DEVELOPMENT AND IMPLEMENTATION OF VICTURA™ TWINALLOY™ STEEL ROLLS IN THE LATE FINISHING STANDS OF HOT STRIP MILLS *

Zhi Zhang[1]
Stefan Wahlund[2]
Mats Söder[3]
Tom Adams[4]
Jason Sychterz[5]

Abstract

By applying high-end rolls with utmost performance and superior surface quality, hot strip mills can be further optimized. Operations in the mill have been also waiting for improved roll solutions that can minimize required roll changes which impact production efficiency. Limitations are usually due to the low performance and surface degradation of the rolls in the late finishing stands (F5 – F7). VICTURA™ is the most recent developed grade for rolls utilized in the late finishing stand at Union Electric Åkers (UEÅ). These rolls have been tested and applied in mills all over the world. A significant improvement over the enhanced ICDP rolls has been observed. Hot strip mills are realizing improved operating efficiency and Total Cost of Ownership (TCO) through the transition of their entire roll inventories to these break-through products.

Keywords: Hot Strip Mill; Enhanced ICDP Roll; VICTURA™ Roll; Late Finishing Work Rolls; TwinAlloy™ Steel

[1] *Ph.D, R&D Manager, Union Electric Åkers, Åkers Styckebruk, Sweden.*
[2] *B.Sc, Director Product Mgmt&Marketing, Union Electric Åkers, Åkers Styckebruk, Sweden.*
[3] *Ph.D, Senior Metallurgist, Union Electric Åkers, Åkers Styckebruk, Sweden*
[4] *Director, Cast Roll Technology & R&D, Union Electric Åkers, Carnegie, PA, USA*
[5] *M.Sc, VP, Union Electric Åkers, Carnegie, PA, USA*

1 Introduction

Hot Strip Mill rolling (Conventional Mills, Compact Strip Mills and Steckel Mills) operations have been waiting for improved roll solutions that minimize required roll changes, which impact productivity and mill stability. Enhanced Indefinite Chill rolls were first introduced back in the mid-1990s. Recent alloy developments have resulted in improved wear characteristics by bringing together technologies of the iron based Indefinite Chill graphite, iron carbide and matrix morphology combined with tool steel-based carbides. The enhanced metallurgical properties are characterized, as are the results and benefits of the extended mill performances achieved. Hot Strip Mills are realizing improved Total Cost of Ownership (TCO)[1] through the transition of their entire roll inventories to these break-through products.

2 Evolution of the roll use at late finishing stands

The evolution of roll technology has been driven by the consumers. They demand higher quality and cheaper cost products. This translates into the steel user demanding a better product from the steel mill (higher strength, lighter, better surface, improved profile and flatness). To achieve these, the mill builders have enhanced the mill design with shifting, bending, more power, CVC, pair cross, just to mention a few of the improvements. This puts great demands on the mill rolls which have resulted in developments in both the process and product side.

On the process side, static mono-block cast rolls were replaced by double pour rolls and then finally, centrifugal cast and CPC methods[2]. Most Hot Strip Mill finishing stand rolls are centrifugal cast. The exception being in Japan and various North American Mills, where CPC rolls produced in Japan are used.

There have been few revolutionary changes in roll grades. Prior to the 1970s, ICDP rolls were used in all stands. Adamite steel gradually replaced ICDP in the early stands. In the late 1970s, after initial setbacks, high chrome iron quickly replaced adamite as they seamlessly provided significant performance improvements. HSS rolls were introduced in the early 1990s. Despite another quantum improvement in performance, their adoption has been rapid in many applications but slow in others due to mainly lack of sufficient roll cooling.

While these early stand improvements have gone on, little has been done for the delivery stands. The manufacturing of this roll has changed (chill to indefinite chill, static to double pour to centrifugal pour) but the grade remained the same for over 60 years. In the early 1990s, British Roll makers made an improvement by adding powder containing carbides to the liquid melt. In 1997, Åkers patented a technique to do this without adding powder as the powder tended to segregate due to density differences.

