HOT STRIP MILL CENTRIFUGED WORK ROLLS: QUALITY AND RESULTS[1]

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Abstract
It is nowadays usual for any mill to require rolls with improved results in terms of performance, surface quality and often also a particular resistance to accidents. In many times, unfortunately, people have been induced to think that small changes of roll chemical analysis might solve the critical situation. The aim of this paper is to present several results from use of different grades of spun casting materials starting from roughing stands down to finishing stands in hot strip rolling. The sound knowledge of the roll surface damages together with an optimization of roll control and grinding procedures in the turning shop should represent a necessary step to start any discussion about roll grades and results. The introduction of new special wear resistance alloys with better technological properties, which are usually also more expensive, implies a major attention to understand if all the potentialities of these materials can give real opportunities of improving mill situation. In this work it's presented an evaluation among the results of classical materials and recently developed materials taking into account the different flat rolling applications.
Key words: Hot strip mill; Centrifugal casting rolls; Wear; Redressing procedures.

CILINDROS DE TRABALHO CENTRIFUGADOS PARA LAMINADOR DE TIRAS A QUENTE: QUALIDADE E RESULTADOS

Resumo
Hoje em dia, qualquer laminador demanda cilindros com boa performance, qualidade superficial e resistência a algum tipo de acidente, em particular. Muitas vezes, infelizmente, acredita-se que uma pequena mudança de composição química do cilindro possa resolver uma situação crítica na operação. O objetivo desse artigo é apresentar resultados de diferentes cilindros centrifugados, de cadeiras de desbaste e acabadoras em trens de tiras a quente. Para se começar qualquer análise de tipos de cilindros e seus rendimentos, é necessário entender como o procedimento de retíficação na oficina de cilindros lida com a superfície deteriorada dos cilindros, após uso no laminador. A introdução de novas ligas resistentes ao desgaste, de tecnologia de produção mais dispendiosa, implica em maior atenção na exploração de potencialidades do laminador, como um todo. Esse artigo apresenta uma avaliação de materiais clássicos e avançados nas diversas condições de laminação a quente de produtos planos.
Palavras-chave: Laminação de tiras a quente; Cilindros centrifugados; Desgaste; Procedimentos de retificação.

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INTRODUCTION

The hot strip mills belong to hot finishing mills group. The various types of hot strip mills may be classified according to their design features and in particular according to roll arrangement and slab route.(1) The production of hot strip in coil form is done in multi-stand continuous or in single-stand reversing mills. Large mills fully integrated with the steel plant and with the highest productivity (multimillion ton / year) belong to the first group as well as modern minimills that normally process the coming out steel directly from caster machine, although they reach lower productivities. In the Steckel mill, on the other hand, a single reversing stand rolled the slabs to strip: this mill has a cost effective preference when the production rate is relatively low. Table 1 shows a rough classification within the hot strip mill family where the main technical data are highlighted.

Table 1 Classification of Hot Strip Mill

HOT STRIP MILLS		
CONTINUOUS or REVERSING HSM	Mill capacity 4-5Mt/year Slab thickness 180-240mm Coil thickness 1.5-20mm Coil weight 40t (max)	Roughing stands ✓ Stand n° 1-5 ✓ Motor power 10-30 MW ✓ Max speed 6m/s Finishing stands ✓ Stand n° 5-7 ✓ Motor power 30-70 MW ✓ Max speed 20m/s
MINI MILLS	Mill capacity 1-2Mt/year Slab thickness 55-75mm Coil thickness 1.2-12mm Coil weight 30t (max)	Roughing stands ✓ Stand n° 0-3 ✓ Motor power 2-10 MW ✓ Max speed m/s Finishing stands ✓ Stand n° 5-7 ✓ Motor power 20-40 MW ✓ Max speed 20m/s
STECKEL MILLS	Mill capacity 0.5-1Mt/year Slab thickness 170-220mm Coil thickness 2-15mm Coil weight 30t (max)	Finishing stands ✓ Stand n° 1 ✓ Motor power 5-10 MW ✓ Max speed 10m/s

Mill and roll design have a direct influence on roll performance: the roll materials with its specific properties must be matched with the mill requirements to guarantee the best results in terms of roll consumption and quality of rolled strip. Taken for granted that the rolls have to resist to stresses imposed by the rolling operations and therefore not fail in normal working conditions, the evaluation of roll performance become more ticklish because the mill situation (production mix, campaign length, mill stability, lubrication, etc.) in connection with specific way redressing the roll in turning-shop can easily obscure all the potentialities of a particular roll grade. In these evaluations, especially using new high wear resistance alloys (i.e. HSS), also the cost of the roll assumes a big influence and in many cases hinder all the efforts done to improve some aspect regarding the roll behaviour. In the following paragraphs, after a brief summary of the main metallurgical and mechanical properties of the roll materials used in hot rolling, there are several examples regarding real situations showing the behaviour of new roll grades in comparison with classical products and in relation to hot strip mill configuration (Figure 1).

