THE NEW DANIELI SLAB CASTERS IN OPERATION IN ARCELORMITTAL DUNKERQUE AND FOS SUR MER SITES (FRANCE)[1]

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Abstract
ArcelorMittal, entered since 2004 a comprehensive renovation program aiming at the complete rebuilt of its largest slab casting complexes in Europe located in France, Dunkerque (Northern) and Fos-sur-Mer (Southern). Danieli has been identified as its technological partner for this renovation plan, one of the largest projects ever established, involving the reconstruction of slab casters covering an overall productivity of almost 10 million tons per year of slabs. The overall program involves the complete rebuilt of 4 two strand slab casters, 3 in Dunkerque and one in Fos-sur-Mer in step by step bases: already 3 casters have successfully put into operation, while the last one is expected to be started up during 2009. At Dunkerque site, 4 casters are going to be demolished and replaced by 3 Danieli slab casters, one per year. Two casters are already in operation confirming the goals of the project in terms of improvement of slab quality and increase of plant productivity. Also in Fos sur Mer a two strand curved slab caster has been completely demolished and replaced by a state of the art vertical curved caster. The design approach for the new slab caster in Fos-Sur-Mer has been done according to the modern engineering techniques, with a “maintenance free oriented” approach. According to the modern FMDSE analysis the technical risks have been identified in advance and the design has been improved directly during the engineering. RAMS analysis (Reliability-Availability-Maintainability-Safety) has been carried out all along the engineering stage, resulting in a design accomplishing a total calculated availability for the new caster of 98.9%.This paper describes the main features of the new casters as well as the main results already reached by the casters in operation.
Key words: Slab casters renovation; Technology for continuous casting of steel; RAMS - FMDSE - AMDEC analysis.

OS NOVOS LINGOTAMENTOS DE PLACAS DANIELI EM OPERAÇÃO NAS USINAS DA ARCELORMITTAL, DUNKERQUE AND FOS SUR

Resumo
ArcelorMittal, desde 2004 faz parte de um programa abrangente que visa à reconstrução completa de seus maiores complexos de Lingotamento de placas localizadas na Europa, França - Dunkerque (Norte) e Fos-sur-Mer (sul). A Danieli foi escolhida como parceira tecnológica para este plano de reforma, um dos maiores projetos já estabelecidos, que envolvem a reconstrução do Lingotamento de placas cobrindo uma produtividade global de quase 10 milhões de toneladas por ano de placas. O programa completo envolve a reconstrução completa de 4 lingotamentos de 2 veios cada, 3 em Dunkerque e um em Fos-sur-Mer, passo a passo baseado em: 3 lingotamentos já com sucesso colocado em funcionamento, enquanto o último é esperado para partir durante 2009. O objetivo deste desafiador programa é melhorar a qualidade, tornar mais competitivos os custos de produção, com à remodelação completa dos lingotamentos, introduzindo a auto manutenção com a aplicação de tecnologia .Em Dunkerque , 4 lingotamentos SMS vão ser demolidos (um lingotamento por ano) e substituído por 3 lingotamentos Danieli.Dois lingotamentos já estão em operação confirmando plenamente os objetivos do projeto em termos de melhoria da qualidade e aumento da produtividade da planta. Também em Fos sur Mer um lingotamento curvo de placas de 2 veios foi completamente demolido e substituído por um Lingotamento curvo vertical Danieli. A concepção de design para o lingotamento de placas em Fos-sur-Mer tem sido feita de acordo com as modernas técnicas de engenharia, com uma "auto manutenção”. De acordo com a moderna análise FMDSE os riscos técnicos foram identificados com antecedência e o design tem sido melhorado diretamente durante a engenharia. Análise RAMS (confiabilidade, Disponibilidade, Manutenabilidade e Segurança), foi realizada ao longo de toda a fase de engenharia, resultando em uma disponibilidade total calculada para o novo lingotamento de 98,9%. Este documento descreve as principais características dos novos lingotamentos, bem como os principais resultados já alcançados pelos lingotamentos em operação.
Palavras-chave: Renovação lingotamentos de placas; Tecnologia para o lingotamento contínuo de aço; Análises RAMS - FMDSE - AMDEC

