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SUSTAINABLE ALTERNATIVE IN COLD ROLLING TECHNOLOGY FOR THE SUBSTITUTION OF CR-PLATING PRACTICE ON FORGED WORK ROLLS[1]

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Abstract

The demand in terms of respect of the environment, safety in operation and high rolling performance while minimizing the total cost in use are the new trends in the near future of cold rolling industry. The intrinsic properties of HSS forged grade regarding wear resistance and incident resistance allow to skip chrome plating and to minimize roll damages while roll life in stand is extended. In this paper these properties will be described in the frame of industrial cases and their associated key parameters to achieve such unprecedented results.

Keywords: Cold mill rolls; Forged rolls; HSS.

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1 INTRODUCTION

The general trend for development in cold rolling both for the ferrous and the non ferrous metal industries is to roll faster, thinner and wider while achieving perfect control of flatness, thickness and surface aspects compatible with a high productivity. This trend calls for the use of advanced rolling technologies that control key rolling parameters. The key objectives that are directly linked with work roll technology can be identified as listed here below:

- To roll harder grades (AHSS) while keeping the mill incident rate low. Indeed these incidents may create safety problems (roll spalling) and poor mill availability due to frequent stops for the roll changes.
- To roll consistently in tighter tolerances with respect to flatness, thickness, roughness and surface quality.
- To guarantee very long runs while keeping the roughness transfer constant.
- To widen out without leaving a track line on the strip from roll wear or dirt build-up; this is one of the most aims in cold rolling mills (schedule-free rolling).
- To optimize the overall costs of rolling remains a permanent and essential objective.

Some key parameters as roughness retention and surface aspects can be guaranteed through chrome plating of work rolls. This practice is effective and efficient, but is becoming more and more questionable and in a near future unacceptable due to environmental restrictions. Consequently investments for new chrome plating pits are nowadays rather questionable even if chrome plated rolls are still commonly used in temper mills and early stands of tandem mills.
To fulfill these key objectives new forged work roll grades have been continuously developed and will be discussed in this paper.

2 EVOLUTION AND TRENDS OF WORK ROLLS FOR COLD ROLLING

Nowadays forged work rolls (2 to 6 %Cr) are mainly used in cold rolling processes. Chrome plating of these rolls is applied to improve the wear resistance in terms of roughness retention which, in turn, will ensure, for instance, consistent and higher gloss of car bodies after painting. This technique was initially developed for temper/skin pass mill applications. In these applications, chrome plated work rolls exhibit 2 to 8 times longer lifetimes than uncoated rolls, mainly because of a better roughness retention. The implementation of this technique was progressively extended to the reduction mills.[1-3]
Previously tandem tinplate rolling mills (especially the early stands) were using High Chromium (17% Cr) cast iron rolls (HiCr with a Nodular Iron core) as an alternative to forged rolls, in order to keep a higher level of roughness as long as possible, allowing a good bite grip to avoid lateral shift leading to derailment of the strip. However, due to their specific thermal properties, namely the lower conductivity, increasingly more problems associated with oil film rupture and subsequent lack of lubrication occurred when mill speeds were increased. This led to rolling mill incidents and catastrophic failure of rolls due to the intrinsic weakness of cast iron grades. Consequently the use of cast high chromium iron grades was almost abandoned except for a few mills accepting to operate at low speed to keep the conditions of lubrication in the rolling bite under the critical limit above which destruction of the oil film occurs.

Attempts with cast high chromium iron work rolls grades were also performed in the tandem mills for sheet but were rapidly discontinued because severe pollution of the strip surface by iron fines occurred. This pollution was promoted by a microstructure exhibiting a coarse carbide network (Figure 1). Subsequently the next generation of cast work rolls for cold rolling was reconsidered and a new type of rolls was tested. This new spun cast grade comprised a Semi-High Speed Steel shell and a Nodular Iron core. It resulted in a better in-service behavior but as the thermal crown behaved differently to forged rolls, the steady rolling state was delayed. In order to get rid of thermal crown issues, the semi-HSS rolls are today supplied as monoblock forged rolls but their limitation in hardness level does not allow their usage in later stands of tandem mills for sheet due to their reduced resistance against indentation.(4,5)
To get harder rolls the chemistry has been completely reconsidered leading to the manufacturing of forged monoblock HSS grades.