The new generation of enhanced carbide ICDP rolls resulted in a performance improvement of up to 25%, well short of the 2 to 4 times improvement with HSS rolls over high chrome iron rolls. Historically it had been common to have an early stand roll change half way through the campaign as the ICDP rolls outlasted the adamite / high chrome iron rolls. Currently, HSS rolls can be used for 2 to 7 campaigns. Since, with few exceptions, rolls are changed in parallel, it takes as long to change one stand as it does to change all seven. For all the other benefits of HSS rolls (lower roll cost, better surface, better profile and shape, better gauge control), the longer campaigns do not result in increased mill capacity. Thus, there is a need of late stand rolls with significantly better performance to achieve productivity improvements and matching the campaign length with HSS rolls (or high chrome iron).

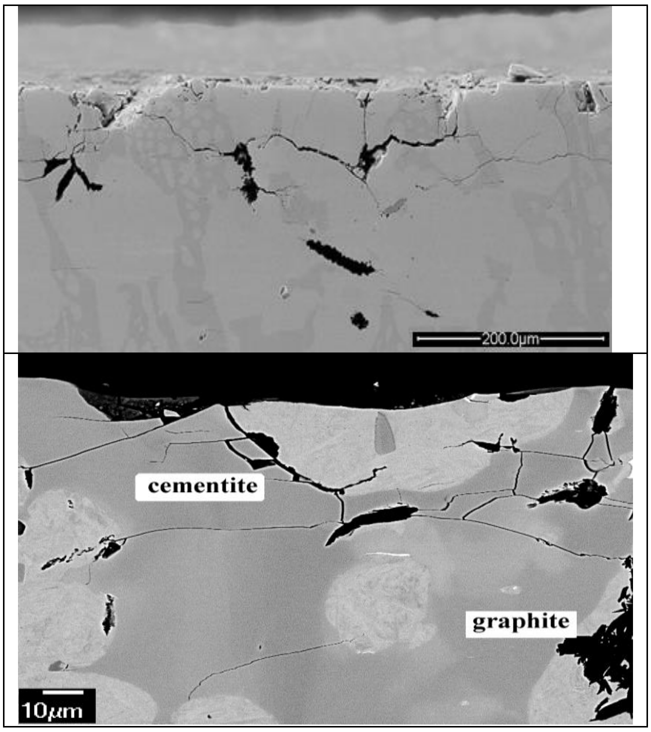

Fig. 1 Cracks formation due to mechanical fatigue at roll barrel surfaces of a MICRA™/APEX™ grade

3 Development of VICTURA™ roll grade

The milestones for delivery late finishing stand roll grades at Union Electric Åkers chronologically are the ICDP ICRA™ grade, eICDP MICRA™/APEX™ grade and the newest TwinAlloy™ VICTURA™ grade. The performance has been ever increasing. ICRA grade in the early stage represents the old design of Ni-hard material and focus has been on creating a mass of cementite over the matrix to generate high hardness, good wear resistance, and resistance to mill damage compared with white iron. In the MICRA™/APEX**™** grade, the MC type of carbide was first introduced to improve the wear resistance. Recently, the VICTURA™ roll material development, by utilizing the TwinAlloy™ Steel concept, aims at improving the surface quality and roll performance by introducing even more MC carbides and others to achieve a better balance of the amount of cementite, MC type carbides as well as graphite, leading to a homogeneous distribution of all phases. The bringing together of two materials or concepts, combines to develop a new and improved product with superior properties.

The bringing together of two materials or concepts, combines to develop a new and improved product with superior properties. Thus, by the approach of TwinAlloy™ Steel technology, the VICTURA™ grade is characterized by both the merits of an HSS SPECRA™ grade and a MICRA™/APEX™ grade. Since it will be aimed at the late finishing stands of a Hot Strip Mill, optimizing the roll surface quality and its wear resistance become the major task. In this type of roll, the free graphite is necessary to prevent sticking and micro welding leading to surface damage and cobbles. In a MICRA™/APEX™ grade for example, the mechanical fatigue easily initiates cracks in a large cementite phase at the barrel surface (Figure 1).