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1 INTRODUTION

Sollac Atlantique plant, part of ArcelorMittal group and located in Dunkerque, North France, is one of the largest integrated steel plants in Europe with a market leading position, prominent in the automotive sector.
The slab casting complex has originally been conceived with 4 two strands machines, located in two separate melt shops.
Existing slab casters had been originally supplied in the seventies by SMS Demag with the same design, with curved roll diagram and 10,5 meters radius.
In 2004 ARCELOR management decided to enter in a comprehensive and ambitious renovation project of the entire casting complex with the following goals:

- Rearrange the production, in one melt shop only;
- Increase plant capacity to about 7 Mtpy, by increasing casting speed and availability of the casters;
- Reduce caster production down times, due to maintenance and non productive times, through a fully segmented design, the application of top feeding dummy bar practice and the use of a fully automatic robot-type segment manipulator for segment replacement;
- Increase the quality of slabs adopting new roll diagram concept, with special emphasis to IF grades for exposed automotive applications;
- -Increase casters reliability thanks to advanced low maintenance design;
- Strongly reduce maintenance costs.

These goals, summarized by ArcelorMittal in the project motto “acierie du future” (in French, the “melt shop of the future”), have been materialized by the decision to use for production only 3 of the 4 existing slab casters, to completely rebuilt these 3 casters according to the latest technologies and advanced roll diagram principles and the shut down of the fourth caster.
From the logistic point of view, in order to minimize the impact on overall plant production, the complete revamping of 3 of the existing machines has been scheduled in following steps, one caster per year, in correspondence to blast furnace scheduled maintenance shut downs.
The overall caster rebuilt order has been awarded on March 2005 to Danieli as technological responsible for the whole project, supplier of all new mechanical equipment and automation technological packages, as well as responsible of the execution of the demolition and installation works.
The overall project is at present already entered into his third and last stage, in fact:

- the first caster rebuilt , called CC23, entered in production on schedule with the first heat cast on December 19th, 2006,
- the second (called machine CC 22) cast his first heat on February 4, 2008
- the third one, called machine CC21, is at present under engineering phase, and the first heat is foreseen at the beginning of 2009.

2 GUIDELINES OF THE DANKERQUE SITE – SOLLAC ATLANTIQUE

The overall project involves almost the complete demolition of the existing casters with the installation of 3 new state of the art casting machines with renovated roll diagram and technological equipment.
Only structural parts such as casting platform, ladle turret, tundish cars and discharge areas are conserved practically unchanged, while the hart of the machine (from mould to last segment) is completely new.

Considering the extremely diversified product mix of the Dunkerque plant, the Customer decided to “customize” caster roll diagrams in order to have the possibility to dedicate each of them to a specific product mix. These are the solutions considered:
Machines CC23 and machine CC21 will be mainly focused on IF grades for automotive applications, hence the caster roll diagram is transformed from curved to “vertical curved”.
Machine CC22, on which High carbon grades for plate applications will be cast, remains curved.
In order to reduce the impact on existing facilities and civil works, to compact the necessary plant shut downs, the selected roll diagram and overall mechanical design has to keep constant the existing casting floor level as well as the bottom profile of existing caster civil works.

2.1 CC23 Twin Strand Machine

The first machine to be completely rebuilt (CC23) has been stopped in August 16, 2006 and put back in operation again on On december 19, 2006 with 121 days down time that included demolition of old equipment, modification of civil works and installation and commissioning of the new machine.
The new equipment include for the two strands: moulds, hydraulic oscillator, all segments, segments supporting structure, segment manipulator (robot type), top feeding dummy bar equipment.
The start-up of the new caster has been practically flawless, already exceeding the contractual performances for production rump-up (20 heats per day) on Dec 28, having cast 23 heats in 24 hours after 10 days only from first heat: half of the time contractually foreseen for this production milestone.
The old machine was partially segmented, 10,5 mt in radius with mechanical oscillator technology, bottom feeding dummy bar, segment extraction by EOT cranes and guides, no soft reduction applied.
The new machine features a 2,3 meters vertical length, 8,2 meters main radius, 33 meters containment, Air mist/water secondary cooling system, and takes advantage of all Danieli cutting edge casting technologies including INMO mould and integrated hydraulic oscillation , OPTIMUM segments, robot-type segment removal manipulator and PRD (periferically drilled)rolls.
Furthermore it is already designed for the application of dynamic soft reduction process and in mould electromagnetic flow control systems.
The main data are summarized in the following table.