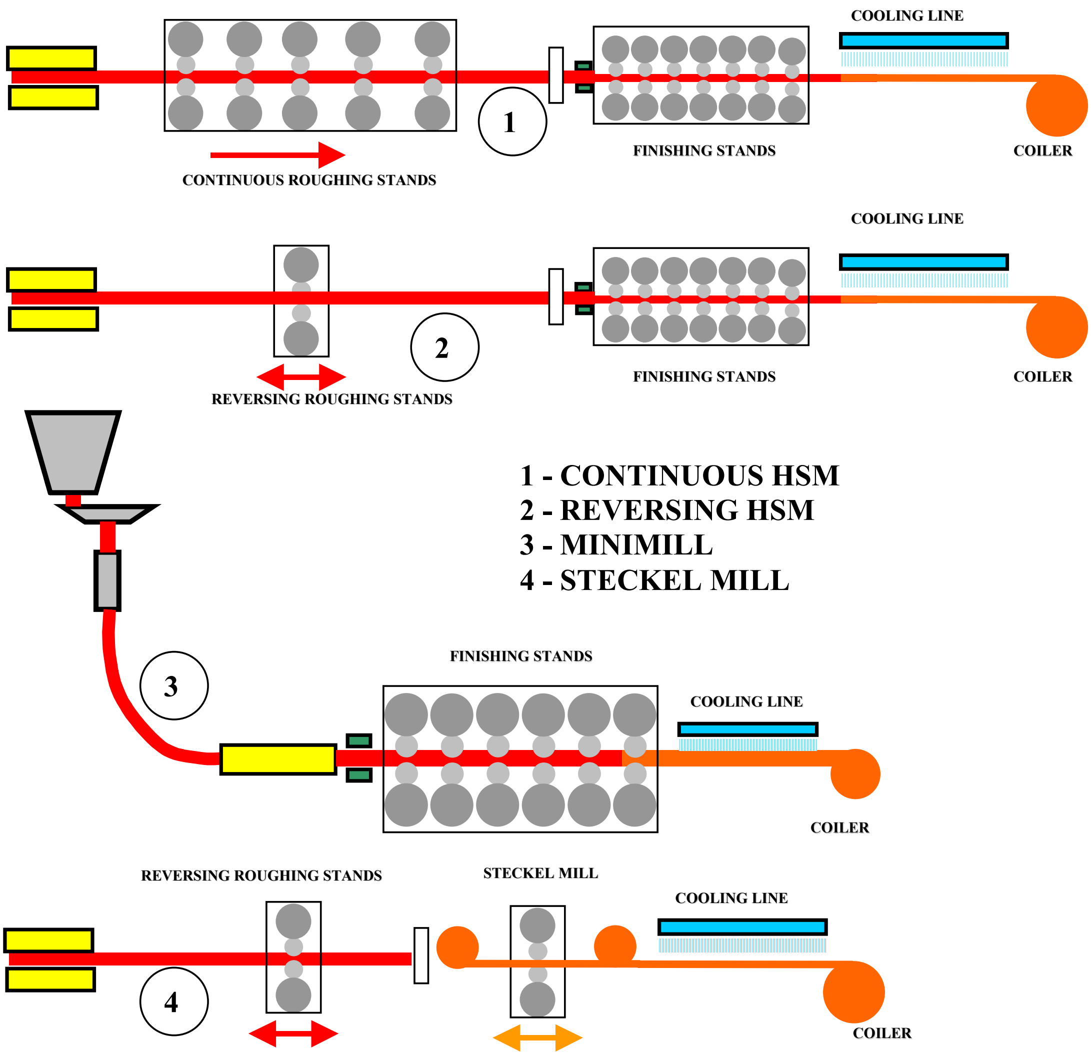


Figure 1 Hot strip mill configurations

CENTRIFUGED MATERIALS FOR WORK ROLLS

The spin casting system is the method to produce bimetallic rolls with the highest productivity rate. This casting system enables to pour alloys in a wide range of chemistry providing a homogenous work shell thickness with a good bonding area in terms of mechanical resistance. The materials for work rolls cover a big segment of Fe-C diagram with a carbon level ranging from 0.5% to 3.5%: depending on the level of specific elements added we can produce steel and cast iron with the most suitable microstructural characteristics for a given mill application. The classical ranges of chemical composition are reported in Table 2.