** Technical contribution to the 11th International Rolling Conference, part of the ABM Week 2019, October 1st-3rd, 2019, São Paulo, SP, Brazil.*

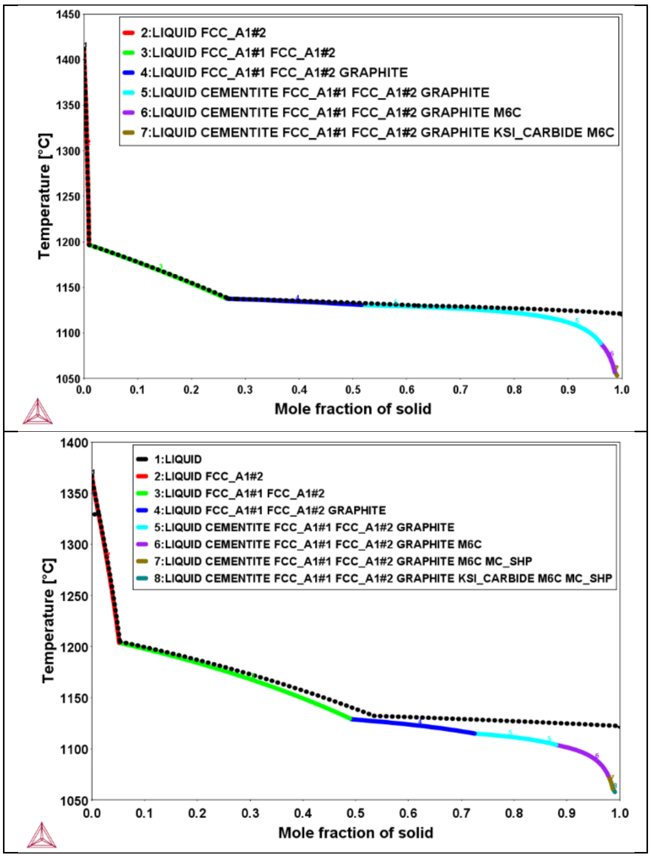

Fig. 2 Scheil model prediction of solidification (top: MICRA™/APEX™; bottom: VICTURA™)

To solve this problem, the amount and size of cementite phase are strictly controlled by special composition design. After introducing a balanced high amount of strong carbides forming elements, the pre-formed MC type of carbides refine the microstructure. Figure 2 shows a thermodynamic prediction of phases during solidification by using the Scheil model. About 10% of pre-formed MC carbides precipitate in an early stage and act as the structure refiner or modifier. These balanced MC carbides refine the formation of graphite as well together with a special treatment. The amount of strong carbides forming elements are well controlled. Their influence on the microstructures are investigated and illustrated in Figure 3. It shows that with the increase content of the V, the morphology of cementite varies significantly. The amount of MC type of carbides increases, too. Efforts are made to obtain an optimized microstructure in terms of amount of different carbides, morphology and distribution. The selected candidates were used to produce prototypes and results show that microstructures are uniformly distributed over the entire shell working layer from the roll barrel surface to the bond region. Figure 4a shows the etched sample with carbides distribution. Carbides are favorable to the material wear resistance, but an excessive amount will increase the tendency of cracking and chipping, especially the large sized cementite. This needs to be balanced with refined graphite and its distributions. The area fraction of cementite in the MICRA™/APEX™ grade is around 35-40%. While in VICTURA™ grade, however, its total amount is about only 10-15%. The precipitation of large amount of MC type carbides will postpone the formation of cementite. Well distributed MC carbides isolate and refine the later formed cementite. This prevent a formation of a carbide network and increase the mechanical fatigue resistance. The MC carbide content is similar to the volume found in HSS SPECRA™ grade.

Moreover, the inverse pole figure (IPF) shown in Figure 5 illustrates the size of matrix microstructure (martensite or lower bainite) at a 500x magnification for both MICRA™ and VICTURA™ grades. Much refined martensite/lower bainite is achieved in the VICTURA™. The refined matrix microstructure together with a uniform graphite distribution will not only improve the robustness of the grade but also can optimize the hardness uniformity that lead to an improved surface homogeneity. By this approach, the hardness of refined matrix in VICTURA™ is 80HV higher than that of MICRA™/APEX™ grade.