2.1.1 CC23 twin strand slab caster main data after revamping

Table 1: Twin strand slab caster main data after revamping

Type	Vertical curved machine
Main radius	8,200 mm
Heat size	270 ton
Tundish capacity	48 ton
N° of strands	2
Support length	33 m
Length of vertical section	2300 mm
Productivity	2.400.000 tpy
Slab width	890 – 1980 mm
Slab thickness	247 mm
Mould	INMO MOULD Vertical type height 900 mm with adjustable width system during casting
Mould level control **Automatic Break out and sticking prediction system**	Eddy current type level detector Complete thermocouple array in mould with Thermal mapping
Oscillation **– Frequency** **– Stroke**	Hydraulically actuated 20÷300 cpm 0÷6 mm continuously adjustable
Steel grades	IF (automotive applications) Low Carbon, Medium Carbon, Peritectic, HSLA
Secondary cooling **Process**	Air mist and water Static soft reduction:provision for future dynamic process with liquid pool prediction mathematical model Multipoint bending/unbending
Dummy bar recovery system	Top feeding system dummy bar and segment manipulator
Segment change system for maintenance	Segment manipulator

2.1.2 CC23 Results

The new vertical curved design has been designed with the main goal to substantially improve slab quality for IF grades for automotive exposed applications that will represent the main product niche targeted by this caster.

Vertical length and main radius has been selected as the optimum compromise between metallurgical needs of improved internal and surface quality and reduced modifications of existing equipment (casting platform and exist roller ways levels).

The caster was immediately put back on production and the production ramp up exceeded expectations, fully demonstrating the reliability of the adopted mechanical and technological solutions.

In the following weeks the plant continuously improved are performances reaching during the months of January and February an average productivity of 22 (270 ton each) heats per day.

For instance, during the first two months (mid December 2006/ mid February2007, 260.000 tons of slabs have already been cast.

Even better results have been reached during the month of March, during which the caster overcome the best production record of the machine before his complete renovation.

We think that the best and more accurate business card for a plant maker is quoting the comments from the customers that use his equipment.

So, in order to describe the production ramp up results and the quality reached by the caster, we quote in the following the ARCELORMITTAL internal newsletter of Dunkerque site “Flash information Aciérie” (Flash information melt shop),

As testified by ArcelorMittal official documents:
“The CC23 caster produced 200.000 tons during the month of march 2007, three months only after his start up.
With 23,3 heats per day as average, this represents at the actual production schedule, a yearly productivity of 2,3 Mtpy
The old record of the slab caster (before renovation) was 179.000 tons per month”.
The superior slab quality reached since start up is testified by the fact that ,immediately after start up the machine has been dedicated to IF grades for automotive exposed applications: always according to ArcelorMittal documents :
“over these 200.000 tons produced, 162.000 tons has been produced via the RH, i.e. the 80% of the production.”

