EXPERIMENTAL APPROACHES TO BRING OUT DAMAGE MECHANISMS OBSERVED IN SERVICE ON HSM WORK ROLLS AND AIMING AT IMPROVING ROLL PERFORMANCES THROUGH NEW ROLL GRADE DESIGN[1]

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Abstract

As a world-wide roll manufacturer the Åkers Group offers products covering almost all the segments of the rolling industry with a permanent will of quality and continuous improvement. Thanks to close relationships with its customers enabling to acquire a good knowledge of their applications, Åkers has set up experimental approaches for a better understanding of the roll degradation phenomena observed in service. These approaches aim at separating each mechanism involved in the global degradation of rolls to bring out the correlation between roll grade properties and the damage mechanisms. Different physical phenomena as oxidation, thermal fatigue or tribology present in the HSM applications have been investigated. Results obtained at the laboratory scale from solicitations with individual or coupled physical phenomena have been confirmed through rolling trials on a semi-industrial pilot-mill.

Keywords: Hot strip mills; Cast rolls.

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1 INTRODUCTION

The current trends in the hot strip mills require more and more severe rolling conditions in order to increase the mill performance in terms of length of runs, rolling of harder grades, wear of work rolls and saving of energy through the reduction of rolling forces and torques in stands through the reduction of friction.

Regarding work rolls, that involves an increase in thermal and mechanical stresses in service which requests improved mechanical, thermal and physico-chemical properties.

In hot strip mills, performances of work rolls are usually evaluated from the amount of strip rolled per millimeter of machined roll diameter (ton/mm) or inversely wear of work rolls can be expressed through the amount of machined roll millimeters per ton of rolled strip (mm/ton).

Another factor supplying an indication about work roll performances in mills is the evolution of rolling parameters as rolling forces during rolling. Rolling forces translate the coupling of physico-chemical, thermal and mechanical phenomena present into the rolling bite and consequently can be considered as an image of the friction coefficient. Moreover, this parameter indicates very surely the energy consumption of mill. In this context, the coefficient of friction is usually fixed and considered as reference in comparison to the rolling force evolution.

Overall damage mechanism of work rolls during hot rolling of steel can be considered as the result of a complex interaction of at least three mechanisms which are oxidation, fatigue (thermal or low cycle fatigue) and friction.

The predominance of a mechanism versus the other ones varies according to the rolling stands (roughing, early or late finishing stands) and the related stresses. In the roughing mills, in tandem as well as in reversing configurations, thermal fatigue is considered as the main damage mechanism of work rolls. For the early finishing stands, abrasion and oxidation are assumed to be the predominant factors. In the late finishing stands, abrasion and low cycle fatigue are the main observed phenomena.

The chemical composition, the thermo-mechanical properties and the thickness/adhesion of the oxide layer formed on the work roll surface during rolling influence strongly the whole tribological behavior of rolls. The chemical composition of roll and the microstructure features in terms of type of carbides and matrix composition have also a significant effect on these roll properties. The R&D development set up in Åkers consists in designing new roll grades thanks to a better understanding of roll damage mechanisms in relation to the rolling configuration. That can be done only thanks to experimental approaches set up for many years now at the laboratory level to emphasize the answer of roll grades against the coupling of selected damage mechanisms as oxidation, tribology or thermal fatigue corresponding to a specific application as roughing, first or last finishing stands. The laboratory approach contributes to decrease the risks and the afferent costs of trials performed at an industrial scale.

The present paper aims at presenting the experimental methodology set up by Åkers in the understanding of damage phenomena for the design of new roll grades.