Retained austenite should be always minimized roll applications. An alpha value measured by using a FERITSCOPE at Union Electric Åkers is a standard method to predict the approximate level. To quantify a true amount of retained austenite in the matrix, however, the Bruker D8 X-ray diffractometer is employed by using Cu-kα radiation. Figure 6 depict the diffraction patterns.

The peaks used for quantification of retained austenite volume are indicated (BCC-200, BCC-211 and FCC-311). As seen in the diffractograms, multiple peaks were found in addition to the BCC and FCC phases. These are probably originating from carbides and the volume of these were not taken account in the quantification.

The amount of retained austenite was calculated by using the intensity of the FCC peak [311] compared to the total (FCC + BCC) with an intensity factor that takes each peak into account. No volume of carbides or other precipitates were considered. The total amount of retained austenite is less than 1%, resulting in a stable and robust roll.

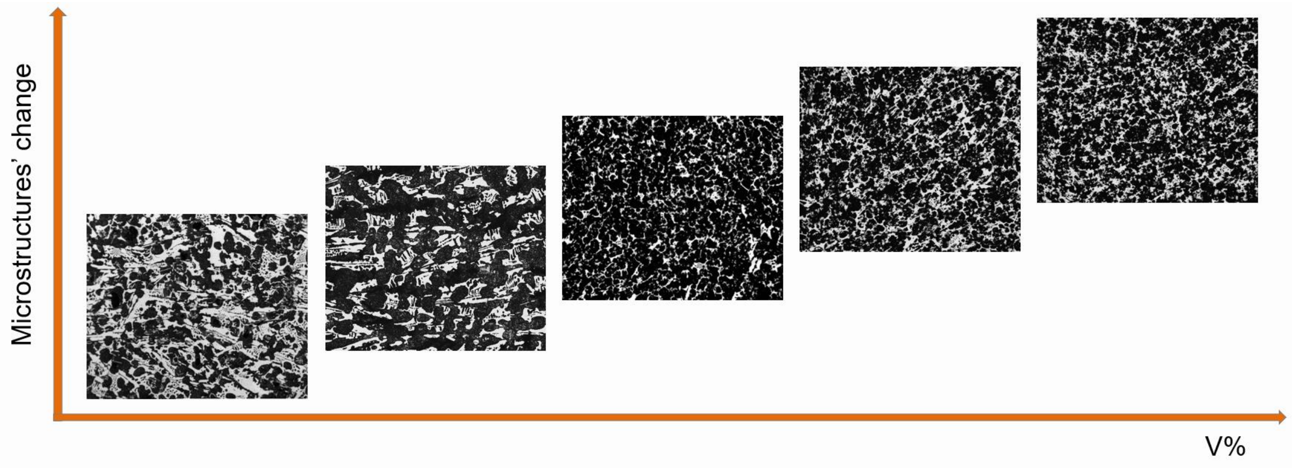

Fig.3 Schematic illustration of the influence of amount vanadium on the microstructures of an eICDP grade

