00008)

Influence of composition and continuous casting parameters on the precipitation of microalloyed particles of B microalloyed steel grades and Mn alloyed steel grades

Questions	Information
success/failure of the proposed solution	Success at Tata Steel and Sidenor • SFEG knowledge has facilitated to industrial partners to identify different boron precipitates on as cast products, and the role played by this element on internal cracking of as cast products • The knowledge of B inducing cracking helped to optimize casting parameters for B steel grades • The influence of austenitic transformation and precipitation of BN and AlN on transformation stresses at the tertiary cooling clarified. Actions to take at industrial practice defined. • MnS secondary precipitation and its influence on surface cracking shown. • Mould powders, secondary cooling intensity and casting speed influence in surface quality of microalloyed steel grades has been shown when casting several slab CC steel grades.
practical application of the results	At Tata Steel the casting speed for casting some niobium microalloyed grades can be 15% increased without impairing the quality. The transportation speed increase along tertiary cooling has reduced transformation cracking. All these measurements led to a high saving estimated on 120.000 pounds/year. • At Tata steel: An improvement in surface quality achieved using a new mould powder with a slightly lower basicity. At Sidenor the industrial implementation of knowledge developed has help to reduce rejection of as rolled bars of microalloyed steel grades. An improvement of internal quality of as cast high carbon boron steel grades achieved.
spread of results among the steelmaking community	Following publications were done along the project: • “Hot Ductility Behaviour of Microalloyed High Manganese Steels, 2nd Int. Conf. on High Manganese Steels”, Abstracts Booklet, Aachen/ Germany, August 2014 • “Influence of composition and continuous casting parameters on the cracking of B-microalloyed and

	high Mn steel grades" 8th European Continuous Casting Conference (ECCC-2014), 23 - 26 JUNE 2014 Congress Graz, Austria • "Hot- Ductility and Precipitation Behavior of Boron in Nb- V- Ti Microalloyed Steels for CC" 8th European Continuous Casting Conference (ECCC-2014), 23 - 26 JUNE 2014 Congress Graz, Austria • "Behaviour of Boron and Manganese in Nb-V-Ti Microalloyed Steels for Continuous Casting" 1st ESTAD & 31st JSI , Paris/ France, 7th-8th April 2014 • "Hot ductility behavior of boron containing microalloyed steels with varying manganese contents" Met. Trans. B,2015, Vol. 46, N. 3, pp 1400-1408. • "Role of boron on the formation of internal cracks in microalloyed high manganese steels for CC". METEC and 2nd ESTAD Conference. Dusseldorf 2015. • "Effect of cooling speed and varying strain rate on the second ductility minima in microalloyed, high manganese steels. TMS, Orlando/ USA, 15.-19. March 2015 (144th Annual Meeting & Exhibition) • "The effect of boron addition on precipitation and hot ductility of 1.5Mn-0.1Nb-Ti carbon steels in as-cast condition". International Conference on Processing of Advanced Materials, THERMEC'2016, May 29 – June 3, 2016, Graz, Austria
TRL at the beginning of the project and at the completion	From TRL2 to TRL6
economic benefits	At Tata Steel estimated saving on 120.000 Pounds/year. At Sidenor a reduction of 1% minimum of the rejection of microalloyed rolled bars will be 0.75 M€/year.
follow-up projects	PMAPIA
Overall assessment	2

Project: Precipitation (RFSR-CT-2005-00014)

Precipitation behaviour of microalloyed steels during solidification and cooling

Questions	Information
success/failure of the proposed solution	Success at Corus, Sidenor, VASD and ArcelorMittal,
practical application of the results	Using data and samples obtained from the 4 industrial casters; pilot plant and laboratory investigations by all the partners and supported by thermodynamic, numerical and kinetic modelling following results obtained: • Effect of heat transfer from strand formed within the mold using different mold powders on the precipitates and consequential surface quality: • Effect of secondary cooling strategies on precipitation and cracking of as cast product. • Effect of strand cooling using different cooling bed conditions on precipitation and thermal stress cracking: • Development and installation of Magnetostrictive Linear-Position Sensor (MLPS) to measure on line billet deformation
spread of results among the steelmaking community	Following papers published based on the research: • Thermodynamics, Precipitation Kinetics, Coupled Models Development: Three Main Axes of Research in Physical Chemistry at ArcelorMittal Global R&D Maizières Process. Steel research int. Vol. 81, N.9,772-779, 2010 • "Hot ductility and transverse cracking of continuously cast C-Mn-Al-Nb-Ti steels", 6th ECCCC, Riccione, Italy, June 2008. • "Precipitation behaviour of Nb – V microalloyed steels during solidification and cooling"., 7th ECCC 2011. Dusseldorf • "Prevention of corner cracks in slab continuous casting" La Revue de Met. 106 (11), 508-517, 2009
TRL at the beginning of the project and at the completion	From TRL2 to TRL6 as the design of needed secondary cooling, and tertiary cooling for casting microalloyed steel grades was proposed, tested and incorporated on industrial environment.
economic benefits	In one of the companies, Sidenor, the 1% reduction on the rejection of rolled bars related to defects coming from the CC form microalloyed steel grades produce a saving of 0,75 M€/year
follow-up projects	KINPCC, PMAP, PMAPIA
Overall assessment	2 (success items different from plants)

Project: KINPCC (RFSR-CT-2011-00008)

