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INNOVATION SPECTRUM OF IRLE ROLLS[1]

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Abstract

The IRLE Group is a traditional German family owned foundry and machine shop existing now since 1693, being a worldwide known leading producer of casted rolls for steel mills, and non ferrous metal mills in general, since 1820. This paper is focusing developments of recent years achieved at IRLE, at compound work rolls for flat steel rolling mills. These rolls are used as work rolls in hot strip, Steckel, medium and heavy plate, skin pass as well as sheet mills. The paper is giving an overview not only of the improvements made in the material qualities as well as chemical and mechanical characteristics itself, but is showing also an overview of the research, investigations, investments and efforts made by IRLE in the respective production processes. The product developments were made together with key end-users aiming rolls with longer live time, higher wear resistance, higher resistance to torque, bending forces and corrosive environments, with optimized tribological characteristics (e. g., surface qualities of the materials) and thermal resistance to fire cracks. The innovations at IRLE will always follow cost relevance for customer´s benefit. The constant drive for an overall economic efficiency improvement of the rolling mill process is persecuted in the research efforts and targets. Thus, costs are saved for the end user with regard to prior processes in the production of flat steel, with stable high qualities of the resulting steel sheet coils. After a short description of the main materials, methods and procedures used to achieve these goals in an industrial production of bi-metallic rolls at IRLE, such as centrifugal casting technologies, the achieved results are discussed, giving an overview of the resulting compound rolls and material qualities available for the worldwide market nowadays. Compound materials that IRLE offers include steel, steelbase, steelbase graphitized materials, chrome iron or steel, indefinite chill, as well as semi and high speed steels. According to end users´ needs, a barrel hardness range of 65 to 85°ShC (470 to 690 HV) is available. Trends, such as the use of high speed steel rolls at plate mills and improvement of the metal cores on rolls which have to resist to heavier loads and torques shall be further discussed in future papers.

Key words: Work rolls; Hot strip steel and plate mills; Material and production process improvements.

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1 INTRODUCTION

The IRLE Group is a traditional German family owned foundry and machine shop existing since 1693. IRLE is a worldwide known leading producer of casted rolls for steel mills, and non ferrous metal mills in general, since 1820. Since 1884 IRLE is producing also heated rolls for the paper industry, so called calender rolls, as well as rolls for the plastic, rubber and food industry later on. This paper is focusing the developments of recent years achieved at IRLE, at compound work rolls for flat steel rolling mills. These rolls are used as work rolls in hot strip, Steckel, medium and heavy plate, skin pass as well as sheet mills.

1.1 Brief History of the Application of Rolls in Steel Mills

Modern steel rolling processes were developed, among other reasons, to increase the output of forged production processes (hammers). In 1793 a patent was granted to Henry Court for the use of a mill with grooved rolls, which enabled a 15 times higher production output than a hammer in the fabrication of iron bars. Even before that, waterpower driven slitting mills were used to produce raw material for nails or in adaptations, hoops for barrels and iron with half-round or other type of sections. In the first production step of slitting mills, flat bars of iron were passed between flat rolls, becoming thick plates. A modern tandem steel mill is shown in Figure.

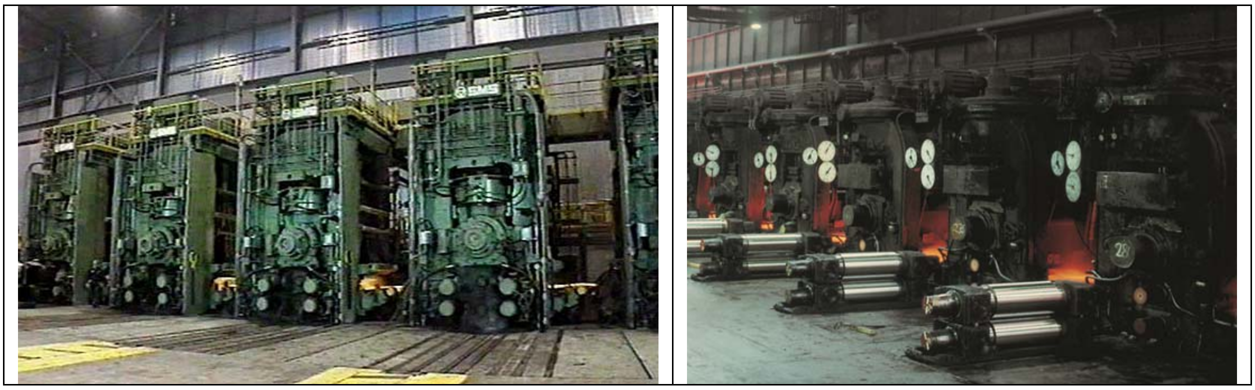

Figure 1: modern tandem steel mill (left) and a further example of a hot strip mill (right).

In 1820, the same year in which IRLE produced its first rolls for the steel industry, John Birkeshaw established the first rail rolling mill.(1)
With the advancements of technology in the rolling mills, the size of the work rolls grew rapidly along with the increasing demands to its materials, and in consequence, to the production processes of these rolls.

1.2Single Casted and Compound Rolls

At the beginning, all rolls were made of single casted iron or steel. In the end of the last century however, rolls with compound materials started to be developed more intensively. Searching for optimal characteristics at the core and shell of a roll, which materials have to withstand to different demands regarding its use in the mill, IRLE developed a series of compound (bi-metallic or multiple layer) rolls of different material types, with diverse chemical and

ISSN 1983-4764

mechanical (physical) properties, as well as developed different production processes to achieve the hunted target properties. Figure 1 shows a comparison between single casted rolls and compound rolls.
The product developments were made in close connection with key end-users (steel mills) aiming rolls with longer live time, higher wear resistance, higher resistance to torque, bending forces and to corrosive environments, with optimized tribological characteristics, such as roughness and friction (grip), and with thermal resistance to fire cracks.
The innovations at IRLE will always follow cost relevance without losing focus on the achieved technical advantages. The constant drive for an overall economic efficiency improvement of the rolling mill process is persecuted in the research efforts and targets. Thus, costs are saved for the end user in regard to prior processes in the production of flat steel, with stable high qualities on the resulting steel sheet coils.
Compound materials that IRLE offers include steel, steelbase, steelbase graphitized materials, chrome iron or steel, indefinite chill, as well as semi and high speed steels. According to end users´ requests, a barrel hardness range of 65 to 85°SHC (470 to 690 HV) is available.
In the further items, this paper is giving an overview not only of these improvements made in the material qualities and chemical and mechanical characteristics itself, but also an overview of the research, investigation, investments and efforts made by IRLE in the respective production processes.