2 OXIDATION

According to the considered stands in the hot strip mills, the average temperature of the rolled strip varies between 1200°C at the entry in the roughing mill and 800°C at the exit of the last finishing stands.
Usually the numerical modeling performed about the thermal regime involved in the rolling bite of a hot strip mill gives a mean superficial temperature of work rolls between 500°C and 650°C. But the extreme surface of work rolls might achieve a much higher temperature during a very short contact time due to the fast cooling afterwards.
Whatever the thermal level considered, that contributes to the formation of oxide scales at the roll surface into the rolling contact. Oxidation of rolls holds an important part in wear and friction behavior. As homogeneous, thin and adherent, the oxide scale is efficient against wear promoting low friction. Contents of alloying elements as chromium, vanadium or molybdenum through the precipitation of carbides can also influence the whole oxidation behavior of roll grades.
Thus this is essential to understand the correlation between the roll microstructure and their oxidation behavior. For that Åkers has developed two experimental approaches:[1-3] thermogravimetric (TGA) tests and in-situ oxide growth tests through Environmental SEM. The first one allows to obtain the global kinetics of a given grade and more particularly the oxidation parameters as the activation energy Q and the oxidation constant Kp. The second one allows determining the sequence and the contribution of the different metallurgical phases (matrix, carbides …) of the microstructure on the overall behavior in oxidation of the given grade.
According to the application, the tests are performed at very high temperatures between 650°C and 950°C in dry air or wet atmosphere. The results are coupled with SEM observations and EDS analysis on the surface and in cross-section (Figure 1). Topographical measurements of oxide scale surface can be added (Figure 2).

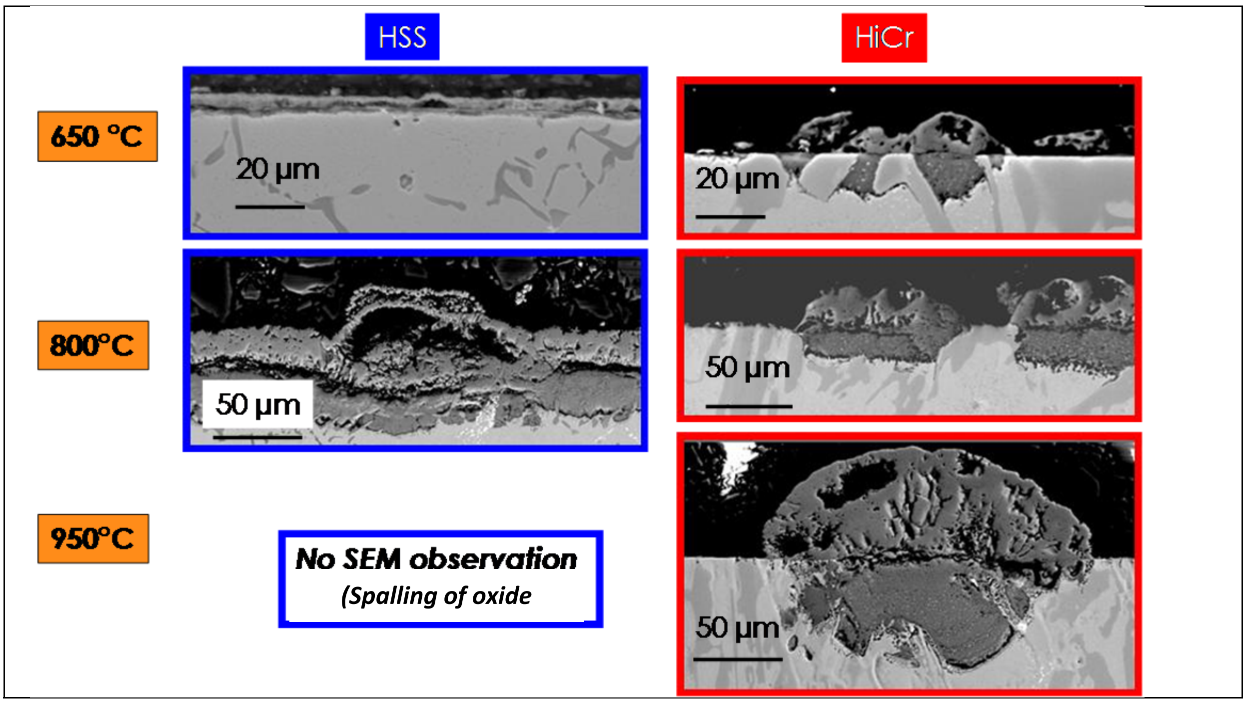


Figure 1. Example of SEM observations performed in cross section after TGA tests on HSS and High Chromium iron (HiCr) at oxidation temperatures between 650°C and 950°C for 3 hours.[2]