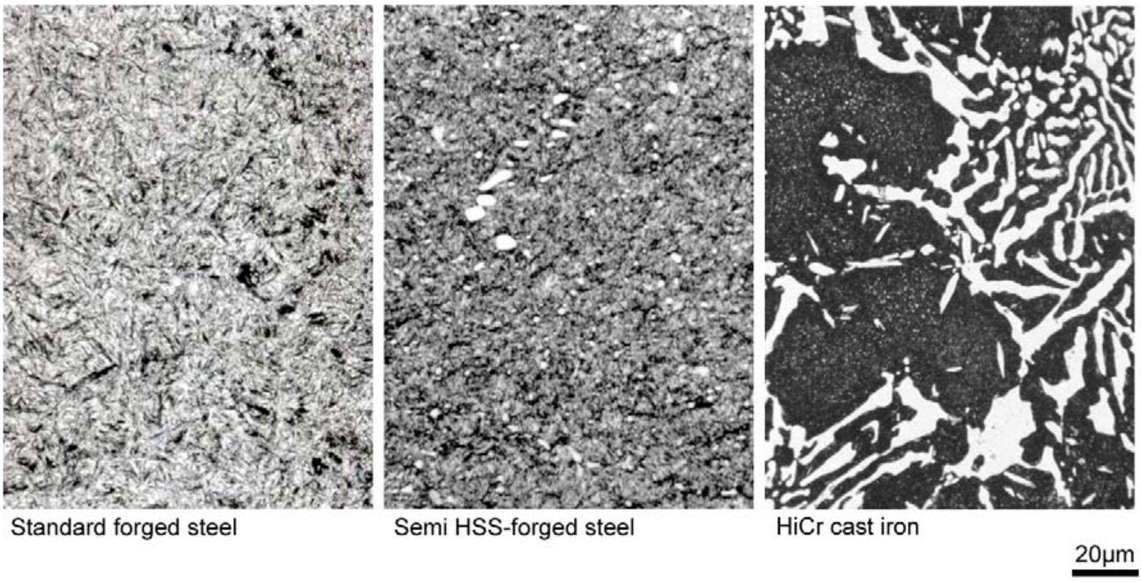

Figure 1: Comparison of work roll microstructures.

3 HSS GRADE METALLURGY AND PROPERTIES

In order to withstand high rolling stresses and to guarantee a satisfactory strip surface aspect, most cold rolling mills are currently using forged work rolls. In all these applications, novel advanced work rolls to be implemented must meet the following requirements: safety in operation, superior performance, minimised effective cost in use and increased mill availability time.
With regard to safety in operation, the rolls must resist major incidents in the mill like strip breaks and pinches that generally lead to superficial cracks and subsequent spallings. Occasionally such spalls occur in a very violent and dangerous way ("exploding rolls"). The advanced roll should have low internal stress, as well as high resistance to mechanical and thermal cracks. Superior performance relates to extended mill campaigns for greater uptime of mill operation and quality of the rolled sheet. In this case, the following properties are required: excellent indentation resistance, high surface appearance of the sheet, increased roughness retention to avoid slippage on the first stands, and retention of high transfer of roughness for the last stands. To satisfy stricter environmental regulations implemented worldwide, the

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advanced roll should have an exceptional roughness retention permitting the elimination of chrome plating.
Although all these expectations for the cold mill application seem antagonistic when considering standard forged grades (Figure 2) they are achieved with the advanced generation of high speed steel forged rolls called forged HSS rolls.