1.3 Static and Dynamic Casting Processes for Compound Rolls

The first compound rolls were casted in two steps. First the whole mould is filled up with the liquid metal of type A, then - after solidification of a shell of certain thickness in the barrel area - a second liquid metal of a different composition (type B) is pressed into the mould, displacing the part of still liquid metal of type A. The result: a roll with two types of materials with different compositions, one of high wear resistance in the shell and one ductile in the core. This process is called static production of a compound roll by the displacement method.
Since the static production of a compound roll has certain cost and process disadvantages (for example high energy costs and ambiguous compound zone), the search for cheaper and better production alternatives were only a natural consequence. Certain combinations of compound materials also cannot be achieved by a static production due to unfavorable properties at the transition zone. The transition zone is defined as the interface zone between material types, where neither material A nor B does predominate. The transition zone is a failure sensible and critical zone of a compound roll and has to be observed in detail. Out of these challenges, the dynamic production processes for compound rolls were born, taking advantage of centrifugal forces known since centuries. This time they were applied at spin moulds in the casting procedure of molten metal. IRLE produced – according to its own patent – the world’s first centrifugal cast rolls and has actually the biggest vertical centrifuge installed in the world - see picture at

ISSN 1983-4764

Figure 23.[2]
Dynamic processes through spin casting can be subdivided in some categories, such as horizontal, vertical, inclined and combined. They are further explained in item 2.

1.4 Targets of the Research and Developments Works at IRLE

The targets of IRLE´s management for this research and production development efforts were very clear: to offer to all kind of flat materials hot rolling mills the best rolls available in the market in regard to live time, wear resistance, resistance to torque, bending forces, to corrosive environments and fire cracks,[3] in regard to tribological characteristics, such as roughness and friction (grip) and to further specific demands of the products´ end users. Mile waypoints to achieve this target were investments made in state of the art, partially self developed, production technologies and capacities. Included in these efforts were the production technologies for compound rolls, such as the spin casting production (horizontally, vertically, combined), in all sizes and weights demanded by actual mills and mill designers, including foreseeable future developments. But also in other productions steps and respective procedures, such as in the melting facilities and heat treatments furnaces, changes and investments were executed to achieve optimal results. Last but not least, only special attention on a key relevant variable in all production processes - IRLE´s employees - enabled the company to achieve success through continuous training of its worker teams. Frequent training is given in regard to new production technologies, resulting materials and products, and in regard to constant quality monitoring.

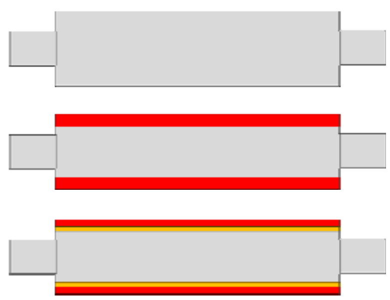

Figure 1: single casted roll (top), a bi-metallic compound roll (center) and a tri or multiple layer metallic compound roll (bottom). The different colors above represent different types of metallic materials.

Figure 2: installation works of biggest vertical centrifuge of the world at IRLE in Netphen-Deuz, Germany.

2 MATERIAL AND METHODS

2.1 Materials

ISSN 1983-4764

Table 1 is giving an overview of actual common work roll materials for hot rolling mills of flat products. Generic layout of different types of hot rolling mills of flat steel are shown in Figure 3.

2.1.1 Single casted rolls

Single casted rolls are mentioned here only for a completeness purpose of the overview of material types. Since this process is well and long known, we will not detail it further on.

2.1.2 Compound casted rolls

Compound casted rolls can be produced from 2 (bi-metallic) or more metal layers. These rolls are normally produced either by static or dynamic processes - compare Figure 4 b and Figure 5.

- **Bi-metallic or double poured**

Bi-metallic, double poured compound rolls have a core and shell of different materials and properties linked through an interface zone. The interface zone should be clear defined, with a small width but without weakening linking defects, bubbles or inclusions.
Theoretically and in accordance to the possibilities given by the production process, the thickness of the shell can vary from only some millimeters (thin) to quite some centimeters (thick). Practically, a shell which is too thick in relation to its core will lead to a fragile roll. On the other hand, a shell which is too thin will wear to fast and reduce live time of the roll. For that reason accurate shell thickness production and control is a major quality surveillance issue.
Shell thickness has also to be considered and sometimes adapted in concern to the roll neck outer diameters, due to limitations of the centrifugal production processes. A shell / core interface zone with a position to close to major roll neck outer diameters should be avoided. A mixture of harder shell with softer core material may appear on the surface of the necks leading to unequal wear behavior. Efforts to avoid shell material to penetrate in the roll neck regions during the casting have been made, but a breaking through successful result is not known or published until now.

- **Tri-metalic or multiple layers**

Tri or multiple layer compound rolls (like an onion) are not yet so frequent but have been tested and investigated, and should be treated or consulted in separate papers. Advantages may be more resistance to roll breakage and smoother interface zones between core and shells, however, also possible additional problems may appear at the additional interface zones.

2.2 Methods

As shown in Figure 4 and Figure 5 compound rolls can be produced either in static or dynamic processes.

2.2.1 Static processes

A stating castings process is mentioned here only for a completeness purpose of the overview of production procedure types. Since this process is well and long known, we will not detail it further on (refer to Figure 4).