Table 2 Main elements in a spin casting work rolls (wt%)

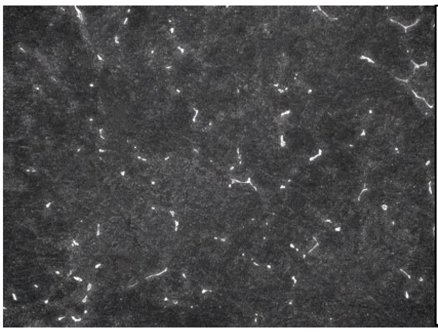
Class of material	C	Cr	W_{eq}*	V	other
Semi-HSS	0.6-1.0	3-6	4-7	0-1	Nb
High Cr Steel	1.2-1.6	10-14	4-8	<0.5	-
HSS	1.2-2.2	3-6	4-10	3-6	Nb
High Cr Iron	2.4-2.8	14-18	2-6	<3	Nb
Indefinite Chill Iron	3.2-4.2**	1.5-2.0	<1	<2	Ni, Nb

** Weq= W+2Mo; ** Ceq= C+1/3Si*

All these materials are special alloys with a high content of carbide formers elements that give microstructures with optimal mechanical and technological properties at elevated temperatures. In general, the microstructure is characterized by tempered martensite surrounded by a more or less continuous network of eutectic carbides; let's see, in brief, some peculiarities about the microstructure of these materials.

- Semi-HSS

An alloyed martensitic matrix with a not interconnected network of eutectic chromium carbides (M_7C_3) give a steel with optimal properties at high temperature: thermal fatigue resistance it's the best feature of this material[2] (Figure 2).



CARBIDES: 2-4% (MAINLY Cr_7C_3)

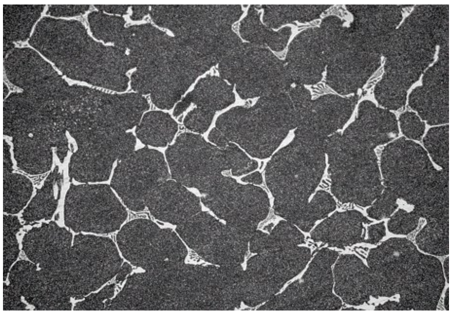
MATRIX: TEMPERED MARTENSITE (750-800 $HV_{0.1}$)

HARDNESS: 75-80 ShC

Figure 2. SemiHSS microstructure

- High Chromium Steel

The content of carbon and chromium produce a considerable amount of eutectic M_7C_3 carbides. Other elements, like molybdenum and vanadium, are added to increase the thermal softening resistance of martensitic matrix so to improve its opposition to wear phenomena (Figure 3).



CARBIDES: 8-12% (MAINLY Cr_7C_3)

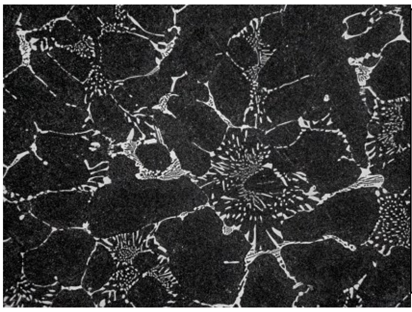
MATRIX: TEMPERED MARTENSITE (650-750 $HV_{0.1}$)

HARDNESS: 70-80 ShC

Figure 3. HCrSteel microstructure

- HSS

In this class of steel the carbon is combined with different carbide formers elements and then the microstructures can be different too. The type and the quantity of primary carbides in the microstructure have a big influence to the final characteristics of the matrix and then the optimization of heat treatment plays an important role.[3,4] The wear resistance is the main strong point of these steels (Figure 4).



CARBIDES: 6-15% (M_XC_Y)

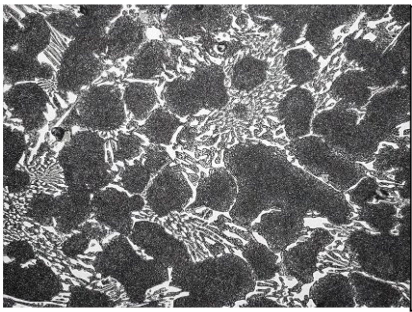
MATRIX: TEMPERED MARTENSITE (650-800 $HV_{0.1}$)

HARDNESS: 75-85 ShC

Figure 4. HSS microstructure

- High Chromium Iron

This family of white cast iron, with a big presence of eutectic chromium, shows good resistance against rolling abrasion phenomena. Small adjustments in chemical composition and suitable heat treatments[5] can be possible to answer at the specific work rolling situations (Figure 5).