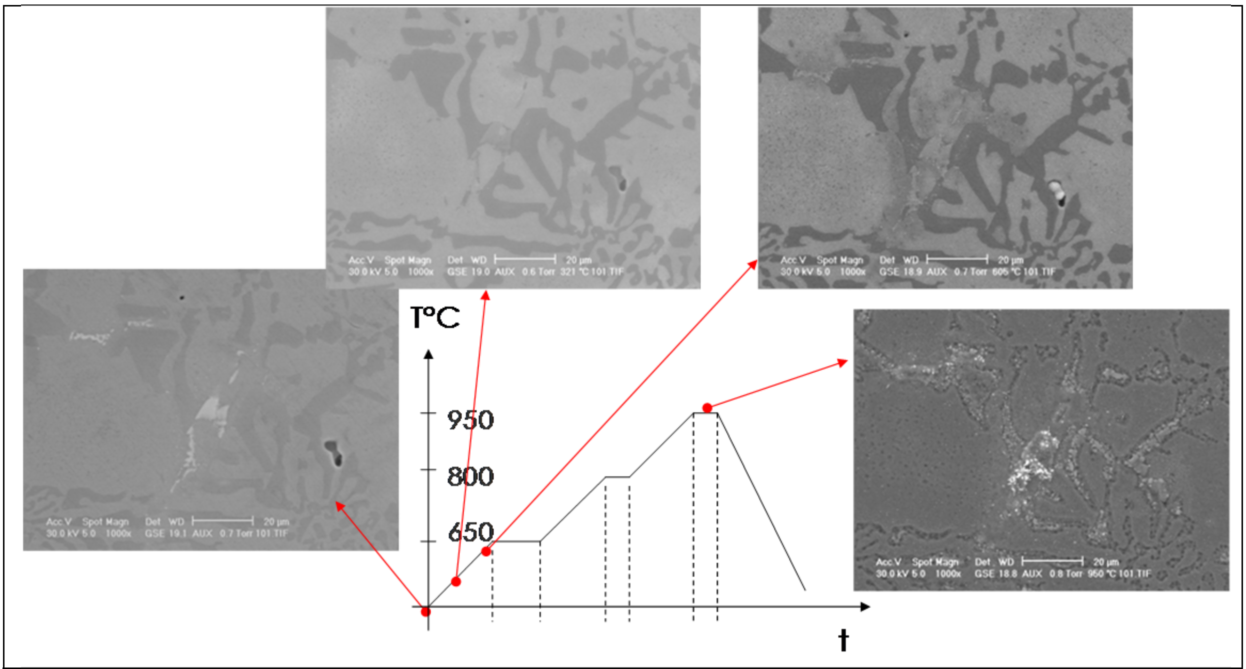


Figure 2. Example of in-situ oxide growth test through Environmental SEM in the case of oxidation of a high chromium iron according to the given thermal cycle between room temperature and 950°C.(2)