ISSN 1983-4764

2.2.2 Dynamic processes

The use of dynamic processes, taking advantage of centrifugal forces, was mainly born out of the challenge to combine different materials at compound rolls as well as optimize its productions costs in relation to the static process. In dynamic casting processes, the mold into which the molten metal is casted is spinning around an axis. Dynamic casting processes can be subdivided into some categories accordingly to the orientation of the spinning axis and consequently of the centrifugal forces in relation to gravity. In the following the horizontal, vertical, inclined and combined processes are briefly explained (refer also to Figure 5).

- **Horizontal spinning**

The spinning axis is horizontal and thus in a rectangular angle (90°) to gravity. Refer to the left side of Figure 5 a. Theoretically, be-, tri- or multiple-layer compound rolls could be fully produced in horizontal centrifuges, including casting of the core. However, in an industrial production it is more efficient to cast only shells on the horizontal centrifuge, filling those shells which require a core later on and outside the machine, in a static vertical process. This enables short productions times for each centrifugally casted shell (refer also to following item d) - Combined processes). IRLE has 4 horizontal spinning machines.
Advantages and disadvantages of casting of shells through horizontal spinning are:
Advantages:

- high production efficiency. After shell solidification mold can be quickly taken out of the centrifuge and next shell can be produced.
- in general, lower investment cost in relation to vertical spinning.
- easy handling of molds with overhead cranes.

Disadvantages:

- rotating masses at high temperatures represent considerably safety risks to operators, installations and environment on floor level. Respective costly security measures have to be taken to avoid accidents.
- due to risk limitations, size and weight limitations have to be considered in respect to exponential increasing risk limitation costs.
- subsequently process steps outside the horizontal centrifuge have sometimes narrow time frames, due to cooling down of the casted shell.

- **Vertical spinning**

The spinning axis is vertical and thus parallel to gravity. Refer to Figure 5 b. Be-, tri- or multiple-layer compound rolls can be fully produced in vertical centrifuges, including casting of the core. The biggest vertical spinning machine is actually installed and producing at the IRLE Company in Netphen-Deuz, Germany.
Advantages and disadvantages of casting of compound rolls through vertical spinning are:
Advantages:

- normally bigger sizes and weights can be produced more economically in comparison to horizontal spinning processes.
- a high flexibility in sizes and weights is given.
- spinning also of the core material gives good possibilities to enhance core properties and qualities.

ISSN 1983-4764

- full casting procedure of compound roll is done in the centrifuge - roll is completely casted when taken out of the machine.
- possibility of higher spinning speeds in comparison to horizontal centrifuges enables better qualities in the casted materials.

Disadvantages:

- lower production efficiency in comparison to horizontal spinning.
- generally higher investment costs in equipment and installations.
- vertical handling of mold and rolls require higher overhead cranes and buildings.
- rotating masses at high temperatures represent considerably safety risks to operators, installations and environment. Respective costly security measures have to be taken to avoid accidents (centrifuge normally installed under floor level).
- parabolic curve of inside surface of shell and eventual shell material flow into lower roll neck.

- **Inclined spinning**

Inclined spinning is a combination of vertical and horizontal spinning, where a certain degree of inclination (for example 30° or 45° from horizontal position) is given to the spinning axis of the centrifuge. The process tries to combine advantages from vertical and horizontal centrifuges but naturally combine also some of their disadvantages.

- **Combined processes**

In combined spinning production processes of compound rolls, either the inclination of the spinning axis is changed during different phases of the production (between horizontal and vertical) or part of the product is done by a spinning procedure (shell), while the other part is statically casted (core). Advantages of combined spinning processes are given when roll sizes and weights are smaller.

ISSN 1983-4764

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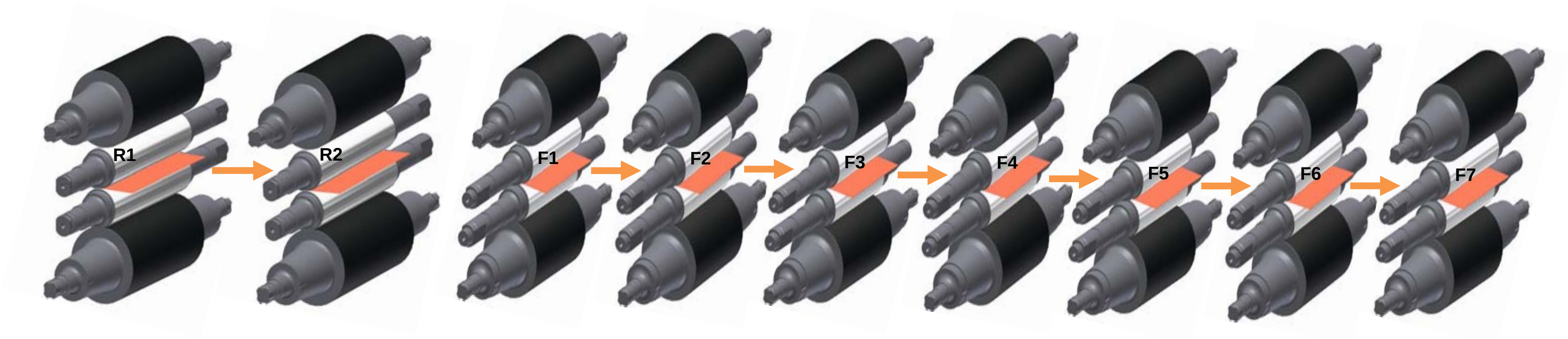
Generic plate mill
Generic Steckel mill
Generic skin pass mill
Generic sheet mill



Generic hot strip mill

Figure 3: Generic layout of different types of hot rolling mills of flat steel. Non specific back-up rolls are generally denominated as BUR and respective sequential number of stand or stand name. Eventual vertical edger rolls appearing in entrance and/or exit of rougher mills (R1, R2) are named as E1 or E2.