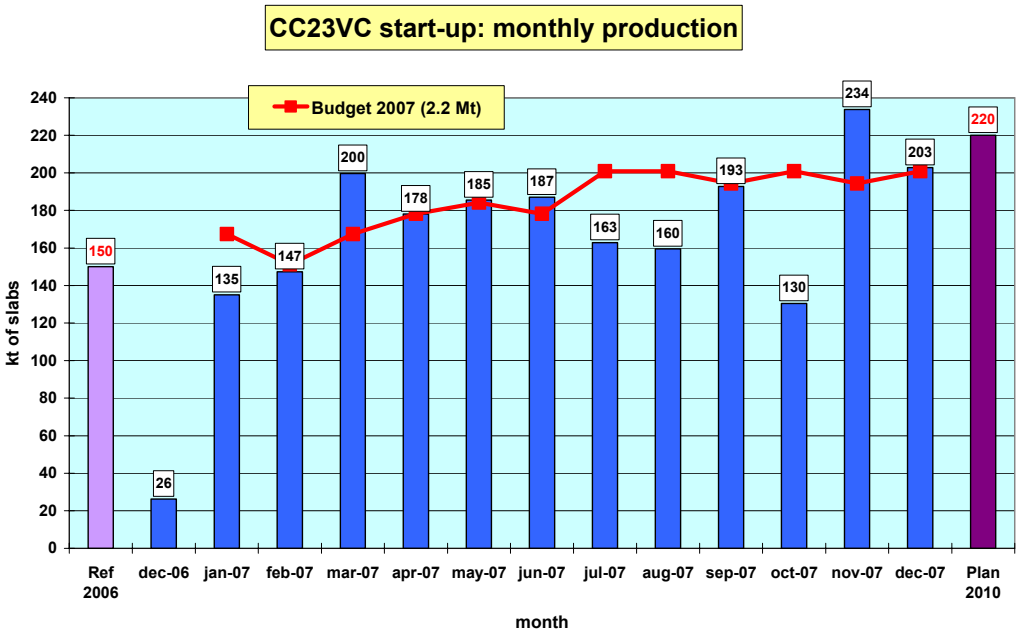

Figure 1: ArcelorMittal Dankerque site: Production of the first year

As far as quality is concerned, always using ArcelorMittal documents words:
“Let’s meet with the quality: results behind expectation.
The vertical part of the caster is performing his task; and the surface defects on the cold rolled coils have been suppressed, showing in the following figure.

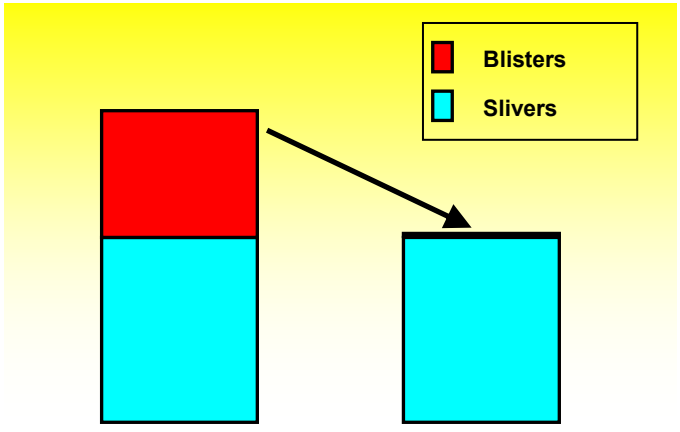

Figure 2: Surface defects suppressed on the cold rolled coils

After one year of stable production, as testified by the attached production schedule, we can state that all the goals of the phase one of the project have been reached. In fact the machine has been able to producing within the first 12 months of production more hat 2.150.000 tons in total, including the first months of ramp up and learning curve.
CC22 Dunkerque: twin strand slab caster, curved design
Also “PHASE 2” has been successfully accomplished.
The complete rebuilt of caster CC22, has been realized with the successful start up at the beginning of February 2008, after a record shut down of 91 days only.

2.1.3 CC22 main data

The CC22 is the caster in Dankerque that will be dedicated to produce the “special steel grades”.
In its rebuild the CC22 has been has been kept curved with main radius of 10,500 mm. In fact, it is believed beneficial for crack-sensitive steel grades both for internal and surface quality to maintain curve design, having no bending unit and extending the multipoint straightening zone over 8 roll pitches. Furthermore, keeping curved design, reduced impact in the civil works during reconstruction is required.
Wide range of steel grades are cast, being included practically in the product mix all the carbon steel grades such as:

- HSLA, both for strip and plate production, including Pipe steels
- Peritectic
- Medium Carbon
- Si steel grades
- High carbon and very High Carbon (with C>1%)
- And residual production of Interstitial Free and Low Carbon, too

Hereafter the main technical data of this new two strands curved machine.

Table 2: Technical data of new two strands curved machine.

Type	Curved machine
Main radius	10,500 mm
Heat size	270 ton
Tundish capacity	48 ton
N° of strands	2
Support length	30,8 m
Productivity	2.200.000 tpy
Slab width	890 – 1980 mm
Slab thickness	247 mm
Mould	Existing
Mould level control **Automatic Break out and sticking prediction system**	Existing Complete thermocouple array in mould with Thermal mapping
Oscillation	Existing, mechanically actuated
Steel grades	Medium Carbon, Peritectic, HSLA (for pipes and plate applications),High Carbon, Si Steel
Secondary cooling **Process**	Air mist Dynamic process with liquid pool prediction mathematical model Multipoint unbending
Dummy bar recovery system	Top feeding
Segment maintenance	Segment manipulator with a fully automatic control (robot)

2.1.4 CC22 results

The startup of the “PHASE 2” has been as fast as the one for the CC23 made 14 months before.

As reported in the Figure 3 at the nineteen days after start-up 30 heats have been cast, and more than 500 heats within 33 days. Particularly the actual production have been exceeded the production scheduled internally of the company, as reported in the Figure .