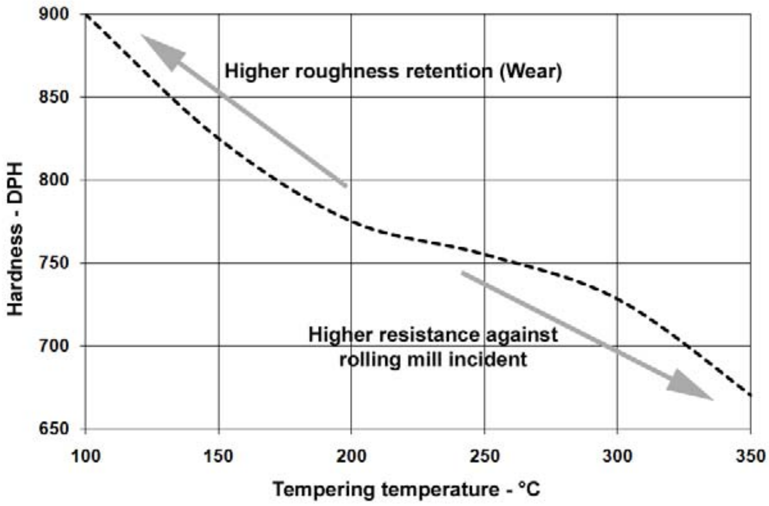

Figure 2: Antagonism between application and desired properties of standard forged rolls.

The microstructures of forged HSS grade compared with standard grades are illustrated in Figure 3. The HSS structure consists of a tempered martensite matrix with a homogeneous distribution of secondary Cr, Mo, V carbides (VC, Mo_2C). Few eutectic carbides, M_7C_3 type, forming during the solidification phase can also appear at a low magnification level depending on the ratio and level of carbide forming elements. As shown in Figure 4 all of these carbides are harder than cementite yielding enhanced performance in terms of wear resistance particularly as regards roughness retention. The high hardness level of HSS rolls (up to 820 HV / 855 LD) obtained by high tempering temperature (around 500°C / 930°F) gives a very high resistance to marks combined with an extremely high resistance to thermal cracks and damage induced by strip breaks.

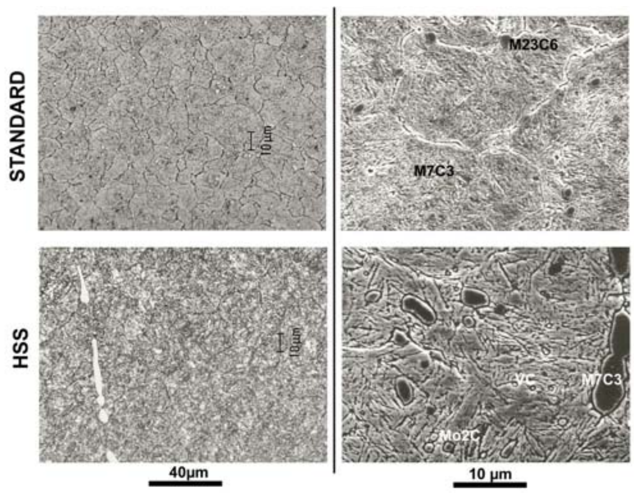

Figure 3: Microstructures of standard and HSS grades.

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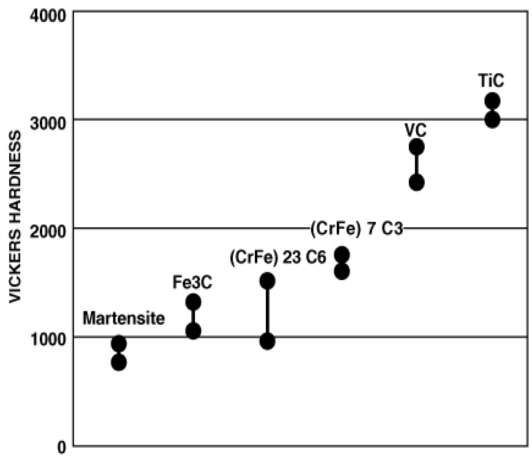

Figure 4: Hardness of the carbides.