CARBIDES: 20-30% (MAINLY Cr_7C_3)

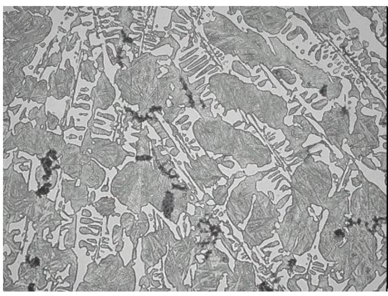
MATRIX: TEMPERED MARTENSITE (600-700 $HV_{0.1}$)

HARDNESS: 70-80 ShC

Figure 5. HCrIron microstructure

Indefinite Chill Iron

In these special cast irons there is the coexistence of graphite and cementite. In this particular microstructure the graphite makes possible important anti-sticking properties while the extended precipitation of iron carbides act like deterrent for abrasion. The use in this cast iron of vanadium and niobium makes possible a refining of the dendritic solidification structure;[6] this situation in association with the presence of hard MC carbides give very interesting results in terms of roll consumption and quality of roll surface (Figure 6).



CARBIDES: 25-35% (MAINLY Fe_3C)
GRAPHITE: 2-5%

MATRIX: TEMPERED MARTENSITE (500-600 $HV_{0.1}$)

HARDNESS: 70-80 ShC

Figure 6. Indefinite Chill Iron microstructure

WORK ROLLS AND APPLICATIONS

The several arrangements of HSM and the different rolling conditions that a roll can encounter moving from roughing to finishing stands make difficult a general discussion about the most suitable roll grade material to choose. Now some general guidelines are given, discerning between roughing and finishing rolls (Table 3).

- <u>Roughing Stands</u>

In the continuous mill the use of HCrS covers 50% of the applications while the rest is equally shared between SemiHSS and HSS. SemiHSS rolls have a large employment in reversing stands of carbon steel rolling (almost 70%) while in stainless steel rolling HSS rolls are capturing the entire market. For the Steckel mills the use of HCrS is still strong, while in the minimills the utilization of HSS is preponderant in respect to HCrS (70% against to 30%).

- <u>Finishing Stands</u>

In the early finishing stands survives a competition between HCrI and HSS. For carbon steel rolling some particular rolling situations are not suited to fully benefit from the use of HSS. On the contrary, in stainless steel rolling, the use of HSS rolls gives various and considerable benefits.
In the last finishing stands enhanced carbides ICI rolls are gaining market share, mainly in the heavier applications (i.e. stainless steel production) and in the stable mill situations where it’s clearer the positive performance gap between these ICI grades in comparison with standard one.

Table 3. Work roll materials and applications

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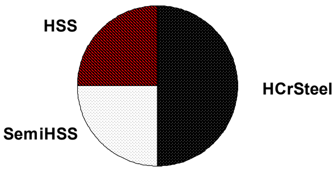
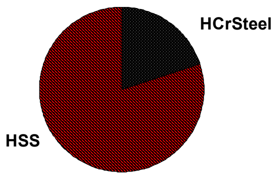
<tr><td>
</td><td>ROUGHING</td><td>
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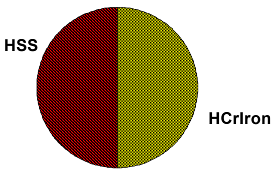
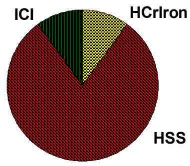
<tr><td>
</td><td>EARLY FINISHING</td><td>
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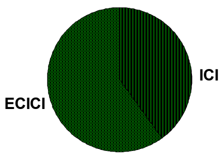
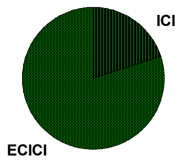
<tr><td>
</td><td>LAST FINISHING</td><td>
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ROLLS IN SERVICE BEHAVIOUR

The main purpose of the following results reported is to highlight the level of consumption and the surface damaging among the different types of rolls actually in use. These types of results should represent always a basis to follow and optimise the grinding practices of the rolls and also helping to carry out correct information when trials begin with new rolls.