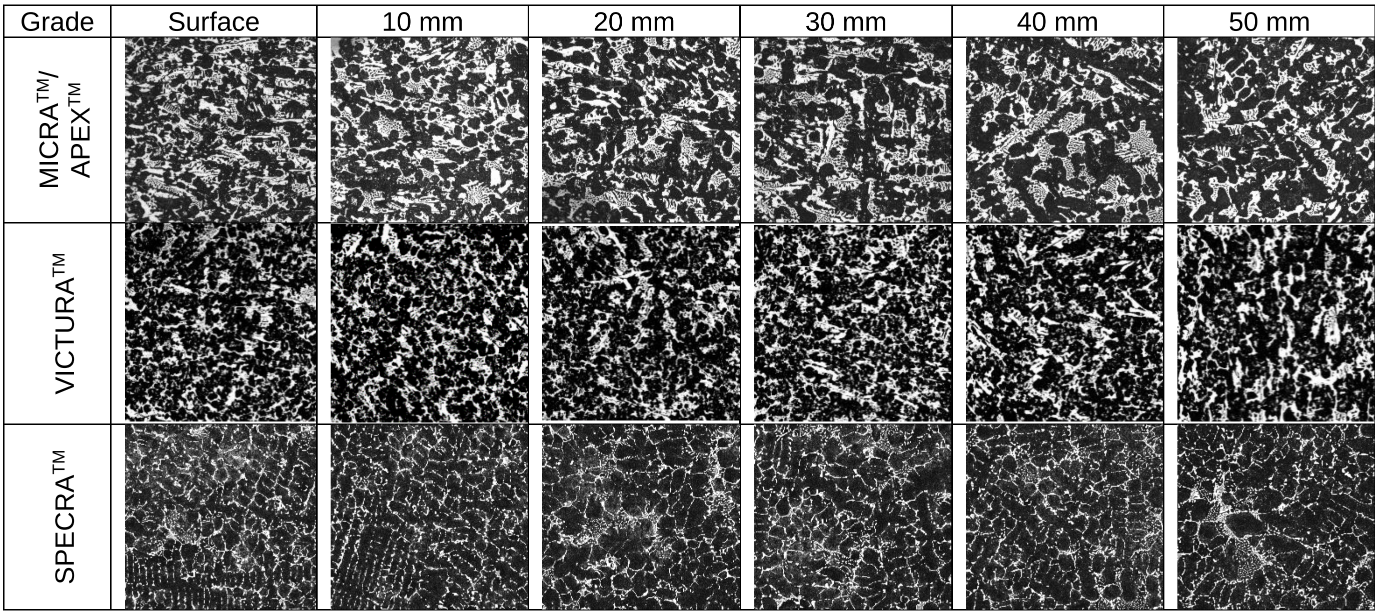

Fig. 4a Carbides distribution over the shell depth from surface to the bond region (x100)

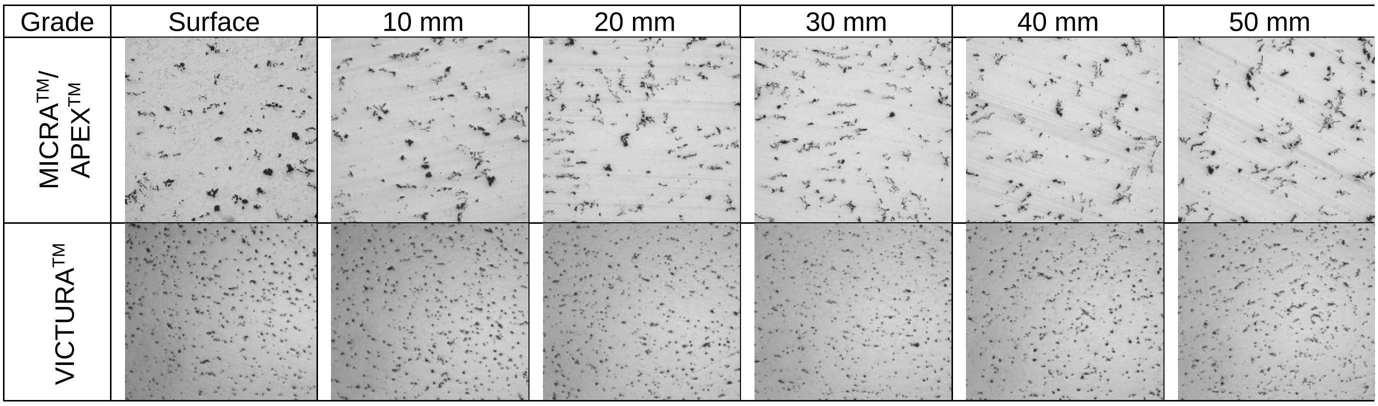

Fig. 4b Graphite distribution over the shell depth from the surface to the bond region (x25)

