THE EVOLUTION OF WORK ROLL MATERIALS FOR THE ROUGHING MILL APPLICATION

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SUMMARY

Since the beginning of hot rolling a variety of different materials have been used for work rolls in the roughing stands of hot strip mills. Increasing quality demands as well as the economical pressure from the rolling mills, have forced the roll manufacturers to develop enhanced roll grades for this application. The final quality of the hot strip and even the cold strip is already preset in the roughing mill so that each disturbance of the roll gap geometry or surface aspects have significant impact on the final product.

This paper gives a description of the existing rolling conditions in the roughing stand and the required roll properties. It will also give an overview about the evolution of roll grades from Adamite and Nodular Iron qualities up to the more enhanced Chrome Steel and Semi-HSS grades including specific material characteristics and field results.

One paragraph is dedicated to the latest development, the implementation of HSS-rolls in the roughing application. The Åkers Group has started trials in several mills all over the world.

Keywords: roughing mill rolls, roll grades, high-speed steel

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1. INTRODUCTION

The driving forces for the development of materials for roughing mill work rolls are the ever increasing demand of the cost/performance ratio, an improved product quality, and safe rolling conditions. Until the late 70's the standard qualities for this application were Adamite and Nodular Iron rolls. In the early 80's the Chrome Iron and Chrome Steel grades found their way into the roughing stands. A significant improvement followed in the 90's with the invention of the so-called semi-High Speed Steel (semi-HSS). Today, inspired by the massive research on rolls for the finishing stands, the High Speed Steel (HSS) roll grade is on its way to be used more and more in the roughing application. Initially HSS grades were used only in mills producing a high amount of stainless steel. In these stainless steel applications the Semi HSS developed some problems with surface deterioration and exhibited less than superior performance. The HSS roll seems definitely to have a potential to become a common grade in the roughing application.

2. CONDITIONS OF THE ROUGHING APPLICATION

Since the introduction of the continuous casting process and the end of the slabbing mills, the roughing stand rolls are facing new challenges. Today 100% of the slabs are produced in continuous casting machines with constant dimensions that can only be varied in rough steps by moving the chill walls. Today the roughing stands do not only reduce the slab thickness from 250 mm to 20-50 mm but the width is reduced by edger rolls or slab presses in steps up to 150 mm. A significant width reduction results in an unfavourable dog-bone shaped slab profile that must be compensated by the horizontal work rolls. The dog-bone profile causes a variety of problems like uneven reduction over the slab width, roll slippage, uneven loads and roll wear along the barrel. The final profile of the hot strip and even the cold strip are already preset in the roughing mill so that each disturbance of the roll gap geometry has significant impact on the final product. For this reason it is evident to produce a transfer bar with tight profile tolerances already in the roughing mill. Disturbances of the transfer bar profile can be partly compensated in finishing stands with CVC or roll bending technology, but they can also lead to edge- and mid-waves causing a high risk of mill cobbles. Another important quality aspect of the transfer bar is the temperature before entering the finishing stands. The heat-loss in the roughing stands must be limited and controlled so that there is a restricted time period for the roughing process.

The mechanism for roll wear in the roughing mill is also influenced by thermal deterioration. The work rolls of the roughing mill experience the hottest bar temperature at a slow rotational speed. This factor combined with a heavy reduction, 35% - 50%, of a relatively thick slab equate to significant heat transfer into the roll. This heat transfer, combined with long gap times, produces a cyclical heating and cooling that the rolls must endure. Frequently occurring stall conditions can induce thermal stresses in the roll material which can easily exceed the hot yield strength of the material and can lead to gaping fire cracks.

3. DEMANDS ON ROLL PROPERTIES FOR THE ROUGHING WORK ROLL

Due to the aforementioned factors, it was realized that improvements made in the roughing mill positively affect mill productivity. Optimising the cost per ton ratio while improving or maintaining the strip quality is the main objective. Mill demands with respect to work roll properties can be summarized as follows:

- High friction coefficient allowing high bite angles with respective high reductions leading to a small number of passes, a reduced heat loss on the transfer bar and a higher throughput in the mill.
- Resistance to mechanical wear and thermal fatigue to prevent unfavourable wear profiles allowing extended campaign lengths and reduced downtimes
- Resistance to thermal cracking to withstand stall conditions
- Controlled oxidation characteristics to prevent peeling and banding effects to maintain an excellent surface quality over extended rolling campaigns
- High Threshold of Safety Against any Mill Induced Damage

4. EVOLUTION OF ROLL MATERIALS FOR THE ROUGHING STANDS

Since the inception of the hot strip roughing mill, there have been many different roll grades that have been and still are being used. Table I contains microstructures of some of the most common roughing mill roll grades.