ISSN 1983-4764

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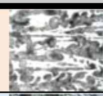
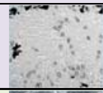
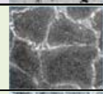
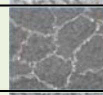
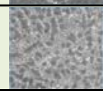
Table 1: Overview of casted roll materials for hot rolling mills of flat steel. At least 16 main different material sub groups are available. A lot of further sub categories can be split accordingly to concentration of alloys like chrome (Cr) or carbon (C), accordingly to mean concentration of carbides in the matrix of the microstructure or even to hardness ranges achieved at barrel surfaces

Materials and qualities of roll shells*				Position in the mill / # of mill stand**	Microscopic structure of shell material [x 100]
Family Market usual name	**Sub group Market usual name**	**Sub group IRLE name**	**Hardness range [°SHC]**		
Chilled cast iron	Chilled cast iron - single and double poured	K 30, K 40	55 - 82	SMW	
Nodular iron	Nodular iron - perlitic - single and double poured	SP	45 - 71,5	E1-2, R1-2, SMW	
	Nodular iron - acicular - single and double poured	SA	50 - 78,5	R1-R2	
	Nodular iron - heat treated, single poured	SP/A	40 - 68	E1-2	
Indefinite chill	Indefinite chill - double poured (ICDP)	I	50 - 85,5	PM1-2, SM1-2, SPW, SPB, SMW, (R1-2), F4-7	
	Indefinite chill enhanced - double poured	I plus	71,5 - 88,5	SM2, SPW, SPB, (R1-2), F4-7	
High chrome iron or steel	Cr-Steel - double poured	CR 5	55 - 85,5	SM1, R1-2	
	(Cr-Steel), Cr-Iron - double poured	CR 15	55 - 85,5	PM1, SM1, R1-2	
	Cr-Iron - double poured	CR 25	64 - 91,5	PM2, SM2, SPW, SMW, R1-2, F1-3	
	Cr-Steel enhanced - double poured	CR 5 plus	55 - 85,5	SM1, R1-2	
	(Cr-Steel), Cr-Iron enhanced - double poured	CR 15 plus	55 - 85,5	SM1, R1-2	

ISSN 1983-4764
Laminação Rolling
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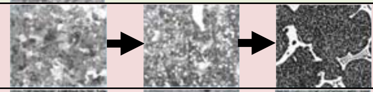
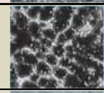
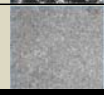
Materials and qualities of roll shells*				Position in the mill / # of mill stand**	Microscopic structure of shell material [x 100]
Family Market usual name	Sub group Market usual name	Sub group IRLE name	Hardness range [°SHC]		
	Cr-Iron enhanced - double poured	CR 25 plus	64 - 91,5	SM2, SPW, R1-2, F1-3, (F4-7)	
Steel / steelbase	Steel / Steelbase - single poured	ST 0, 10, 20, 30	31 - 59,5	E1-2, BUR	
	Steelbase - graphitized - single poured	STG 0, 10, 20, 30	31 - 59,5	E1-2, R1 (also two high stands)	
High speed steels	Special steel, high speed steel (HSS) - double poured	SST	71,5 - 94,7	R1-2, F1-3, (F4-7)	
	Modified special steel, semi HSS - double poured	SST mod.	72 - 91,5	R1-2	

** Roll shells are meant when roll is a compound roll (double poured). Developments at roll cores and necks will be treated in more detail in a future IRLE paper. Actually they are normally from nodular (or grey) iron.*

***Refer to Figure 3.*

ISSN 1983-4764

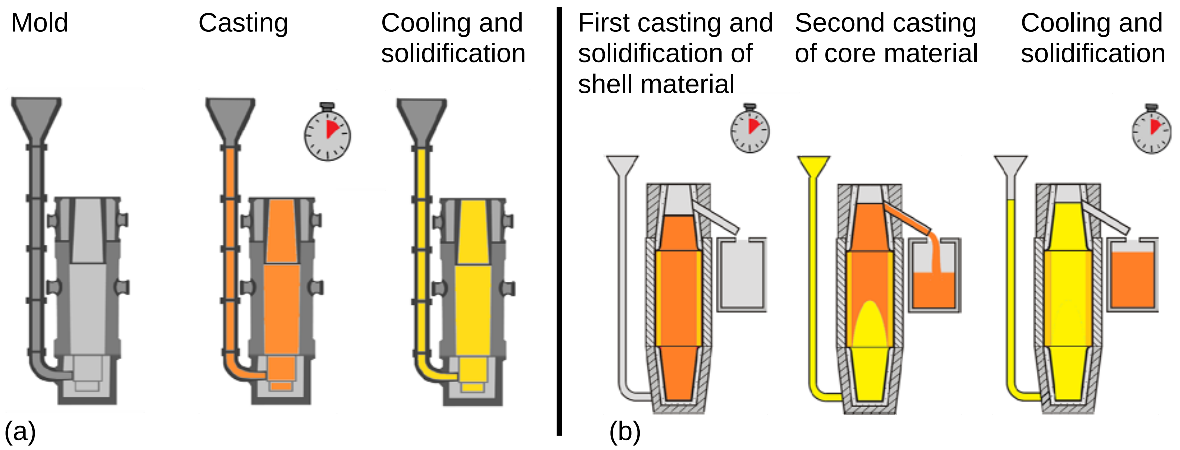


Figure 4: Static castings: (a) single casting - one material and (b) compound casting - different materials for core and shell.

3 RESULTS AND DISCUSSION

High production rolling mill rolls that are tuned with the specific rolling mill conditions are used nowadays in modern plate mill or hot strip mills. IRLE developed through and parallel to the methods mentioned before the respective materials for this optimized and specific application in the rolling mills. This development is been continuously improved. These rolls demand an extensive control of the production process and careful quality control of 100% of each roll. Quality is checked, among others, with manual and automatic ultrasonic equipments. Results reveal for example freeness of composite errors and shell thickness. Erro! **Autoreferência de indicador não válida.**Erro! **Autoreferência de indicador não válida.**Figure 6 shows a result of an automatic ultrasonic testing and respective evaluation of a roll for a ThyssenKrupp rolling mill.
Some of the latest results and innovations achieved in the wide range of wear resistant materials for high performance rolls of IRLE are resumed in the following for the generic hot strip mill proposed. Please refer also to Figure 3 and Table 1 for first material recommendations to each position of respective mill.