Kinetics of precipitation during continuous casting of plate steels

Questions	**Information**
success/failure of the proposed solution	Success at Dillinger and voestalpine Stahl The aim was to prevent surface cracking in CC of microalloyed steel due to the presence of nitrides and carbides precipitates. Slab samples in as-cast or heat-treated conditions, together with lab samples investigated by electron microscopy. Particle size distribution investigated, and the nucleation history derived. The precipitation kinetics knowledge helps to optimize the kinetic model of the MatCalc software. The model considered capable to forecast the precipitation of the main nitrides and carbides during CC.
practical application of the results	At Dillinger, the understanding of the precipitation kinetics helps to predict the cracking susceptibility of a given steel grade during CC given its chemistry and the process parameters. At voestalpine, the knowledge gained may allow to improve the secondary cooling in order to reduce the precipitation and improve the steel ductility at high temperature. The thermal cycle simulator may be used in order to predict the precipitation behaviour of new steel grades during continuous casting.
spread of results among the steelmaking community	An oral presentation describing the alternating Nb/Ti-concentration due to cyclic cooling was given at EUROMAT2013 by Wojcik T. [TUW] Some results from DH were also used in the frame of the PhD thesis of Charles-Edouard Muller [DH], Technische Universität Berlin.
TRL at the beginning of the project and at the completion	From TRL2 to TRL6
economic benefits	VA mention that surface cracking of slabs on 0.08-0.20 % C microalloyed steel grades produce a high rejection of plates due to surface transversal cracks on slabs. The project seems to help to reduce that problem.
follow-up projects	PMAPIA
Overall assessment	2 (success items different from plants)

PROJECT: 7210-CA/182,183,334,904

Improvement of internal quality by controlling the microstructure of microalloyed cast steels.

Questions	**Information**
success/failure of the proposed solution	Success at two industrial partners Dillinger Hütte and Imatra. Also, for steel plants related to IRSID.
practical application of the results	Mould EMS influence on Internal microstructure higher influence that superheat, secondary cooling or casting speed. When no M-EMS: the CET is controlled by superheat. Primary and secondary arm spaces no dependent with casting parameters, and some dependence on C and S content of the steel.
spread of results among the steelmaking community	"Investigation of the solidification structure on continuously cast slabs" steel research 70 (1999) No. 10, p. 403/11 -Master Thesis at the Universität des Saarlandes.
TRL at the beginning of the project and at the completion	From TRL2 to TRL6
economic benefits	No mention in the report
follow-up projects	Not explicitly evident
Overall assessment	2 (success items different from plants)

PROJECT: 7210-PR/084

Determination of high temperature surface crack formation criteria in continuous casting and thin slab casting.

Questions	**Information**
success/failure of the proposed solution	Success at Rautaruukki, Dillinger Hütte, TKS. • Surface cracks mainly related to oscillation marks (OSM) and big austenite grain boundaries (AGB). • Thermal cycling enough to produce cracking.
practical application of the results	• Intensive cooling pattern on Dillinger CC5 • Oscillation strategy with non-sinusoidal mode, high frequency and stroke on Rautaruukki CC6
spread of results among the steelmaking community	"Improvement of surface quality on peritectic steel slabs" steel research 73(1), 15-19, 2002
TRL at the beginning of the project and at the completion	From TRL2 to TRL5
economic benefits	Not explicitly mentioned
follow-up projects	Not evidenced
Overall assessment	2 (success items different from plants)

PROJECT: 7210-PR/084

New secondary cooling patterns for peritectic and microalloyed steel

Questions	**Information**
success/failure of the proposed solution	Success at ProfilARBED. Limited industrial tests at Corus. Hot ductility improvement with temperature cycling around austenite transformation. SSCT Industrial tests with SSCT at Corus
practical application of the results	Corus find difficulties to apply SCCT technology: cracking due to temperature cycling. ProfilARBED: transverse defects located on the beam blank flange tips at loose side were reduced by decreasing secondary cooling intensity. On-line quenching is nowadays mainly applied when hot charging.
spread of results among the steelmaking community	Technology that seems necessary when hot charging of billets “A new secondary cooling concept for avoiding surface cracks during casting peritectic and microalloyed steels” 4th ECCC, Birmingham', 14–16; 2002.
TRL at the beginning of the project and at the completion	From TRL2 to TRL7
economic benefits	At ProfilARBED the solution of cracking problems by reducing secondary cooling has allow the suppression of the limitation of residual elements such as the copper (Cu) with related savings.
follow-up projects	Determination of high temperature surface crack formation criteria in continuous casting and thin slab casting (**7210-PR/084)**
Overall assessment	2

PROJECT: **DEFFREE (RFSR-CT-2008-00007)**

Integrated models for defect free casting

Questions	**Information**
success/failure of the proposed solution	Success in three plants (DUFERCO, CAS, DUNAFERR)
practical application of the results	The major results of the project are the three developed transient on-line models, LMI, CastManager and the inverse mould heat flux difference model and the critical parameters determined for steel quality.
spread of results among the steelmaking community	1. Reger M, Vero B, Csepeli Zs, Jozsa R: Prediction of Centerline Segregation of CC Slabs, In: 7th European Continuous Casting Conference. Düsseldorf, Germany, Düsseldorf: 2011, pp. x1-9. 2. Reger M, Vero B, Cepeli Zs, Szabo Z, Józsa R, Kelemen T: Effect of Supporting Rolls Settings on the Inner Quality of Cast Slabs, VIIIth. OATK Conference, Balatonkenese, Hungary, 9-11 oct. (2011) 3. Reger M, Kytönen H, Vero B, Szelig A: Centerline Segregation of CC Slabs, MATERIALS SCIENCE FORUM 649: pp. 461-466. (2010) 4. Réger M: Estimation of Strains and Stresses Developed on the Slab Surface, In: XVth FMTÜ Conference, Cluj-Napoca, Romania, 25-26 March,.2010.03, pp. 255-258
TRL at the beginning of the project and at the completion	From TRL2 to TRL7
economic benefits	The on-line models are general and were applied to other casters, and are currently used
follow-up projects	General reference in recent process monitoring projects
Overall assessment	3