1. CONTINUOUS ROUGHING STANDS
   The wear consumption of HSS rolls can be 20-40% lower than HCrS rolls (Figure 7).

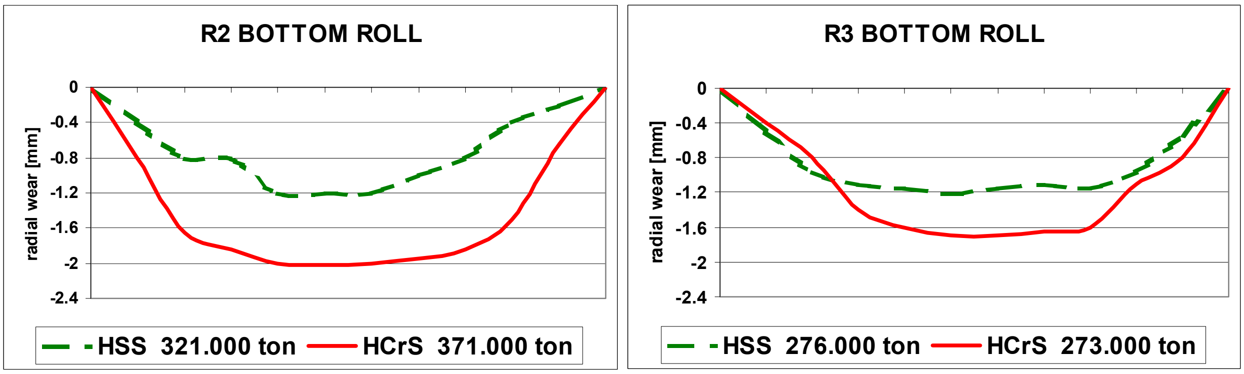


Figure 7 Comparison of wear profile between HSS and HCrS in roughing stands of continuous HSM

A comparison in R4 stand between HSS and SemiHSS points out that HSS rolls can guarantee longer campaign with lesser consumption (Figure 8).

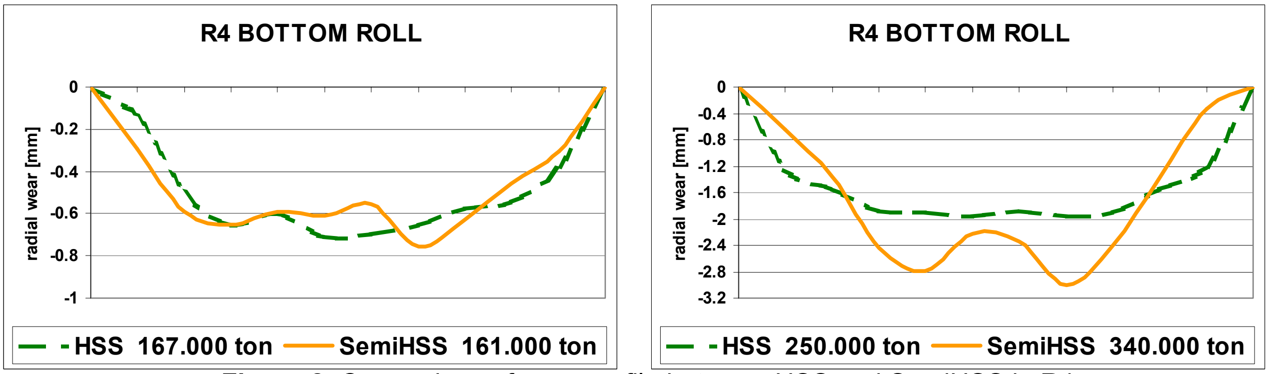


Figure 8. Comparison of wear profile between HSS and SemiHSS in R4

A diffuse pitting represents the common damaging on the surface together a firecracks pattern, due to the thermal fatigue stresses, that involves the eutectic carbides (Figure 9). The surface of SemiHSS may be affected by a plastic deformation for about 0.1mm in deep; this situation influences negatively the roughness of the roll but not the wear profile (Figure 10).