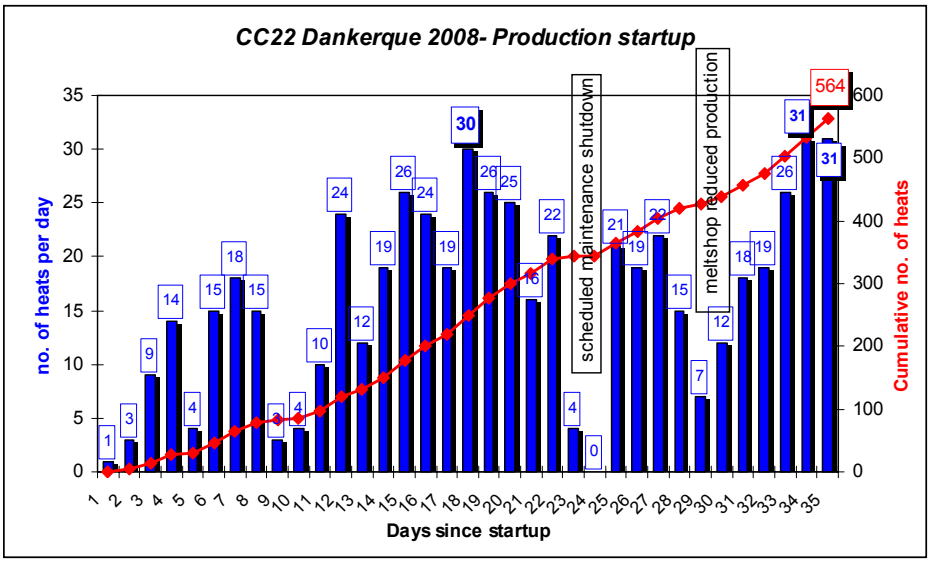

Figure 3: AM Dankerque CC22 production start-up

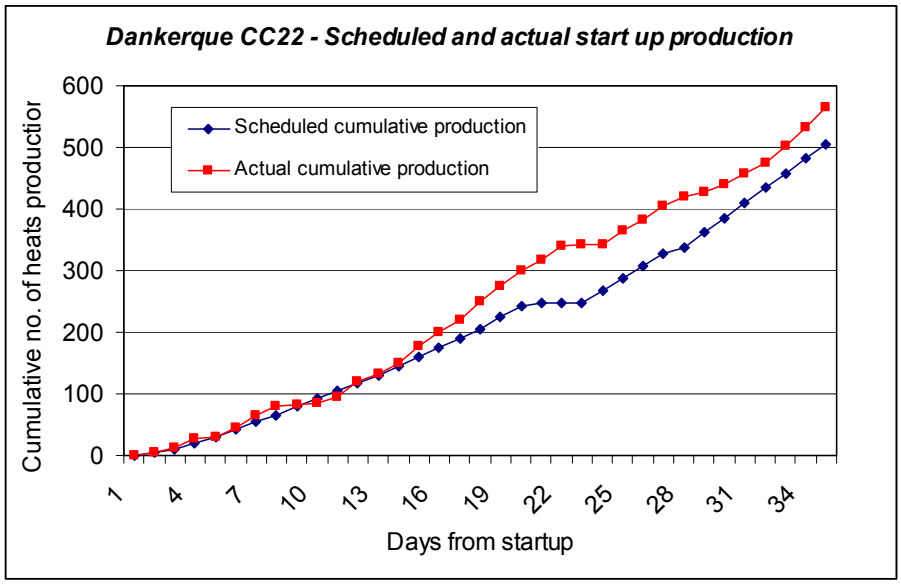

Figure 4: AM Dankerque CC22 comparison between scheduled and actual cumulative production (no. of heats)

All the steel grades being in the product mix have been already tested in the first 3 months after commissioning and actually fine tuning in casting practice is now on going for the most delicate ones. The reconstruction of CC1 in Fos sur Mer site – Sollac Mediterranee

The plant in Fos Sur Mer it is dedicate to a very wide range of steel grades, being concentrated in niche production that usually is not made in others plants of its group.

Mainly HSLA steel grades have been produced, but the testing is also actually including IF steel grades, Dual Phase, Low and Medium Carbon for a total production of 2,7 Mton per year.