ISSN 1983-4764

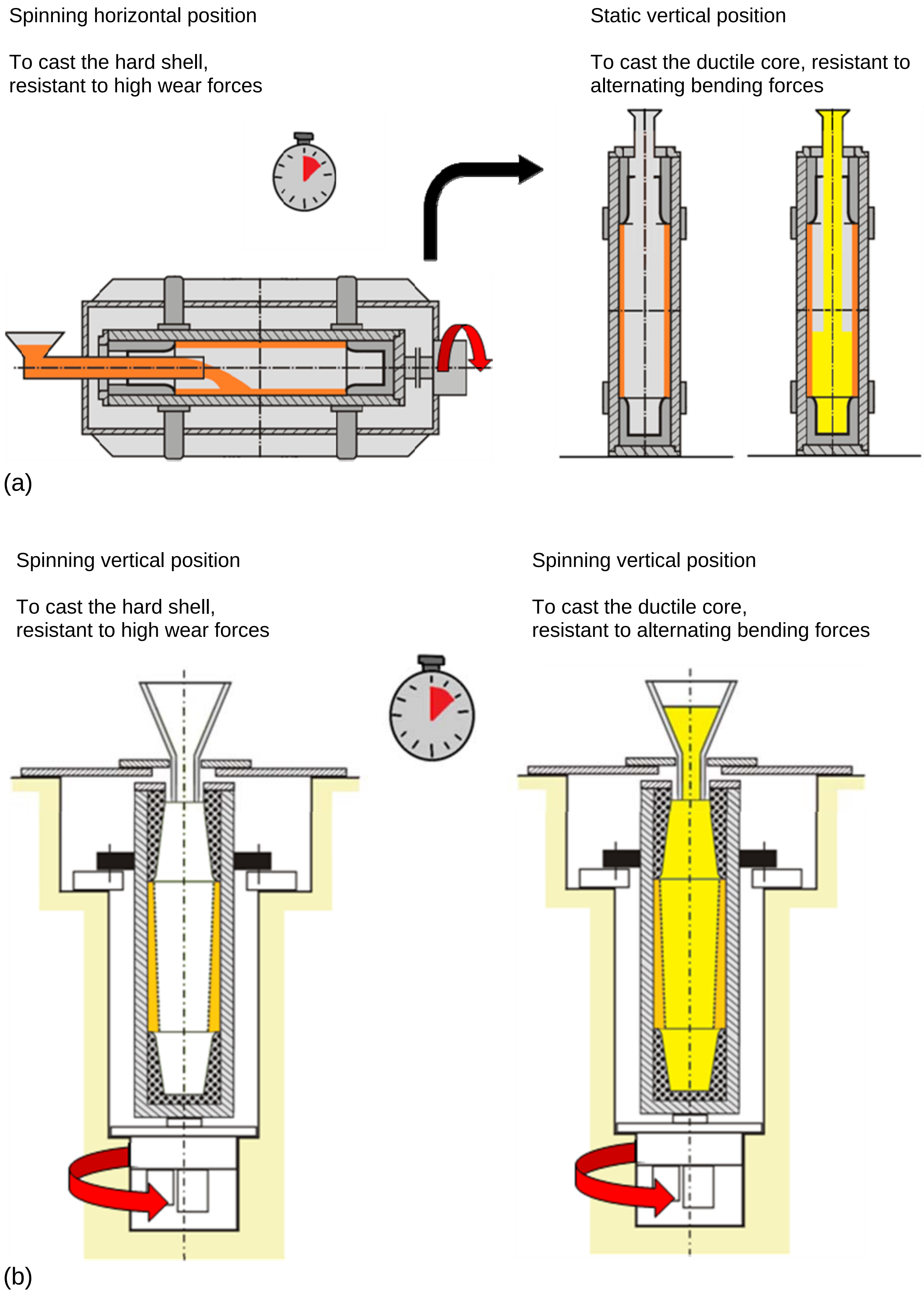
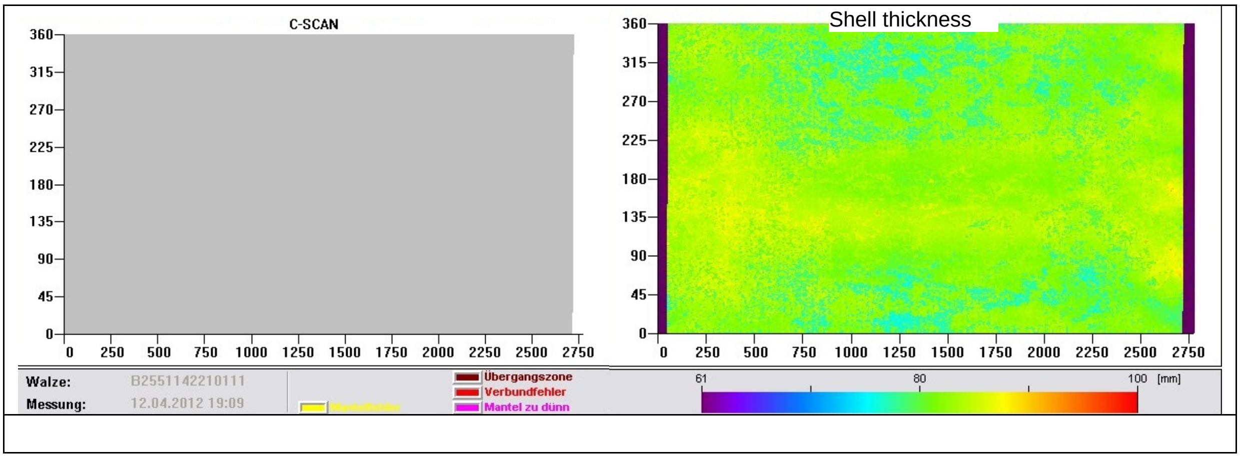


Figure 5: Dynamic compound casting: (a) horizontal spinning of shell material till solidification and static filling of core material and (b) vertical spinning of shell material till solidification with subsequent casting of core material.