3 TRIBOLOGY

The choice of elaboration process and/or heat treatment cycles determines the roll microstructure in terms of nature, size and distribution of carbides – eutectic as well as secondary precipitation carbides – and also type of matrix structure.
Tribological studies are set up in order to analyze the contribution of the different elements of microstructure on the friction and wear behavior of a considered roll grade.
These tests have been carried out on a pin-on-disc tribometer(3-5) at high temperature where the disc is heated by a high frequency inductive system and the pin is heated by conduction, convection and radiation only through its sliding contact with the disc. In that configuration, the pin consists of the roll material when the disc consists of the rolled material as a low carbon steel. The disc temperature varies between 20°C and 950°C.
Two kinds of tests can be set up in order to differentiate the contribution of the occurrence of an oxide scale on the pin surface during the sliding contact on the value and the evolution of the Coulomb-type friction coefficient and damage mechanisms.
In the first ones, the pin is put in contact with the disc at the beginning of the friction test when the disc surface is still free of oxide at room temperature. The heating of the disc is launched afterwards. So the study of the roll grade tribological behavior in the transitory period of the sliding contact is promoted.
In the second tests, the heating of the disc is launched at the beginning of the test while the pin is kept out of the contact at room temperature. When the test temperature is achieved at the disc surface and consequently an oxide layer has been formed, the pin is put in contact with the disc and sliding is launched. So the aim of this test is to analyze the contribution of a thick and uniform oxide scale on friction and the wear mechanisms of the roll grade.

An example of results obtained for work roll grades involved in the early finishing stands is given on Figure 3. SEM observations of antagonist worn surfaces show the difference in tribological behavior between the roll grades. This result can be explained by the thickness, the adherence and the nature of the oxide scales formed on the pin surfaces according to the test temperatures. Generally the pre-oxidation of the disc with the formation of a continuous and thick oxide scale induces a reduction of friction whatever the test temperature due to the lubricant effect of oxides. Only when the oxide scale formed on the pin becomes thicker and harder, an increase in wear of sliding surfaces is noticed and consequently an increase in the resulting friction coefficient.

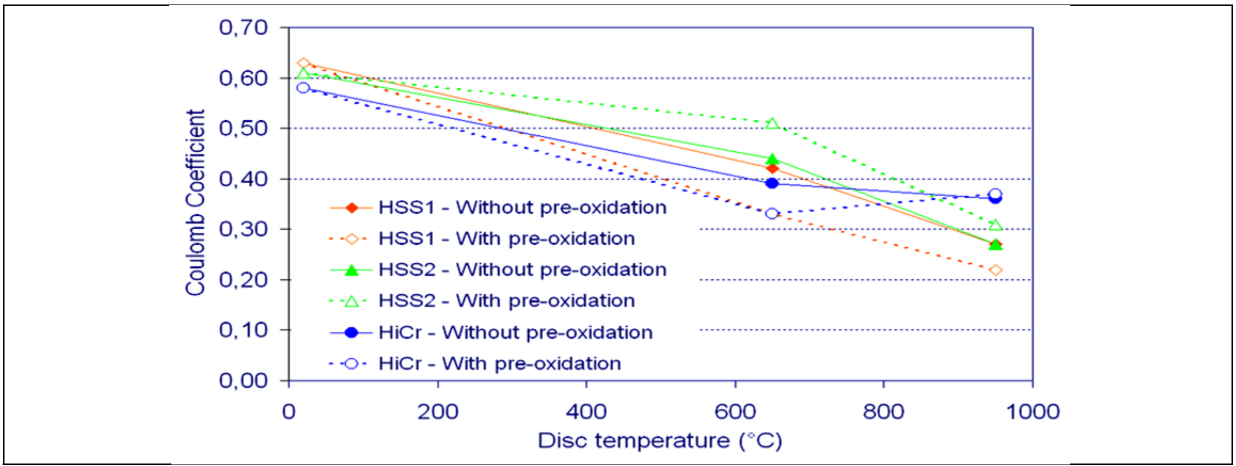
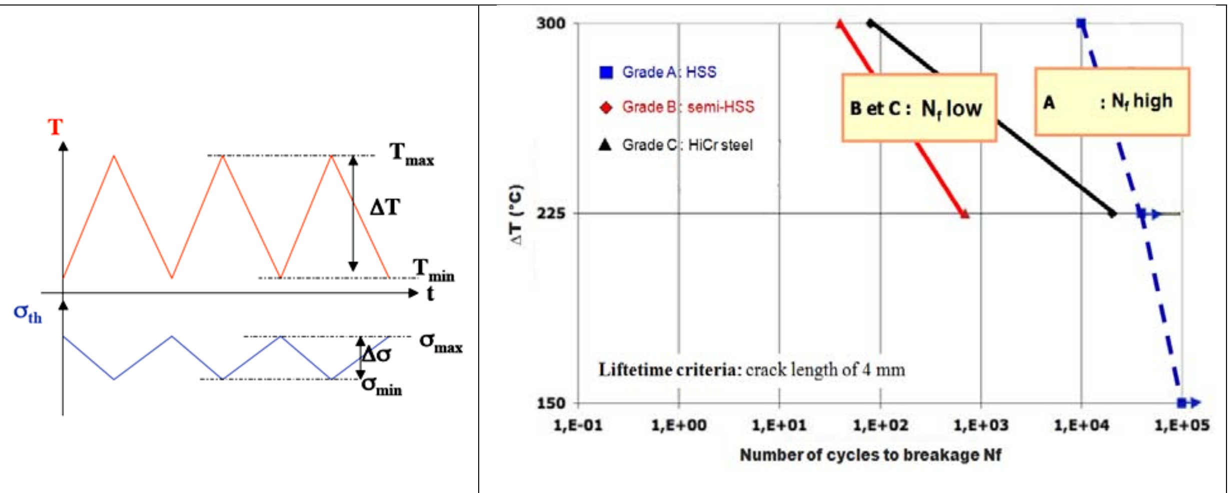