Table 1: Metallurgical properties

Grade	Tempering temperature °C (°F)	Residual stress in skin layers MPa (KSI)	Hardness (HV)
Standard 5% Cr	120/150 (250/300)	-700/-1000 (-102/-145)	780/820
HSS	480/500 (895/930)	-300/-400 (-44/-58)	780/820

As identified in the table 1 on the left, the HSS rolls contain lower internal stresses than standard forged rolls for a same level of hardness. The lower internal stress values observed for HSS rolls result from the accumulation of various tempering treatments at high temperature, which induce an important relaxation of the internal stresses. Due to this fact, the HSS rolls are safer in use than standard forged rolls.

4 FORGED HSS ROLL PREPARATION

4.1 Grinding of HSS Work Rolls

As a result of the development of Advanced High Strength Steels (AHSS) such as Dual Phase steels, work rolls in cold rolling mills are being used under increasingly demanding conditions. As a result of the higher rolling pressures, the work rolls are subjected to considerable wear, which forces the mill to change the work rolls more frequently. The high roll surface wear also causes an increase of the average cycle time needed in the roll shop to redress the rolls according to the quality requirements. In addition, heavy process incidents when rolling AHSS strips often cause excessively high amounts of roll stock removal, because the impact of a mill incident with these hard steel strips on the rolls is large, causing severe crack formation in the roll barrels.
It appears that production of cold rolled AHSS strips is causing the consumption of work rolls in the cold rolling mill to increase. This leads to a less efficient operation and higher costs in the roll shop. Therefore rolling of next generation steel grades calls for a next generation work rolls.

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Grinding trials at the roll shop have shown that application of the standard grinding programme and the standard grinding wheel specifications, normally used for grinding of conventional 3-5%Cr forged steel rolls, does not yield satisfying grinding results for forged HSS work rolls. Grinding of HSS rolls obviously requires explicit attention and modifications of the grinding process. After trials in cooperation with grinding wheel suppliers, HSS rolls could be integrated in the roll fleet as they appeared quite well grindable with the right choice of wheel type and grinding parameters.

4.2 Texturing

A mechanical method like shotblasting cannot be used for texturing the HSS rolls, since it yields only low roughness value (Ra) with HSS grades. Electro Discharge Texturing (EDT) is nowadays commonly used to imprint a desired roughness on the barrel surface.
As the EDT method involves a local melting (electric arc) it creates a profound modification of the superficial roll microstructures. Consequently it is important to know how the roll grade behaves. Trials have been made on samples of various roll grades inserted simultaneously in the same sample holder. The texturing standard conditions of the industrial machine were in capacitive mode with negative polarity. The target roughness Ra was 2.5 to 3µm. The results in roughness measurement indicated no major differences between the grades, despite their wide disparity in chemical composition.
The microstructures of the samples have been examined in cross section by means of light microscopy and scanning electron microscopy as shown in Figure 5. The HSS grade behaves similarly to standard steel grades. The thickness of the white layer is approximately 10 µm at its thickest point. Underneath the white layer there are the reaustenitized layer and a thinner softened zone, since this grade has a high tempering temperature. It is also noted that within the white layer the eutectic carbides have not been affected by the electric arc energy. The above results have been confirmed in-service; there is no major difference between the standard and HSS grades in terms of texturing-ability. Consequently the same parameters of texturing can be equally applied. The behavior in the mill, regarding roughness retention of HSS grades after EDT texturing, appears at least equivalent to standard rolls, and potentially even better due to the presence of hard eutectic carbides in the white layer. This assumption should be confirmed with further trials since the statistical analyses are as yet insufficient for ultimate conclusions.