ISSN 1983-4764



Erro! Autoreferência de indicador não válida.Erro! Autoreferência de indicador não válida.**Figure 6:** Results of an automatic ultrasonic check using the Distance-Gain-Size (DGS) method to confirm freeness of eventual composite errors and shell thickness measuring along complete shell length and circumference.

3.1 High Chrome Steel and Semi High Speed Steels for R1 and R2

3.1.1 High chrome steel rolls

IRLE produces a wide range of high chrome rolls tuned to respective demands and environments of first roughing stands of the flat rolling mills. Among such variables considered are temperature ranges, type of steel or materials being rolled, size of campaigns, in other words, wear resistance demands to the roll, and so on.
The microstructure of high chrome steel rolls are characterized by a martensitic base matrix. Accordingly to the concentration of chrome, defined proportions of M_7C_3 and $M_{23}C_6$ carbides are dispersed throughout the basic matrix. A concentration of 15% of chrome carbides (IRLE grade CR 15) in rolls produced through the spinning process and with a nodular iron roll core has shown excellent performance results. When a higher strength and toughness is required in the mill at a same fire crack resistance level, these same centrifuged rolls, but with lower concentration of chrome carbides such as 5%, have shown the better results (IRLE grade CR 5). A comparison of the respective microstructures is shown in Figure 7. Further alloy composition, especially with Molybdenum, as well as complex heat treatment sequences and procedures lead to a good temperature resistance of the resulting rolls.

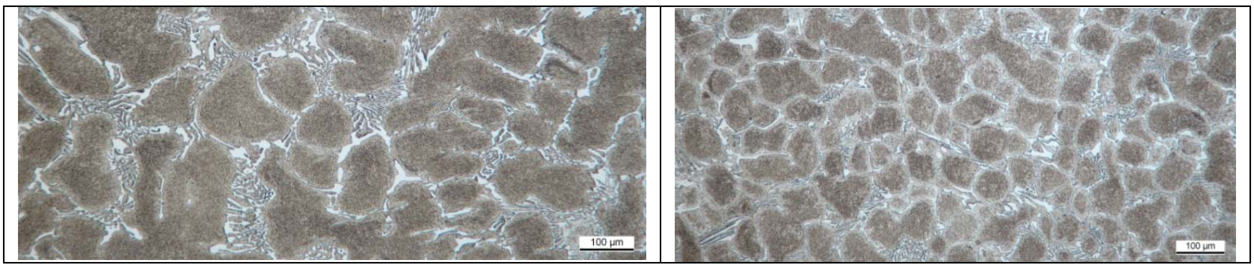


Figure 7: left side: microstructure of a high chrome steel with 5% of chrome carbides (IRLE grade CR 5) and right side: 15% chrome carbides (IRLE grade CR 15).

3.1.2 Semi high speed steel rolls

A further material specifically developed in recent years by IRLE for application at the first or roughing stand rolls of a mill is a modified type of a high speed steel (HSS). Such type of material is commonly known as semi-HSS (IRLE

ISSN 1983-4764

grade SST mod.). SST mod. rolls are produced through centrifugal processes with nodular iron cores, with hardness ranges accordingly to Table 1. The development of this material was done in an interactive process also with end users and it has 2 main distinguishing properties. First: a low carbon content of 0,5-0,9% avoids a cohesive carbide net, thus giving enough toughness to the material to resist to spalls, high pressures and temperatures, as well as thermal loads. Second: a stable martensitic basic structure with a high tempering resistance is formed. Special carbides of MC, M_2C and further carbides of the vanadium, tungsten, niobium, molybdenum and chromium alloy elements are found well defined and finely distributed in the material structure. SST mod. rolls (semi-HSS) have significantly higher wear resistance in comparison to usual high chrome steel rolls. One of the reasons is certainly a higher hardness range between 83-86 °ShC. A respective microstructure can be seen in

ISSN 1983-4764

Figure 8.

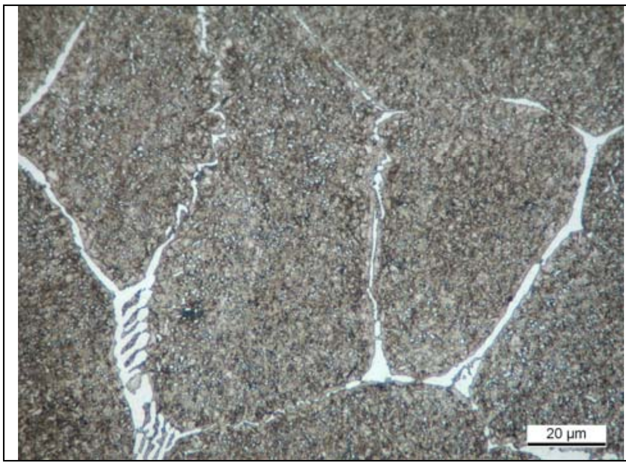


Figure 8: Microstructure of the SST mod. material (semi-HSS type) - tempered martensite with special carbides incorporated.

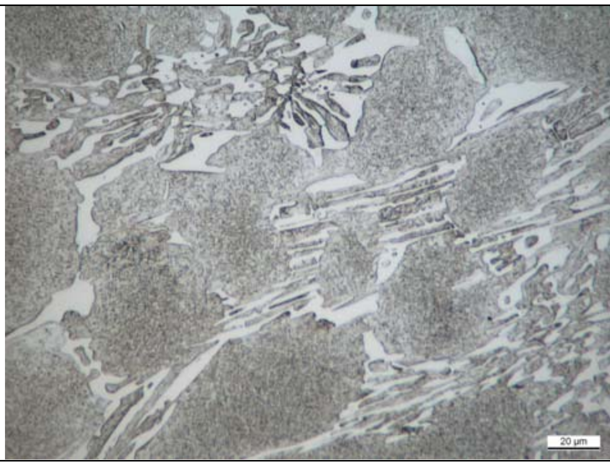


Figure 9: CR 25 - a high chromium iron material with a pronounced chromium carbide net for high wear resistance of the workrolls of first half of finishing stands.