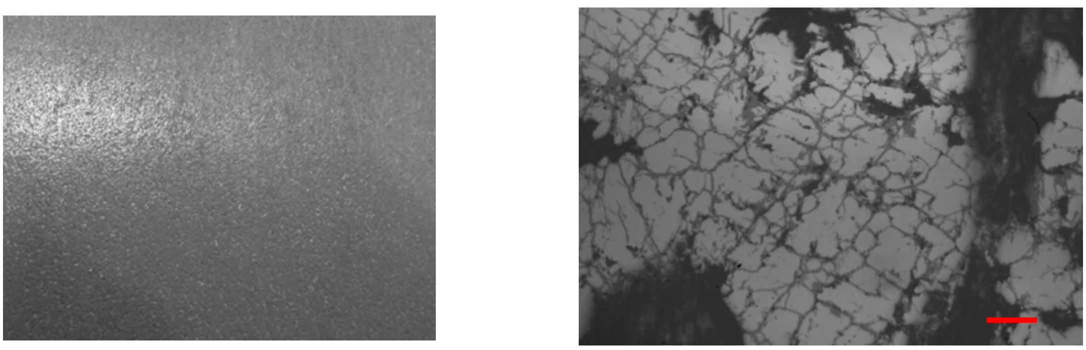


Figure 9 Surface of HSS after the use in R4 (250.000 ton; Ra~ 5µm)

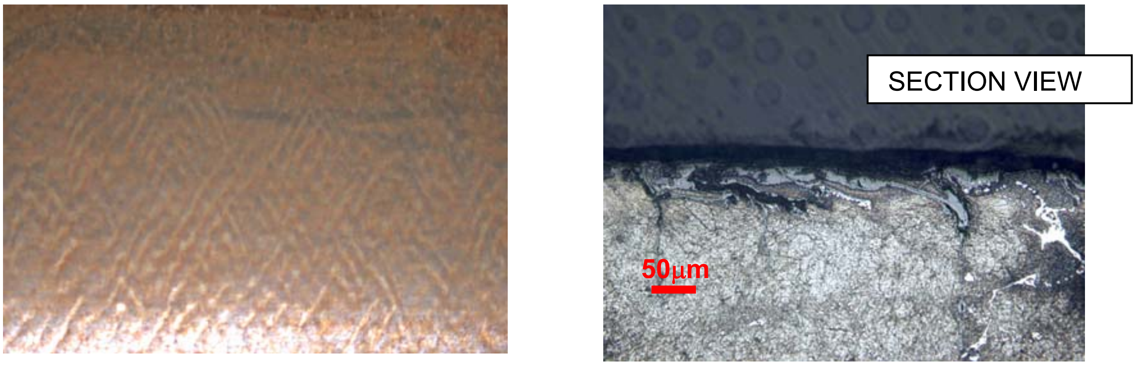


Figure 10 Surface of SemiHSS after a long campaign in R4 (340.000 ton)

2. REVERSING ROUGHING STANDS

For carbon steel rolling in the reversing stands the SemiHSS rolls are well performing. There are several examples where the wear of SemiHSS is lesser not only in respect to HCrS but also as regards HSS rolls (Figure 11).

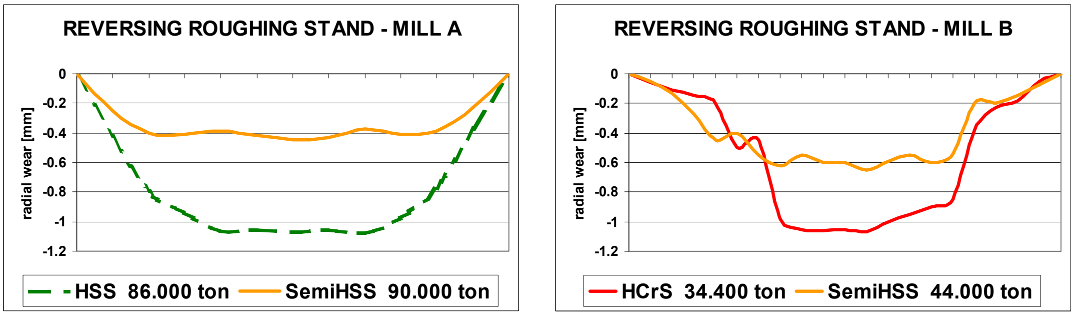


Figure 11 Wear profile comparison in different mills

In other mills, however, the differences about the wear profile are not so evident: the specific working rolling conditions can easily reduce the gap among different roll materials (Figure 12). The surface damaging for SemiHSS and HSS is not so great: the presence of pitting with fatigue thermal cracks generate a roughness (Ra) varying from 2 to 5µm that represents an acceptable range (Figure 13).