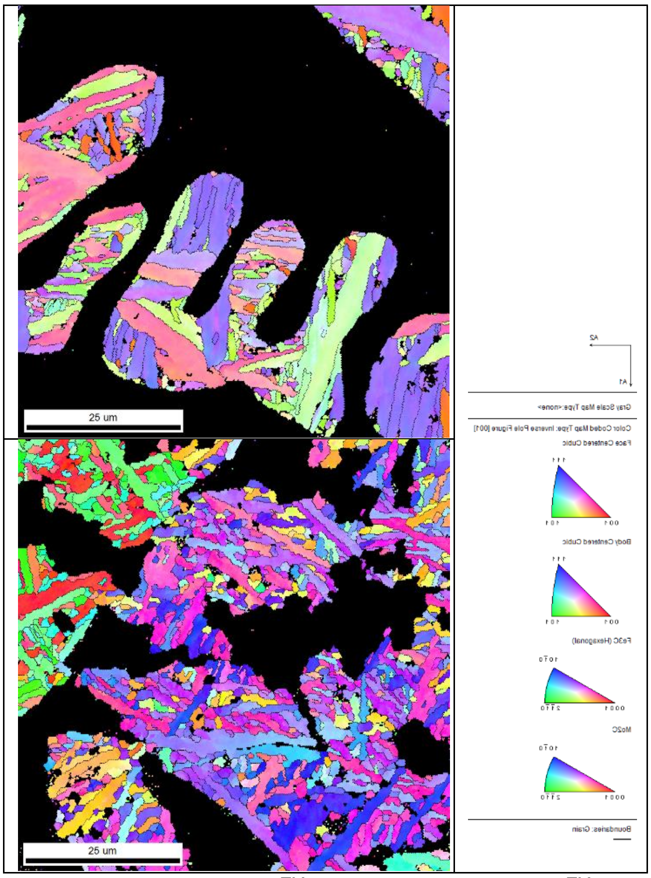

Fig. 5 IPF of a MICRA™ (top) and a VICTURA™ (bottom) grade.

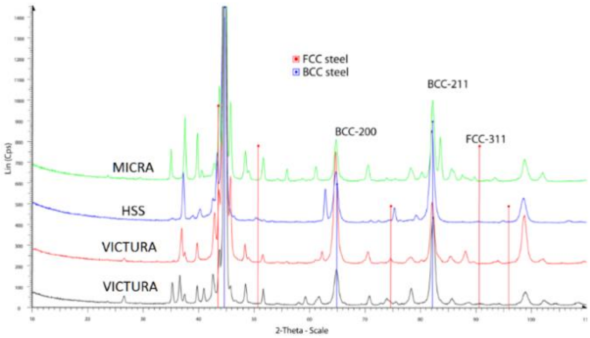

Fig. 6 Diffraction patterns.

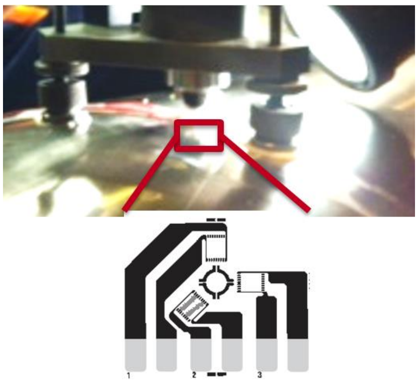

Fig. 7 Strain Gage Rosette

Due to the introduction of high amount of MC type of carbides and the massive martensite transformation during the HT process, the residual stress in the new roll grade was examined to ensure that it is at a low level. A destructive measurement was done in the middle of the roll barrel. In this method, a specially configured strain gage rosette is attached to the surface of the roll barrel; and a small, shallow hole with a diameter of less than 2 mm and a depth of 1.3 mm is introduced into the structure, through the center of the gage, with a precision drilling apparatus. Strains in the immediate vicinity of the hole are measured, and the relaxed residual stresses are computed from these measurements. The strain in three gages can be measured directly from the equipment. Then, the maximum and minimum stress can be calculated by using the following equations:

$$\sigma_{max/min} = \frac{\varepsilon_1 + \varepsilon_3}{4A} \pm \frac{\sqrt{(\varepsilon_3 - \varepsilon_1)^2 + (\varepsilon_3 + \varepsilon_1 - 2\varepsilon_2)^2}}{4B}$$

Where the coefficient A and B can be determined by using:

$$A = -\frac{1+\nu}{2E}\left(\frac{1}{r^2}\right),\ B = -\frac{1+\nu}{2E}\left[\left(\frac{4}{1+\nu}\right)\frac{1}{r^2} - \frac{3}{r^4}\right],\ r = \frac{D_0}{D}$$

D_0 = diameter of drilled hole, D = gage circle diameter

Figure 8 shows the stress value at each drilling of 0.13 mm and it is shown that the residual stress tends to stabilize under 1mm depth. The maximum stress is below 200 MPa, which is in the normal range for ICDP type of rolls.