Figure 3 Example of friction curve obtained for two HSS grades compared with a high chromium iron according to the both configurations of tests i.e. with or without pre-oxidation of the disc.[5]

4 THERMAL FATIGUE

When considering applications such as roughing mills, thermal fatigue tests have been set up according to a specific simulation device designed by the Centre ICA-Albi with an axisymetric geometry promoting an uniaxial cracking (mode I) in a direction perpendicular to the tangential thermal stresses $\sigma_{\theta\theta}$.[6]
The sample is heated at its circumference by an inductive monocoil and water cooled into the core. The assumption is held that the behaviour of samples remains elasto-plastic in the considered thermal range [T_{max}-T_{min}] inducing a stress cycle [σ_{min}- σ_{max}] (Figure 4.1).
Once again the thermal fatigue trials aim at bringing out the role played by the roll grade microstructure and more particularly the interface between the continuous eutectic carbide network and the matrix on the crack initiation and propagation according to the roll grades.
An example of results is given on Figure 4.2. The behaviour of three roll grades as a HSS, high chromium steel (HiCr) and a semi-HSS usually used in roughing stands have been investigated.
The aggravating contribution of superficial oxidation of samples on the crack propagation has not been proved. Despite the highest oxidation rate, the HSS grade presents the highest resistance to thermal fatigue.



1. Thermal cycle applied and stress cycle induced

2. Number of cycles leading to sample breakage

Figure 4 Thermal cycle applied (1.) during thermal fatigue trials for any work roll grade and the result of study work roll grades according the number of cycles leading to breakage of trial samples (2.).(6)

5 PILOT MILL

To confirm the laboratory results, a last approach set up is rolling trials performed on the semi-industrial pilot mill developed by CRM Ghent.(7-9) That configuration remains the closest test conditions compared to the hot strip mill running conditions.
This laboratory evaluation method has been developed at CRM Group in order to reduce the cost and the technical risks as incidents, downgraded products, increased rolling forces when using new work roll grades or testing existing grades under new conditions directly in an industrial environment. This method aims also at understanding better the complexity of tribological phenomena involved in the rolling bite.
A technique of inserts is applied in order to make easy the transition between the development of new roll grades and the trial under rolling conditions close to industrial conditions. That allows also to test several roll grades under the same rolling conditions with a limited amount of material and so laboratory cost.
In order to obtain wear on the inserts, a continuous hot rolling campaign is performed. One campaign consists of several continuous trials where one “baby-coil” is pre-heated in a non-oxidizing furnace to be continuous rolled. A campaign of several coils is usually performed.
The rolling conditions are chosen according to the considered application i.e. roughing, early or late finishing stands.
Evaluation of roll wear on the surface is done through different measurements that are taken after each trial as:

- Photographic images thanks to a normal camera,
- Roughness measurements (Ra-value mainly estimated),
- Microscopic images with a portable optical microscope,
- Replicas taken from the surface for possible additional measurements.

During the trials different process parameters are recorded (e.g. speed, torque, force, temperature …). Additionally a sensor called “Rollscope” (a CCD camera)(10) can be installed in stand and take images from the roll surface during the continuous rolling trial in order to follow on-line the degradation of the roll surface.

An example of trials performed on three new roll grades is presented on figure 6. In particular, the evolution of their surface aspects such as oxidation as well as thermal cracking network is emphasized before and after rolling.

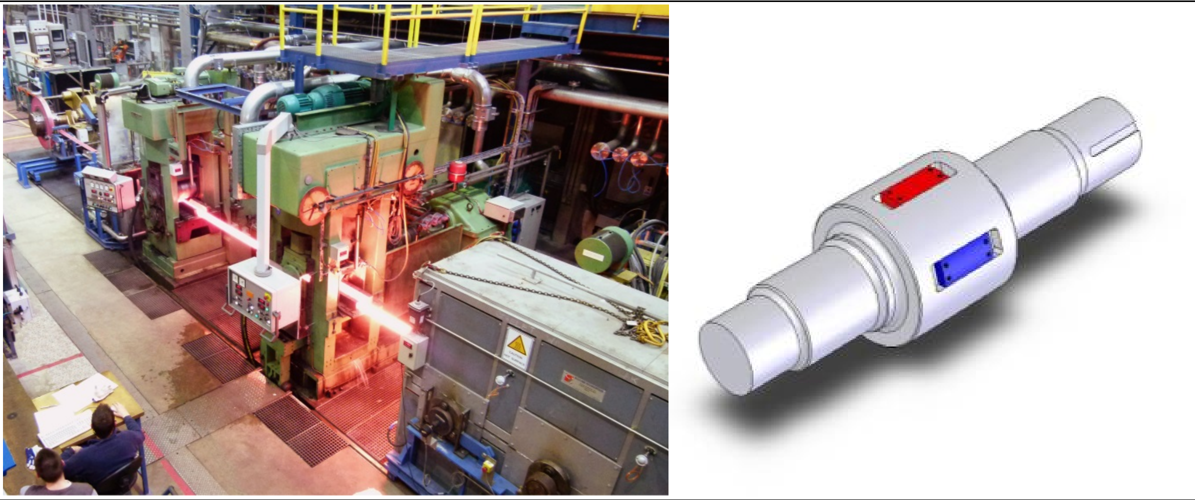


Figure 5 Laboratory hot rolling pilot mill and special work rolls with inserts developed by CRM Ghent.[7]