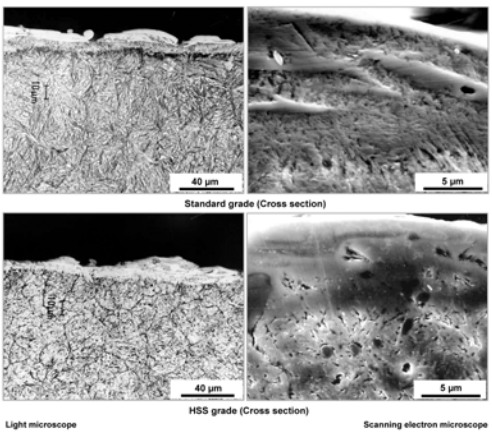

Figure 5: Microstructure after electro dischargetexturing.

5 IN SERVICE BEHAVIOR

Trials have been carried out in 20 rolling mills worldwide including 4Hi and 6Hi configurations for sheet and tin plate applications in continuous and discontinuous tandem mills. Previous papers[(6-12)] have shown the improvement of performance in terms of tons/mm and tons/run using HSS rolls. Table 2 hereunder summarizes the performance improvement to be expected in the mills when using HSS rolls.

Table 2: Overall expected performances

Grade	% run length (tons / campaign)	% roll consumption (mm / 1000tons)
Standard 5% Cr forged	100	100
Standard 5% Cr forged + Chrome plated	~200	100
HSS forged	300 - 500	< 30

The performance for HSS forged rolls can be achieved without using chrome plating to extend campaign length as illustrated in Fig 6 showing the roughness evolution on the barrel versus the rolled strip length. These trials have been made in stand#1 of tinplate tandem mill. The roughness of the HSS grade is seen to decrease less and with moderate scattering compared to the standard chrome plated grade.
Figure 7 highlights the performances obtained regarding resistance to incidents and optimization of grinding policy in the 4th stand of a 5-tandem tinplate cold rolling mill. The trials were carried out in the same period of time and for 180 campaigns. The results demonstrate the superior resistance of HSS rolls to mill incident while stock removal has been minimized. The ratio (HSS/STD) in tons/mm is 2.4 times better.
Both Figure 8 and Figure 9 are related to performances of uncoated HSS work rolls versus standard work rolls in chrome plated condition. Figure 9 summarizes a mill trial in which HSS rolls performed exceptionally well with respect to resistance against mill incidents: the HSS rolls showed an outstanding improvement (8 times better in tons/mm) in case of occurrence of mill incidents. Figure 9 indicates clearly that chrome plating can be skipped definitively since the HSS roll performances (tons/campaign) are equal or even better in comparison with the standard forged steel work rolls in chrome plated conditions.
The improved performances in terms of length/campaign and tons/mm are related to the low work hardening capacity allowing the extension of the campaign in combination with a reduced dressing amount. Such behavior results from the lower level of internal stresses which reduces the comparative Hencky - Von Mises tension induced in the HSS roll as a result of the combined action of internal stresses and operating stresses. Consequently the plastic deformation of the material will be delayed.
Recent comparative trials in pilot mill have demonstrated that chrome plating decrease the frictional coefficient whereas the HSS grades display more significantly such decrease. As this property seems to be interesting in temper mill application, industrial trials are presently in progress to validate this hypothesis.

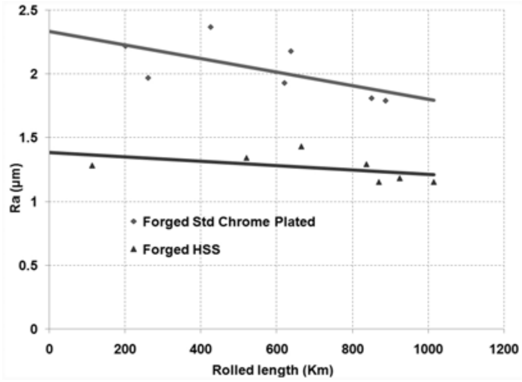

Figure 6: Evolution of roughness versus rolled length in stand#1 of tandem tinplate mill.