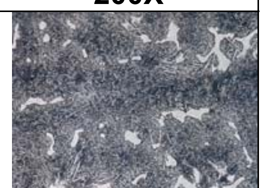
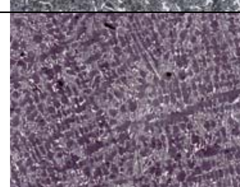
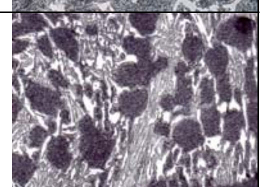
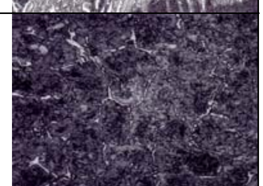
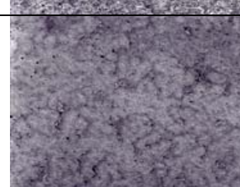
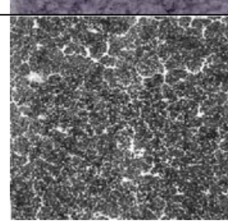
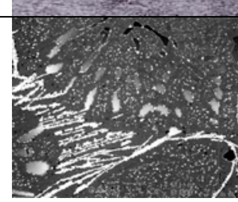
Material	50X	200X
ADAMITE		
High Chrome Iron		
Chrome Steel		
Semi-HSS		
HSS		 500X

Table I Microstructures of roughing mill roll grades

Table II is an abbreviated comparison of chemical analysis and hardness for the different grades [1].

Grade	C %	Cr %	Mo+V+W+Nb %	Hardness ShC
Adamite	1.5-2.5	1.0-2.0	0.5-1.0	50-65
Nodular Iron	3.0-3.4	1.00-1.50	0.1-0.6	55-70
High Chrome Iron	2.0-3.0	15-25	0.5-2.0	73-83
Chrome Steel	1.0-1.8	10-14	1-4	70-80
Semi-HSS	0.4-1.2	3-10	2-10	80-90
HSS	1.0 – 2.5	4-6	4-12	75-85

Table II Analysis and hardness of roughing mill roll grades

Adamite Steel was one of first roll grades to be used. This roll had adequate bite and a sufficient safety factor. It was, however, prone to significant wear and coarse fire cracking (Table III). This in turn resulted in less than optimum strip surface quality. Nodular Iron is also used in the roughing application. This roll grade slightly improved the wear resistance with iron carbide. Some time later High Chrome Iron was introduced. The microstructure consists of eutectic M_7C_3 carbide with finely distributed secondary carbides in a matrix of tempered martensite. The microstructure provided higher bulk hardness. This roll grade provided greater fire crack resistance, improved wear, and allowed for extended campaigns. However, due to the high amount of eutectic carbide, 20%-30%, the rolls were prone to slippage problems, and under today's expectations would require frequent roll changes. The Chrome Steel roll is still the most widely used roughing work roll in hot strip mills today. Its steel shell material with a reduced amount of eutectic M_7C_3 carbides compared to the high chrome iron provides a better bite capacity, a greater mechanical strength, and superior surface/oxidation aspects than prior grades. At that time this roll grade exhibited the most beneficial properties. However, there was still constant pressure to increase roll performance. In order to achieve this goal a new material was developed, Semi-HSS.

Grade	Wear	Fire Crack Resistance	Friction/ Roll Bite	Roll Surface Aspect / Oxidation	Service length	Operating Safety
Adamite	-	-	+	-	-	0
Nodular Iron	-	-	-	0	-	0
High Chrome Iron	0	0	-	+	0	0
High Chrome Steel	+	0	0	+	+	+
Semi HSS	++	+	+	++	++	++
HSS	+++	+	+	++	++	++
- Poor 0 Sufficient +Satisfactory ++Good +++ Excellent						

Table III Roll Material Characteristics

5. THE SEMI HSS QUALITY

From an operational point of view, the Semi HSS roll was the first roll grade that did not make any compromises. It combined an excellent wear resistance and oxidation behaviour with a good fire crack resistance and roll bite capacity. This roll grade can produce excellent profile tolerances at extended service times with a high operating safety. However, there is one operational limiting factor for the use of semi HSS rolls, the rolling of stainless steels. During the rolling of stainless steel grades the slab/strip forms unfavourable oxides on the surface caused by the diffusion of chromium [2].