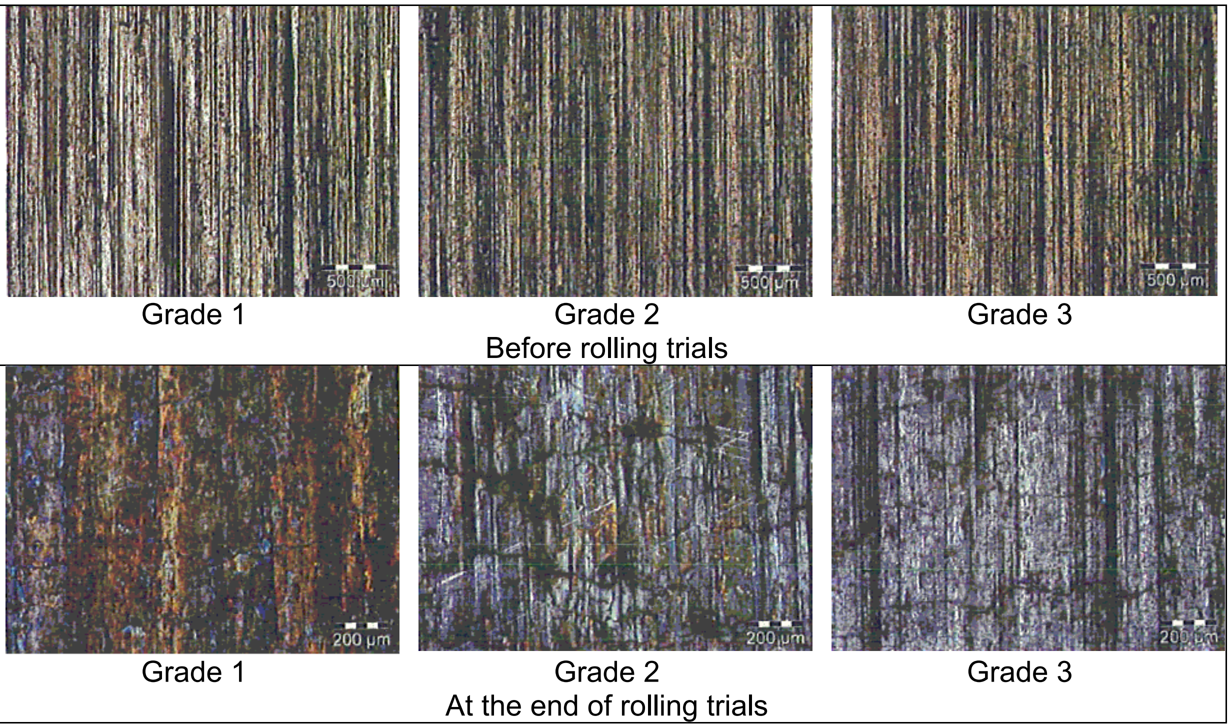


Figure 6 Worn surfaces of three roll grades before and after rolling trials on the hot rolling pilot line of CRM Ghent.

6 CONCLUSIONS

In the frame of new roll grade development, Åkers has set up experimental approaches aiming at analyzing the newly designed roll grades regarding different damage mechanisms involved in hot rolling process. Except semi industrial trials carried out on the pilot line of CRM Ghent, the different tests set up at the laboratory scale consist in studying the interaction of new roll grade microstructures with

thermal, mechanical and/or physico-chemical stresses present as dissociated or coupled in hot strip mills according to the considered stands.
The particularity of these tests – oxidation, tribology, thermal-fatigue or rolling on pilot line – is that they have been performed at high temperature above 500°C. They request to know well the thermo-mechanical properties of roll grades versus temperature in order to achieve a right interpretation of results. Furthermore some of them such as in-situ oxide growth tests, thermal fatigue tests or the trials on the hot rolling pilot line of CRM Ghent enable to follow on-line the development of damage on tested surfaces. In that way, it is possible to understand better which metallurgical phases promote or slow down the occurrence of oxide at the roll surface, how the microstructure interacts on the initiation and propagation of cracks under heating-cooling cycles or the global wear and friction behavior of the roll grade when it is involved in rolling contact with a strip material in rolling conditions close to the industrial ones.
Furthermore the results observed during the tests of oxidation, tribology and thermal fatigue make easy a first evaluation of roll grade behavior expected in service due to the small size of used samples. The coupling of these tests with trials on the hot rolling semi-industrial pilot line of CRM allows confirming the results without requiring the manufacturing of at least two rolls at the industrial scale, limiting in that way the associated industrial risks for the both partners, the roll manufacturer and the steel manufacturer.

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