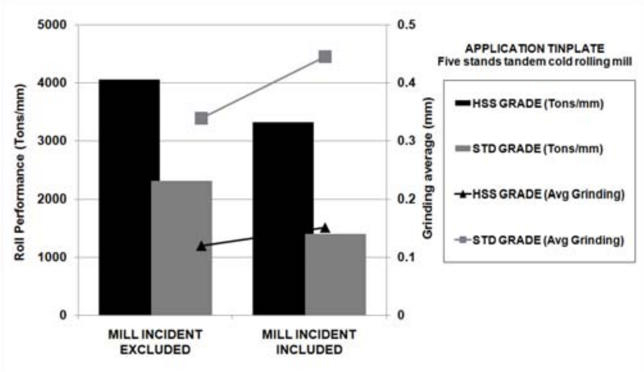

Figure 7: Influence of rolling incidents on roll performance between standard and HSS grades (stand#4).

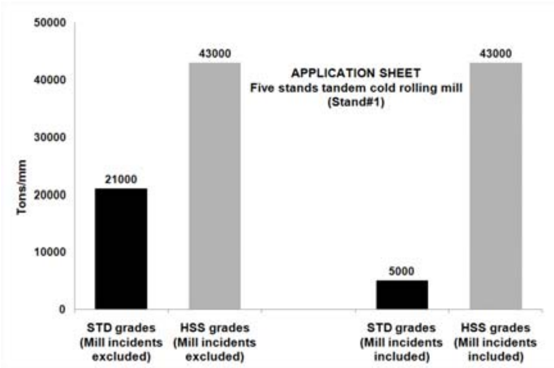

Figure 8: Resistance against mill incident in tandem sheet mill. Results in stand#1.

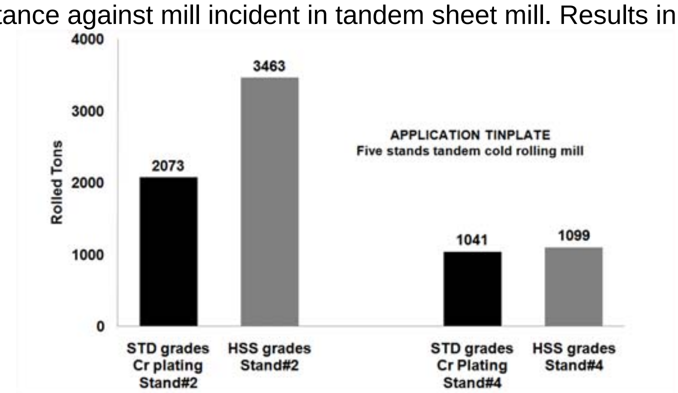

Figure 9: Average campaign lengths of uncoated HSS work rolls and Cr-plated standard work in stand# 2 & #4 of a tinplate mill.

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6 INDUSTRIAL CASE HSS WORK ROLLS TRIAL IN A TANDEM COLD ROLLING MILL AT TATASTEEL IJMUIDEN WORKS (NL)

Figure 10 summarizes trial results obtained in stand #1 of the 5-stand 4-high batch sheet tandem mill at TataSteel Ijmuiden.[12,13] The standard work roll grade at this mill is 3%Cr forged steel, which is used in Chrome-plated condition in stand #1. Two pairs of HSS rolls were used in non-Chrome-plated condition, in 118 rolling campaigns for the regular mill product mix (involving 2 x 118 = 236 roll redressings). In the trial period, 375 rolling campaigns were carried out with the standard grade work rolls in stand #1 (i.e. 750 roll redressings). Average campaign lengths were the same for both roll grades (2.3 kilotonnes), since no attempts were made in this trial to perform extra long rolling campaigns with the HSS rolls. As a result, a superior performance of the HSS rolls is obtained with a lower average stock loss per campaign.