3.2 High Chrome Iron and High Speed Steels for F1 to F3

3.2.1 High chrome iron rolls

For the first half of the finishing mill stands, and also at high quality plate mills, a high chromium iron material (IRLE grade CR 25) is used in the respective work rolls. This material is almost a standard application in innumerous mills of all kind of products. The high amount of chromium carbides of approx. 25% in a stabilized martensite basic structure is achieved through a carefully balanced relation of carbon and chromium, as well as martensite stabilizing alloy elements. A special tempering procedure of several steps was investigated and developed, among others, with the technical university Bergakademie Freiburg in Germany. Numerous casting tests with meticulous investigations of the conversion rates and measuring of the residual stress situations were executed. Due to these developments IRLE is in a position to offer well defined high chromium iron rolls accordingly to rolling mill characteristics (sensitivities) and productivity demands, and that have almost no hardness drop in the depth of the shell. Refer to figure 10.

ISSN 1983-4764

3.2.2 High speed steel rolls

The SST IRLE grade for compound rolls, which is a high speed steel based material, already is and will further develop to the state of the art material for the first half of finishing mill stand work rolls. This high carbon high speed steel also relies on complex tempering procedures to achieve a tempering stable martensite structure. In this basic structure, fine distributed special carbides are incorporated with small and well defined distances to each other. Further fine tuned carbides of vanadium, molybdenum and tungsten, with very high hardness degrees, enables six times higher roll performances in the rolling mill in comparison to other usual roll materials. Refer to Figure 10. The hardness level is kept along the complete shell thickness of the SST rolls, similar to the high chromium rolls mentioned before. The SST material is further characterized by its high temperature resistance as well as optimum surface qualities due to the extreme low wear. However, due to the high sensitivity to rougher mill conditions and rolled products, high speed steel rolls have broken too frequently in trials and in production at some end users and have not found successful applications in all mills. Therefore, application conditions and eventual roll trials should be discussed before complete rolling mill changes.

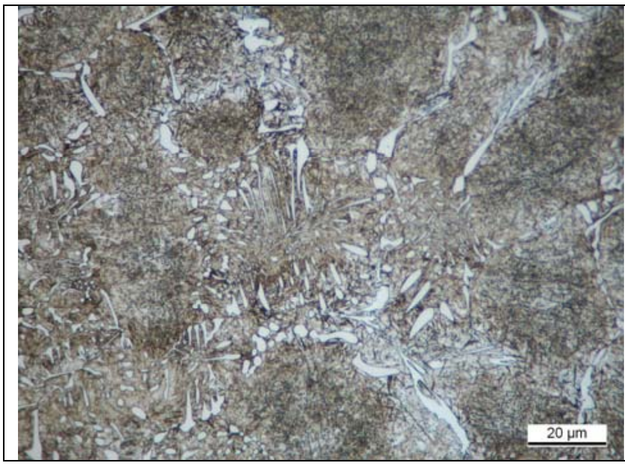


Figure 10: IRLE grade SST - a high speed steel with 85 °ShC hardness for special high wear resistance given by the well defined carbide formations. Developments in metallurgy, alloying techniques and complex tempering procedures lead to this result.

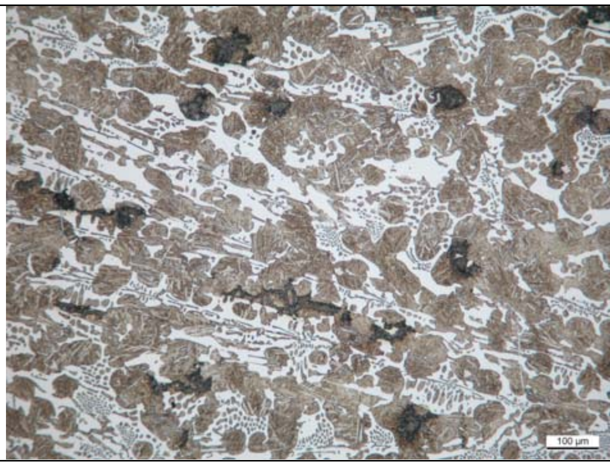


Figure 11: IRLE´s grade I-plus - an enhanced indefinite chill material with defined proportions of special carbides in the martensite, which leads to high performance rolls.

3.3 Indefinite Chill Double Poured Iron for F4 to F7 and Plate Mills

The second half of the hot strip mill finishing stands need rolls with a low sticking effect and which can support high rolling pressure loads. The most striking thing about this material is the elemental precipitated graphite in the microstructure of the martensitic carbide material. The resulting “lubrication” avoids a sticking of the steel strip and reduces rolling mill related surface fire crack propagation into the depth of the roll. ICDP microstructures are shown in Figure 11 and Figure 12.

3.3.1 Indefinite chill double poured rolls

Contrary to what may be supposed by its name, indefinite chill materials (IRLE grade I) are characterized by a hardness drop from the barrel surface until the end of the

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usable shell. This comes from a radial orientated arrangement of the basic structures: there is an increase of the graphite proportion with concomitant decrease of the carbide proportion when going from surface to live end diameter of the shell. Accordingly to hardness requirements, the free proportion of cementite (proportion of carbides) is tuned through the respective alloys. Please refer to microstructure shown in Figure 12.