2.1.5 Rams analysis for the CCM engineering

The renovation of CC1 in Fos Sur Mer, consisting in the demolition of an existing curved machine and installation of a new vertical curved caster, has followed an innovative approach in the concept of the engineering.
The aim of the ArcelorMittal management in Fos Sur Mer was to rebuilt a slab conticaster that could guarantee a reliability and availability at superior degree compared with the actual state-of-art of the machines.
The approach that has been chosen where based on the modern FMDSE, fault tree and FMECA analysis, guiding and checking constantly the solutions adopted for the CCM.
The FMDSE (RAMS) analysis has then been applied, being the following targets:

- **R***eliability*: Capacity of a system to realize a function in a determined time interval
- **A***vailability*: Capacity of a system to realize a function at a given time
- **M***aintainability*: Capacity of a system to be repaired in a determined time interval
- **S***afety*: Propriety of a system to present a risk due to its use

The entire machine has been de-structured in his in its basic units and these basic units have been analyzed in terms of its reliability, considering at the same time its relationship and interaction with its surroundings.
With the FMDSE the reliability and the connected possibility of failure have been considered, together with and time for recovery from the eventual failure. Whenever the total availability of the machine has not been reached, the most critical parts or components of the machine have been reviewed in order to elevate its availability of the machine.
This was the first time that this has been applied to a Continuous Casting Machine supplied by Danieli Davy Distington.
Mechanical and electrical design, together with the sensors of the possible failure have been analyzed and corrected whenever a deficiency of the system were found.
At the end the total machine availability has been calculate. Considering the correction taken during the engineering, the target of 98.56 % for the total available time have been hit.

2.2 CC1 Fos sur Mer: Twin Slab Caster

The rebuilt of the machine has been one of the largest done, since the curved machine have been converted in a vertical curved, but adopting a 9,300 mm as new main radius and with a vertical length of 2,680. The containment length has been extended up to 36,1 m.
New tundish cars, top fed recovery system for dummy bar and segment change manipulator required heavy civil investments.

2.2.1 CC1 main data

In the following table the main data of the machine have been reported

Table 3: Technical data of Fos Sur Mer twin slab caster

Type	Vertical curved machine
Main radius	9,300 mm
Heat size	335 ton
Tundish capacity	57 ton
N° of strands	2
Support length	36,1 m
Length of vertical section	2680 mm
Productivity	2.700.000 tpy
Slab width	830 – 1800 mm
Slab thickness	223 mm
Mould	INMO MOULD Vertical type Height 900 mm. with adjustable width system during casting
Mould level control **Automatic Break out and sticking prediction system**	Eddy current type level detector Thermocouple array in mould with Complete Thermal Mapping
Oscillation **– Frequency** **– Stroke**	Hydraulically actuated 0÷400 cpm 0÷16 mm continuously adjustable
Steel grades	IF (automotive applications) Low Carbon, Medium Carbon, Peritectic, HSLA,API, High Carbon, High Silicon
Secondary cooling **Process**	Air mist type Dynamic soft reduction process with liquid pool prediction mathematical model Multi point bending/unbending
Dummy bar system	Top feeding
Segment change for maintenance	With segment manipulator fully automatically controlled

2.2.2 CC1 (Figure 6) FOS SUR MER RESULTS

Because of its product mix, the most relevant results already achieved in Fos Sur Mer are mainly related to the slab quality and the final product after rolling.
Particularly for slab internal quality in Figure 5 the macro-etching of a Dual Phase steel grade it is reported. The slab has been produced 2 weeks after hot startup. The quality is considered prime class in terms of axial porosity and for internal quality and soundness since no kind of cracks has been found.

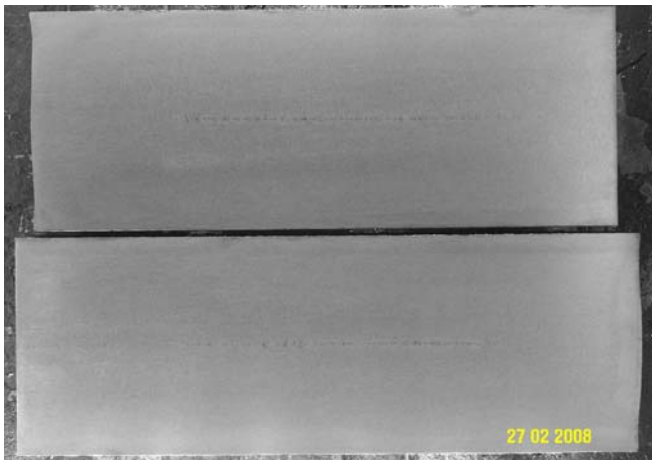

Figure 5: Fos Sur Mer CC1: macro-etching of a Weather Resistant steel grade

Even more important is the cumulative results regarding the surface quality. For ULC and Low Carbon steel grades in fact the surface quality is the best ever obtained, not

only in comparison with the old machine, but also with CC2 recently revamped (by other supplier) for the blisters detected on the strip surface by the on-line detection system at the rolling mill. The analysis is carried out considering independently the no. of heat-in-sequence and in any of these conditions the CC1 is better performing.