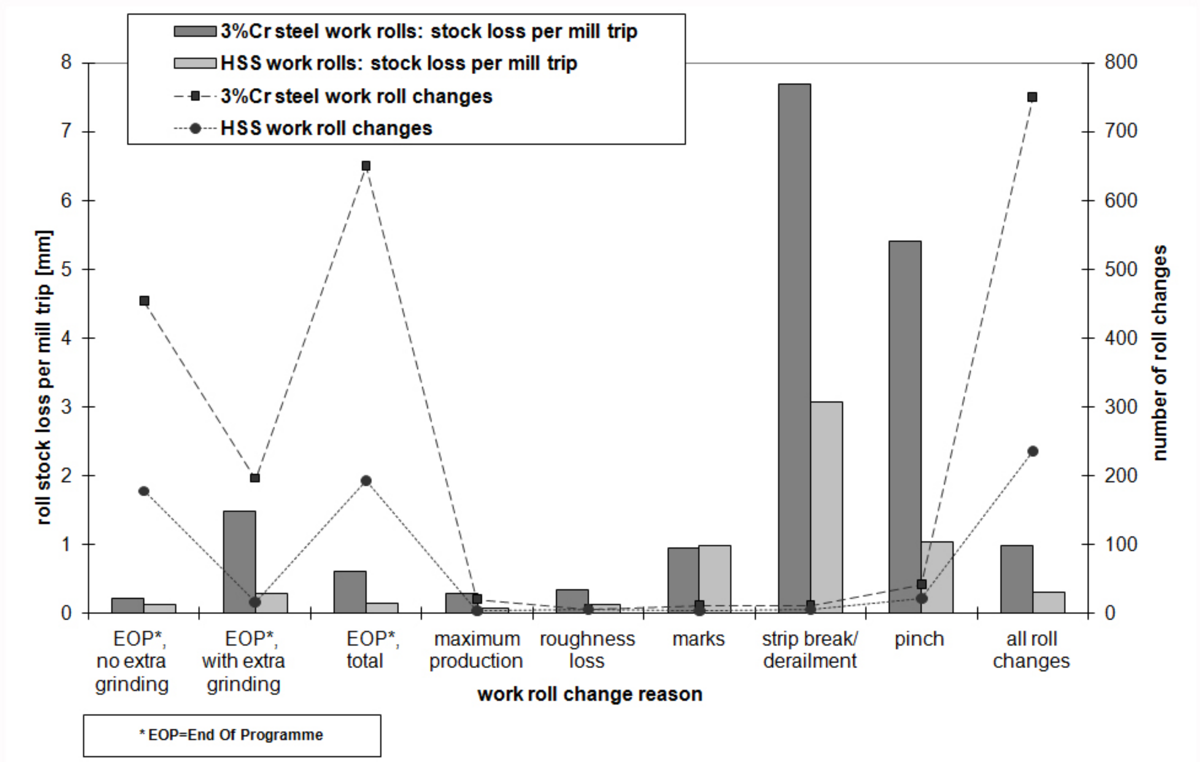

Figure 10: Redressing stock losses for 3%Cr steel work rolls (Cr-plated) versus HSS work rolls (not Cr-plated) in stand #1 of the 5-stand 4-high batch sheet cold rolling mill of Tata Steel Ijmuiden (NL).

7 CONCLUSIONS

The high ability of forged HSS grades to combine metallurgically contradictory properties like wear resistance and high toughness fulfills the demand for advanced cold rolling. Thanks to this breakthrough roll technology outstanding performance has been achieved in the field of:

- Safer rolling condition.
- High roughness retention allowing to suppress the chrome plating operation.
- High roll performance in terms of superior mill incident resistance and/or extended life in stand combined with less stock removal in the roll shop.