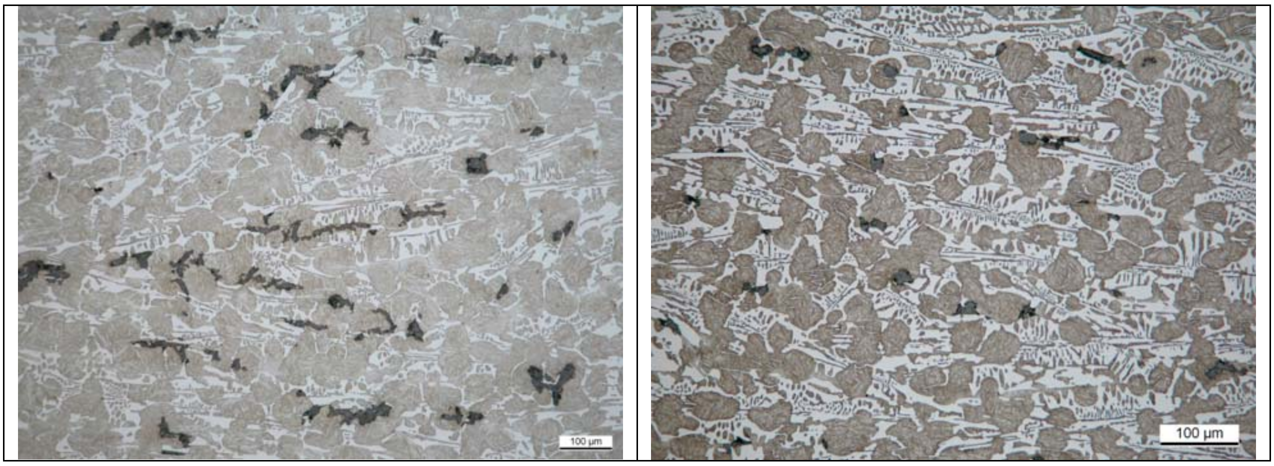

Figure 12: IRLE grade I - indefinite chill materials with different proportions of cementite (proportion of carbides) and graphite tuned through the alloys to attend to different rolling mill demands. Left side: with a hardness of 75° ShC. Right side: with a hardness of 80° ShC.

Different heat treatment procedures and sequences have been developed to achieve a fine characterized bainite / martensite basic structure. Please refer to Figure 13. Resulting rolls have high productivity and need less unproductive grindings due to less fire cracks on the surface and respective good surface quality.

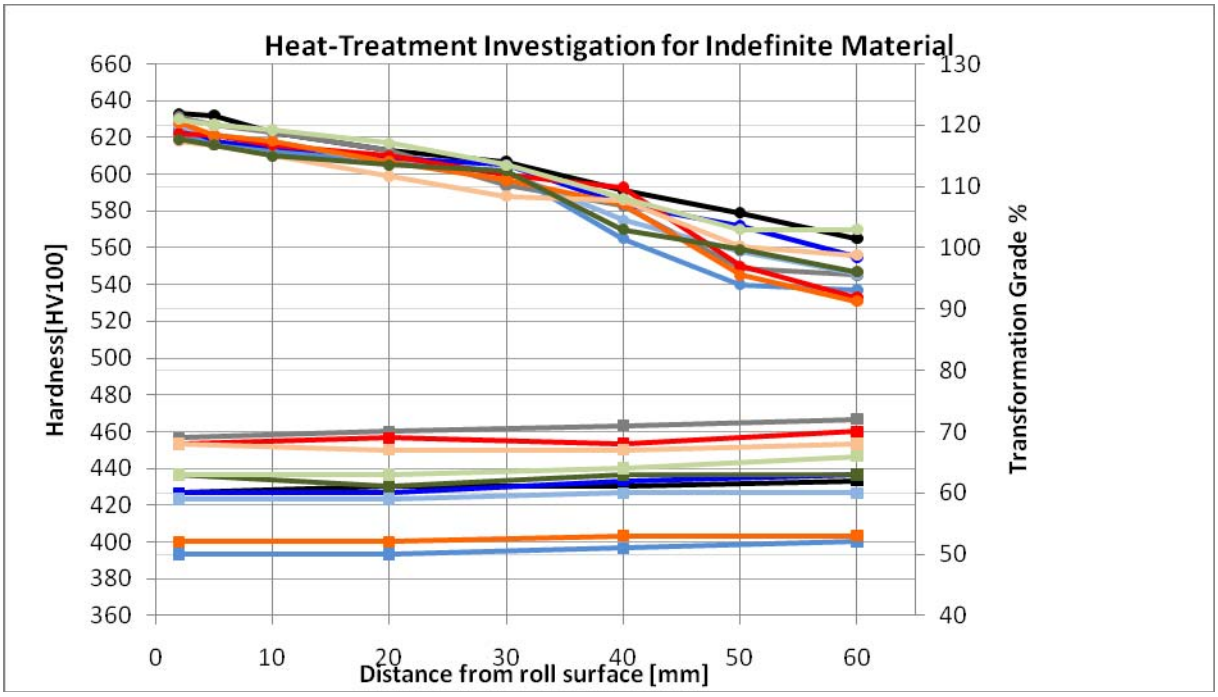

Figure 13: Comparison of 10 different heat treatment procedures of two materials to achieve good transformation grades of the structure, resulting in good hardness values also in deeper depths from roll barrel surface.

ISSN 1983-4764

3.3.2 Indefinite chill double poured enhanced rolls

A disadvantage of indefinite chill rolls is a significant hardness difference between the carbide excretions (cementite) and the bainite / martensite. Due to this, considerable wear is caused by removal of the softer structural component.
IRLE´s I-*plus* grade, an enhanced indefinite chill material, reduces significantly the hardness difference in the microstructure through excretions of a defined tuned relation of special carbide builders in the bainit / martensite. Additionally, a smaller hardness drop is given from the roll barrel surface until the end diameter due to the special carbides and fine-grain type of the microstructure. Please refer to Figure 11. Due to this double effect, 30% higher performances were achieved in comparison to normal indefinite chill rolls. The same special heat treatments as mentioned before are applied.

4 CONCLUSION AND SUMMARY

Results from several hot flat steel mills around the world have shown and demonstrated that IRLE´s efforts in material and production process research, developments and investments are going on in the right direction. To keep its performance positions among the 3 best roll suppliers in the world, IRLE needs and will continue to focus on this two main tasks: how to obtain the best materials in regard to the needs of the rolling mill end users and how to produce rolls from these materials in a most efficient and economic way. Looking back, recent developments in materials and production processes for rolls at IRLE were made parallel and influencing each other. New industrial production processes and controls enabled more noble materials and products, as well as laboratory developed materials frequently indicate a path to efficient large scale production processes.
But it is often still an interactive process, which requires trials and sometimes costly errors. Companies should not only learn from these experiences, but further efforts shall be done together with the respective entities to translate observations and conclusions into mathematical and physical models that could predict and indicate further developments of material properties.

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