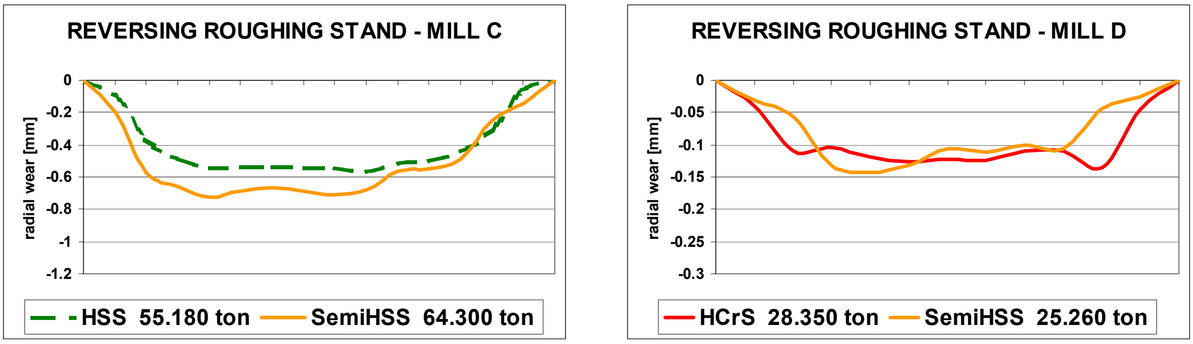
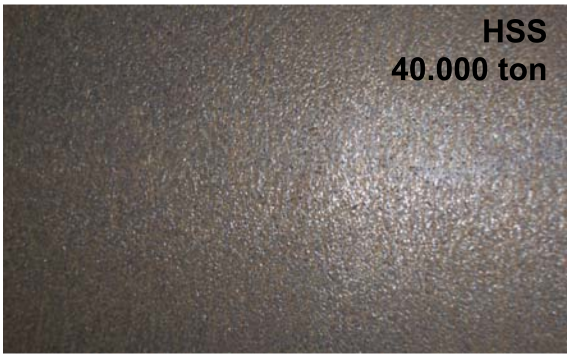


Figure 12 Wear profile comparison in different mills.



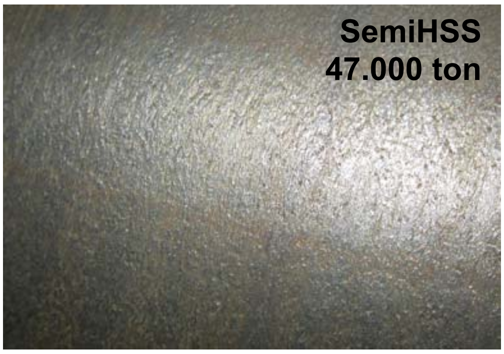


Figure 13 Aspect of the surface after a campaign in the reversing roughing stands

In stainless steel rolling it's confirmed by many results that HSS rolls give the best performance. This application, so heavy, requires a roll with excellent resistance to wear: the presence of an adequate quantity of hard primary carbides appears like a prerequisite to reach positive results (Figure 14).

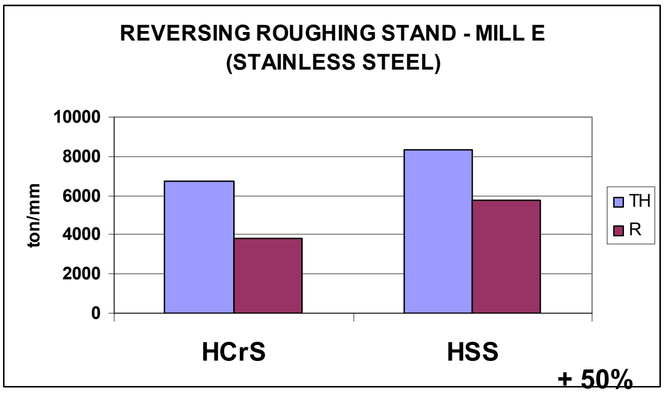


Figure 14 Comparison of results between HCrS and HSS

3. FINISHING STANDS

The results proposed have the aims to underline the different level of consumption that the typical rolls showed in the finishing stands. Drawing general conclusions about the roll performances in these stands, without knowledge the specific mill arrangement and the turning shop practices to restore the rolls, is a non-sense.

The potentialities of HSS rolls are evident; for most applications in early finishing stand this steel doesn't show palpable wear (Figure15). The level of surface damaging takes on a great importance because may establish the length of campaign and therefore the frequency of roll grindings in addition to the extent of them.