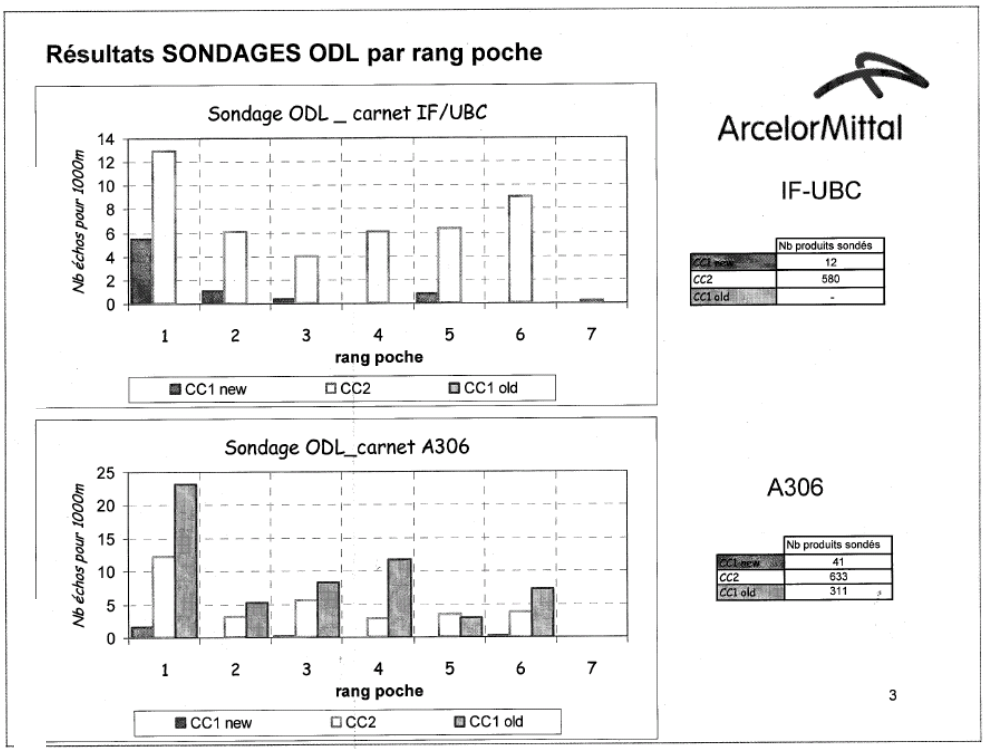

Figure 6: s Sur Mer CC1: Surface quality comparison after rolling for slab production at the end of April 2008

3 DDD: INNOVATIVE TECHNOLOGIES FOR SUPERIOR CONTINUOUS CASTING OF SLAB

Among other features, the new ArcelorMittal machines incorporate two of the most significant innovations developed by Danieli Davy Distington: the INMO mould (INTEGRAL MOTION mould) and the OPTIMUM segment.
Furthermore the robot manipulator developed for segment change, together with the top-fed recovery system for dummy bar system have allowed to reduce the maintenance shutdown time and largely simplified the maintenance operations

3.1 INMO (Integral Mould) Design (Danieli Patent)

The INMO mould concept (INtegral MOtion mould) was originally developed by Danieli Davy Distington together with POSCO, in order to strongly improve the quality of the slabs produced in the existing casters as well as to reduce maintenance issues with the goal to get "the perfect mould":

- Possibility to dynamically change the oscillation parameters according the real casting conditions (casting speed, metallurgical requirements, casting powders properties, etc.)
- Possibility to dynamically select a wide range of curves, particularly from sinusoidal to double sinusoidal with different asymmetry

This is done in the INMO mould by means of HYDRAULIC OSCILLATION control, developed by Danieli Automation and applied in all the oscillators for casting.

- Strict control of the geometrical tolerances in the oscillating parameters (limit deviations from theoretical oscillation set in automation system).

This is achieved in INMO mould adopting a “friction free” (i.e “wear and maintenance free” device: the rolling element” in charge of the strict guidance of the mould.