Phase	Main elements	Vickers Hardness
M3C	Fe (Cr, Mn)	850-1100
M7C3	Cr (Fe,Mo)	1200-1600
M2C	Mo (W, V, Cr, Fe)	2000-2400
M6C	W (Mo, Fe, Cr)	1100-1650
MC	Ti, V, Nb, Ta	2400-3200
Matrix	Bainite	250-650
	Martensite	500-1000

Table IV Hardness of different phases

The formation of hard oxides is an important factor to determine the very high wear speed when rolling stainless steels. Different from the Chrome Steel grade, the Semi HSS microstructure does not contain a closed network of chromium based M_7C_3 carbides, but a small number of very hard MC and M_2C, plus a few M_7C_3 carbides (see Table IV [3]). The lower quantity of carbides and the lack of a eutectic carbide network might be the reasons for the substantial surface deterioration and for not showing a significant benefit in wear resistance when rolling stainless steels. For all other steel grades the performance increase compared to the use of Chrome Steel rolls can be up to 50-300%. Figure 1 shows the evolution of the total stock removal for roughing work rolls in a European Hot Strip Mill after implementing the semi HSS grade.

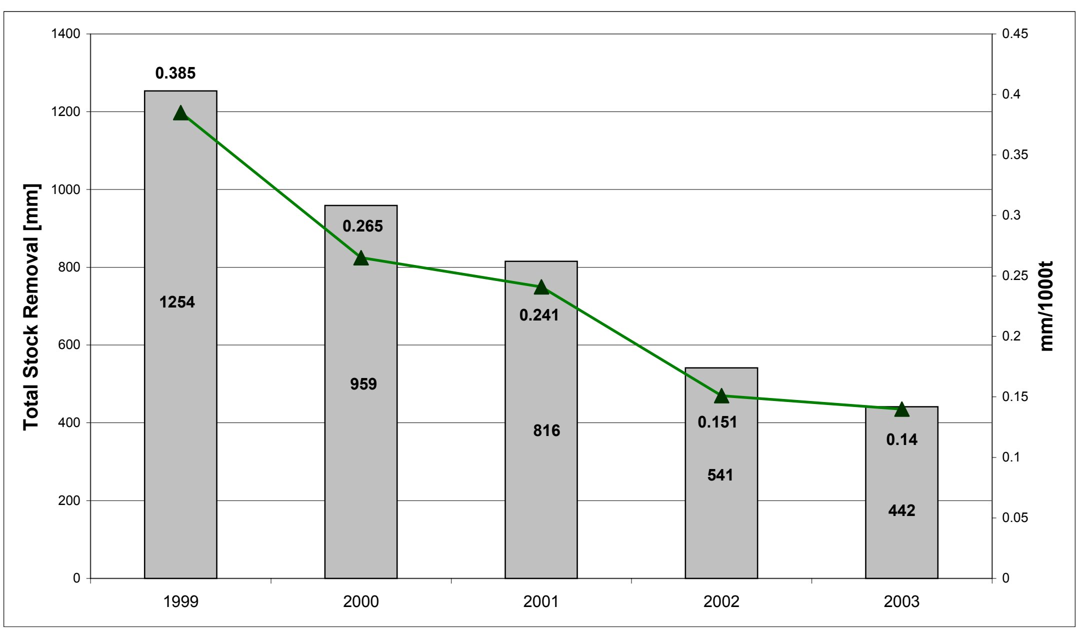


Figure 1 Evolution of the Roughing Work Roll Performance in a European HSM

Beside the significant performance increase, the real benefit of this roll is the ability of extended service length without producing an unfavourable wear profile assuring an accurate profile of the transfer bar. Table V shows a comparison between the usage of Chrome steel and Semi HSS in three different hot strip mills.

Mill	Service Length	
	Chrome Steel	Semi HSS
Mill A	18.000 t	35.000 t
Mill B	40-60.000 t	80- 100.000 t
Mill C	60.000 t	90.000 t

Table V Service Length Comparison

From a manufacturer's point of view, the semi HSS roll has one substantial disadvantage. Due to a variety of material characteristics the fabrication of this product still has a considerably high scrap rate. Roughing rolls normally demand rather high neck strength properties and are therefore normally produced with a nodular core. The differences between the semi HSS shell material and the nodular core material chemistries are in most cases significant. These differences of the two materials can lead to essential elemental diffusion that could result in local remelting of the structure and possible porosity formation in the bond zone [4][5].