- Increased rolling reduction aiming to the rolling of AHSS grades while minimizing the roll surface and sub-surface deterioration.

Due to these specific properties the overall cost in use of the mill is dramatically reduced.

Presently the developments of forged HSS grades aim to implement schedule-free rolling: trials are in progress in some mills to define the key parameters acting when widening out.

REFERENCES

1 D.S. Borselino, D.B. Fabbri: *"Dofasco's Experience with Chrome-Plating temper Mill work Rolls"* Iron and Steel Engineer, April 1983.
2 H. Kleinz, H.H. Urlberger: "*Hard-chromed work Rolls for the Production of Cold-rolled Sheet"*, Metallurgical Plant and Technology International, June 1992.
3 H. Kuwamoto, S. Iwadoh, T. Izubishi, T. Nakayama: *"New Chromium Plating Technology promises consistency of Strip Surface Texture ",* Iron and Steel Engineer, February 1989.
4 C. Gaspard, P. Cosse, A. Magnée: *"Contribution of ESR and Progressive Induction Hardening to the Manufacture of Deep Hardened Work Rolls"*, 26th MWSP conf. proc., ISS-AIME, Chicago, October 1984, pp 75-87.
5 C. Gaspard, S. Bataille, D. Batazzi, P.Thonus: *" Improvement For Advanced Cold Rolling Reduction Mills By Using Semi-HSS and HSS Rolls "*, 7th International Conference on Steel Rolling (ISIJ), Makuhari, Chiba, Japan, 1998
6 C. Gaspard, S. Bataille, D. Batazzi, P.Thonus: *"Alternative Technologies For Manufacturing Intermediate And Work Rolls For Cold Rolling "*, ABM 38th Rolling Seminar, Florianopolis, Brazil, 2001.
7 C. Gaspard, D. Batazzi, P. Cosse, S. Bataille: *"New Generations of Deep and Ultra Deep Hardened Rolls Made by Progressive Induction Hardening"*, 34th MWSP conf. proc., ISS-AIME, vol. 30, 1993 pp 119 – 133
8 C. Gaspard, S. Bataille, D. Batazzi, P.Thonus: *" Forged Semi-HSS and HSS Rolls Designed for Cold Rolling Reduction mills "*, 41st MWSP conf. Proc., ISS, Vol. 37, 1999.
9 C. Gaspard, S. Bataille, D. Batazzi, P.Thonus: *" Current Trend For Cold Rolling Applications With HSS Rolls "*, 44th MWSP conf. Proc., ISS, Vol. 40, 2002.
10 C.Gaspard, J. Ballani, D. Batazzi, T. Adams: *"Use of HSS Rolls To Skip Chrome Plating in Cold Rolling Applications", Materials*, Science & Technology – September 26 – 29, 2004 – New Orleans, LA.
11 C. Gaspard – C. Vergne – D. Batazzi : "*Implementation of HSS Grade in cold Rolling Applications*", Roll 4 2007 – Birmingham,March 2007
12 P.H. Bolt, D. Batazzi, N.P. Belfiore, C. Gaspard, L. Goiset, M. Laugier, O. Lemaire, D. Matthews, S. Mul, T. Nylén, K.M. Reuver, D. Stocchi, F. Stork, J. Tensen, M. Tornicelli, R. Valle, E. van den Elzen, C. Vergne and I.M. Williams, *" Damage resistance and roughness retention of work rolls in cold rolling mills"*, Revue de Métallurgie 107, 245–255 (2010)
13 C. Gaspard, C. Vergne, D. Batazzi, T. Nylen, P.H. Bolt, S. Mul, K.M. Reuver *" Implementaion of In-service Key Parameters of HSS Work Roll Grade Dedicated to Advanced Cold Rolling",* AISTech Conference, May 3-6, 2010, Pittsburgh, Pa, USA