3.2 The Optimum Segment

Thanks to his experience id supplying advanced slab casting equipment, starting from 1959 with the development of some of the first slab casters in the world, Danieli Davy Distington team developed a new generation segment, incorporating

- robust design,
- easy maintainability concepts
- advanced process oriented features specifically conceived for the application of today’s new casting practices, namely dynamic soft reduction.

The FEM analysis has been applied for the calculated stress of the segments design (see Figure 7). Such kind of analysis is required to check if any weak point is present in the structure and a reinforcement of the structure is than applied.

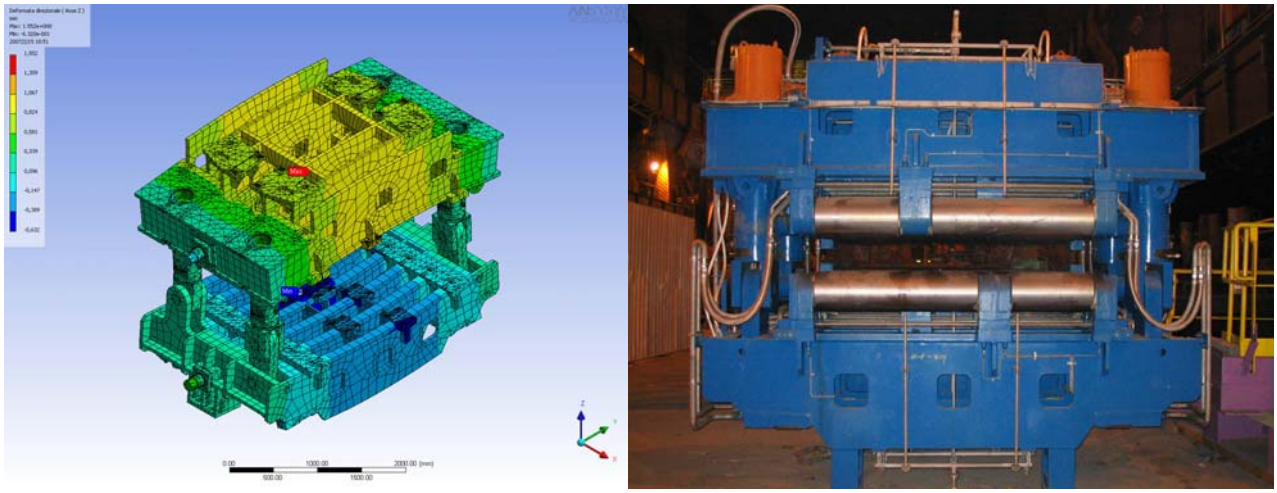

Figure 7: Optimum Segment (pictured) and FEM stress analysis made in the engineering stage for Horizontal Segment

The main features of the Optimum Segment design are:
Robust open ended design for good maintenance access:
No centre guide post
No Link bar restricting access
Minimal Spherical joints
Can be fitted in bow, straightener and withdrawal areas of the caster
Hydraulic clamping of rolls
Independent Drive Roll Hydraulics

3.3 The Robot Manipulator for Segment Change (Figure 8)

The segment change manipulator is designed and put in operation in all the ArcelorMittal above mentioned plants.

The maintenance procedure is shortened and simplified, since it is not needed to remove any cover from the casting floor.
With this robot system the replacement of the segments is shortened, easier and of course does not need the crane availability. No restriction in the building height and width has to be considered, been the robot structure independent from the existing.
For the CC22 the control system has been improved and actually the replacement of the segment is almost completely automatic.

Figure 8: Robot manipulator for segment change

4 CONCLUSIONS

Thanks to the continuous development of new equipment, such as INMO mould and OPTIMUM segment, Danieli Davy Distington has been selected as partner and supplier by some of the leading steel producers in the world for their new slab casters.
The successful start ups described in this article, followed by impressive production ramp-ups, testifies both the success of the joint development of the project in partnership with the ArcelorMittal and the reliability of the equipment.
High quality demands required for the slab soundness in the commissioned casters in ArcelorMittal France have been already recognized.
The full satisfaction of the customer we have been able to reach, the competitiveness of the proposed solutions and the tangible results of the casters already put in operation motivated ArcelorMittal to award to Danieli multiple orders for slab casers.
At present 8 Danieli Davy Distington slab caster (15 strands in total) are in operation or under project execution phase in ArcelorMittal plants in Europe, South America and Asia plants.