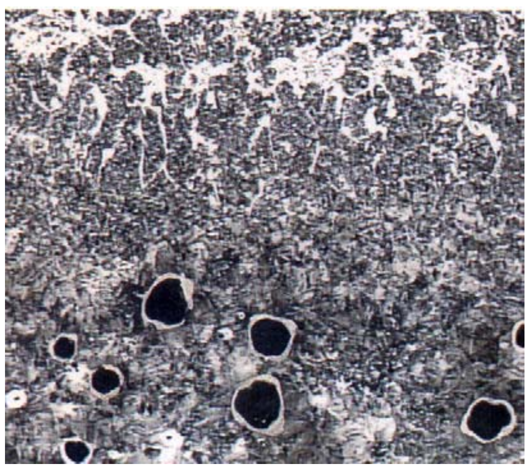


Figure 2 Photomicrograph of the shell/core interface

By adopting special casting parameters in combination with strict chemical control however these difficulties can be conquered.

6. THE HSS QUALITY

The driving force for implementing HSS rolls in the roughing stands is the insufficient performance especially with regards to wear and surface deterioration when rolling stainless steels and the constant high scrap rates and respectively high quality costs during the manufacturing of the semi HSS grade. The development of HSS grades for hot rolling started in the early 90's and since then the rollmakers have put a lot of efforts to overcome production problems and develop the best possible materials.

Today internal scrap levels seem to be down to reasonable numbers and the rolls are successfully implemented in the early finishing stands of hot strip mills.

Although the chemistry and microstructure is different from the Semi HSS, the roll characteristics in the process are very similar. The firecrack resistance is positively affected by the hot yield strength and the absence of a closed eutectic carbide network. These features are present in both materials resulting in a better firecrack resistance than the Chrome Steel grade. The roll bite capacity, meaning the ability of high reductions without slippage, is normally positively affected by low carbon/carbide content in combination with a low hardness. The HSS roll has a high carbon/carbide content and a high hardness in combination with a good roll bite capacity. Due to the high hardness differences of the preferred MC-carbides and the martensitic matrix, the carbides wear less than the matrix creating a high friction with a "spike effect" (Figure 3) providing the basis for the good biting behaviour.

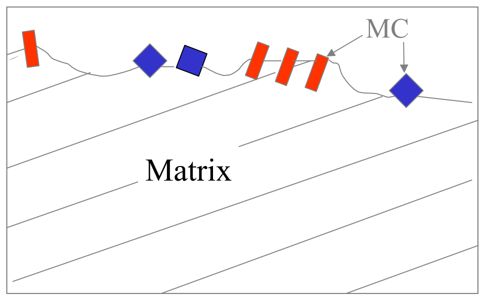


Figure 3 schematic description of the "spike effect"

The wear resistance and respectively increased service length of HSS grades are based on the relatively high amount of alloying elements producing a structure of primary MC and M_2C carbides, eutectic M_7C_3 carbides plus fine dispersed secondary carbides in a martensitic matrix. The total amount of hard carbides is elevated compared to semi HSS, which results in an even better performance and a high resistance against unfavourable "dog-bone", wear profiles during extended rolling campaigns.

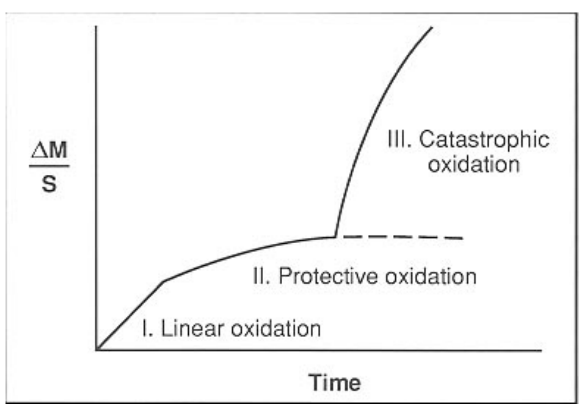


Figure 4 Oxidation scheme

The surface deterioration due to oxidation is another important aspect for roughing rolls. The function of oxide formation of a roll material is initially linear, prior to the oxide being more passive in nature. Elevated temperatures can generate exponential oxidation growth rate factors (Figure 4). A uniform and controlled oxide layer as in Phase II is desirable on the roll surface, to provide a hard and thermal protective barrier. Catastrophic oxidation is represented by fast growing oxide layers, which start to peel off when shear stresses exceed the fatigue strength of the oxide layer. In all mills where HSS-roughers are currently tested there was no unfavourable oxidation or serious deterioration of the roll surface reported. Even when rolling sophisticated stainless steel grades the surface remains smooth and shiny (Figure 5).