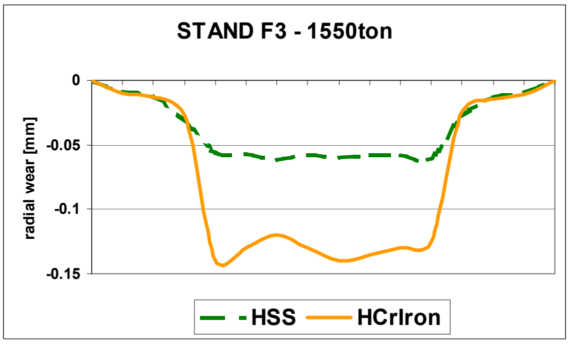


Figure 15 Comparison of wear profile between HCrI and HSS

After a campaign the surface of HCrI can be rougher if compared with HSS one (Figure 16) but only this difference can not be sufficient to justify the use of HSS. The choice of the roll grade more performing or the evaluation of real differences of roll behaviour within the same family of roll material is a task very hard. The following histograms have the unique purpose to show that some modifications to the roll materials (chemistry and heat treatment) can give appreciable improvements although staying in the same class of products (Figure17).

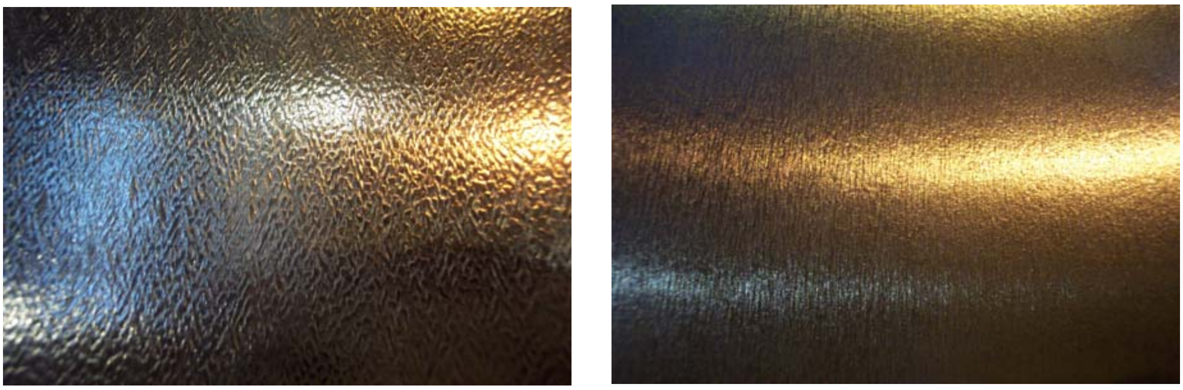


Figure 16 Surface comparison between HCrI and HSS after a campaign in F3

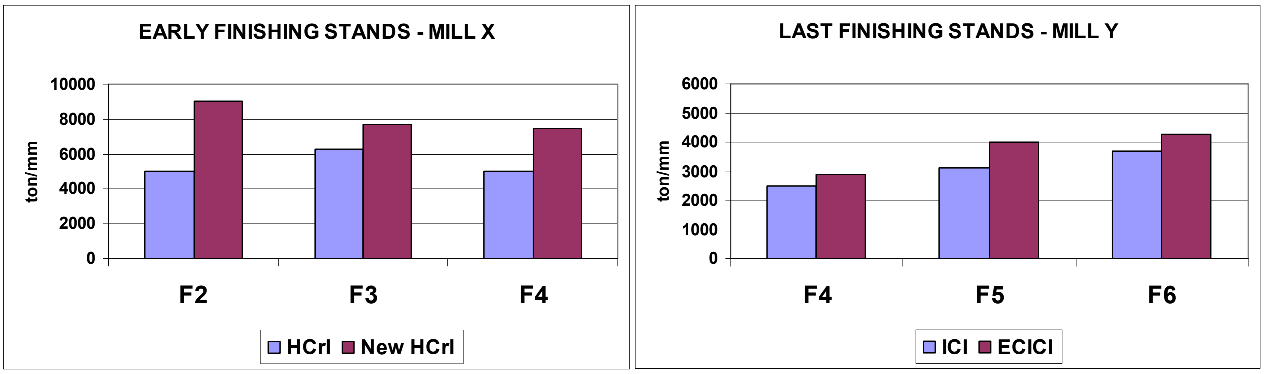


Figure 17. Results from finishing stands

CONCLUSION

Intent of this paper was to collect argumentations regarding the use of centrifuged work rolls in the hot strip mills. By no means are we in a position to strictly define the most suitable roll grade materials to put in the mill to reach the best results. The variables not taken into account in this work are too many.

If our goal is problem solving or overall rolling cost reduction we cannot simply rely on changing roll grades. It's necessary to know the exact level of roll damaging before to start any discussion about roll performance.

Several types of roll materials with optimal properties already exist: it's necessary to find together the best way to capitalize with the maximum benefits their potentialities.

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