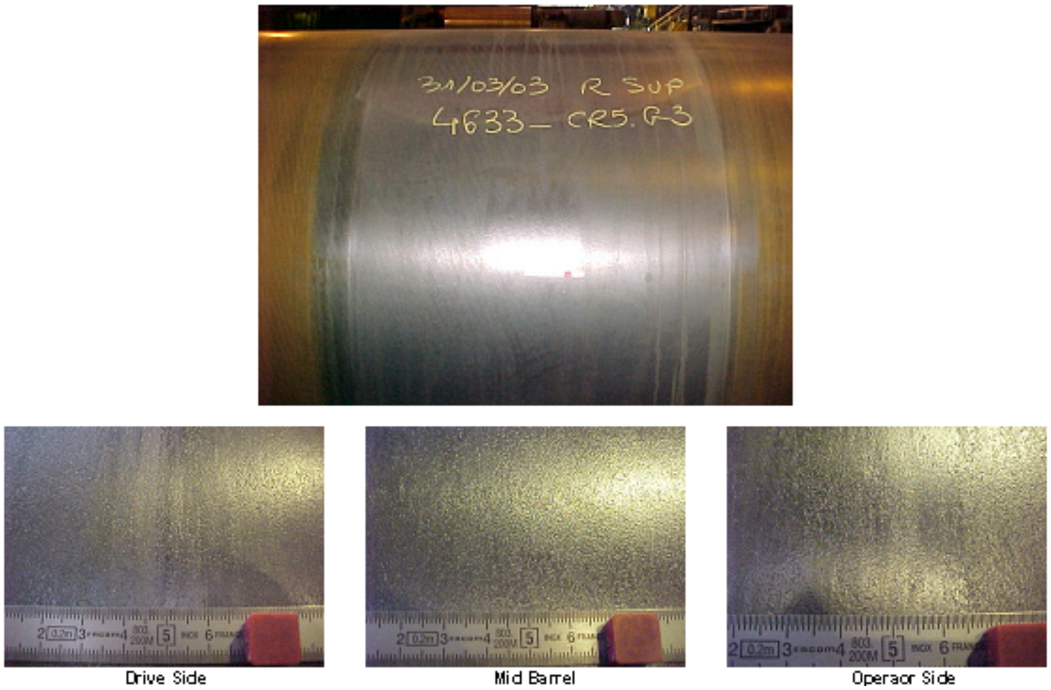


Figure 5 HSS-Roughing Roll surface after rolling 15.000 t Stainless Steel

The Åkers Group has already produced HSS for 11 different customers. Some are producers of stainless steels, but the majority produces conventional steel grades. All mills reported a significant improvement of the performance t/mm compared to the Chrome Steel grades (Table 6).

Quality	Services	Current-Ø	Average Redress (mm)	Tons	T/mm
Chrome Steel	78	785	0,904	56918	807
Chrome Steel	78	785	0,904	56918	807
HSS	157	785	0,598	220444	2348
HSS	157	785	0,598	220444	2346
HSS	73	852	0,537	127759	3258
HSS	73	852	0,537	127759	3258

Table 6 Performance of different rougher grades in a European Narrow Strip Mill

Some mills are using the improved wear resistance for increasing the service time (Table 7).

Quality	roll change after
Chrome Steel	3 days
HSS	10 days

Table 7 Service times of different rougher grades in a European HSM

7. CONCLUSIONS

The introduction of the semi HSS roll grade in the late 1990's had a substantially positive effect on productivity and quality aspects in the roughing stands of hot strip mills. Among the variety of benefits, there remains at least two negative factors when using this roll grade. Number one this grade is not applicable for the rolling of stainless steels and number two the fabrication of this roll still comes along with considerable high scrap rates and high quality costs respectively. In order to overcome these problems, HSS rolls have been developed and were tested in this application. This grade was successfully used for the production of stainless steels. Two stainless steel mills in Europe have converted or will convert to 100% usage of HSS rolls in the roughing stands. But also conventional hot strip mills are testing the new grade with great success. Due to the fact that HSS rolls show similar characteristics in service like the semi HSS grade plus a superior wear resistance there is a great potential that these rolls will be used in more and more roughing applications in future.

8. ACKNOWLEDGEMENTS

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