The origin of the residual stress is the material property difference between the shell material and ductile iron core. In the shell the formation of martensitic matrix will put the roll under tensile type of stress. This makes the shell materials tensile strength an important factor to counteract upon the residual stress. For the new grade VICTURA™ the measured ultimate tensile strength is on average 470 MPa which is about 30% better than

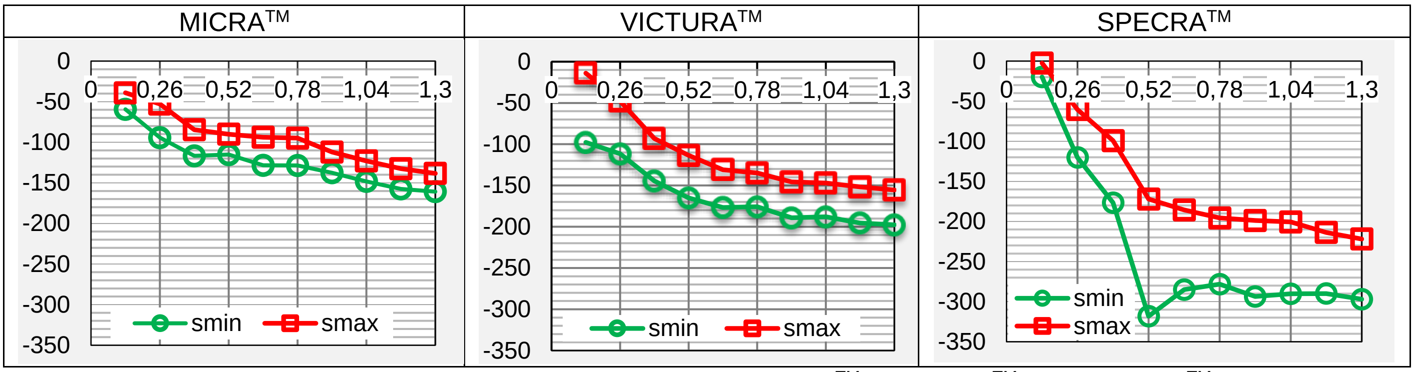

Fig. 8 Residual stress measurement on the middle barrel of a MICRA™, VICTURA™ and SPECRA™ roll (MPa) to a depth of 1.3 mm

MICRA™/APEX™.

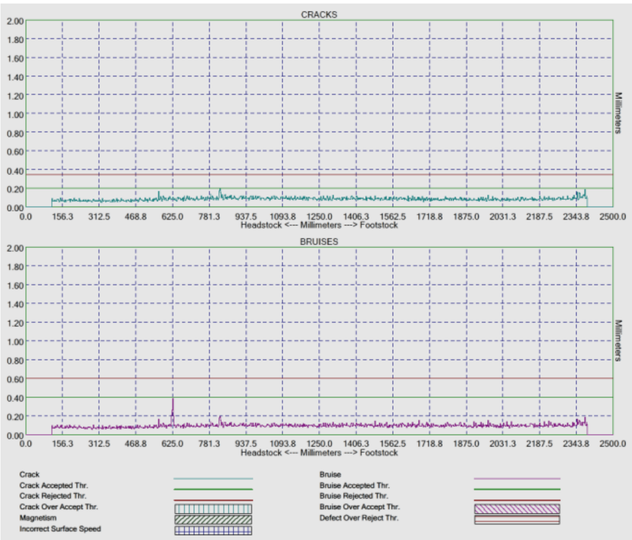

Fig. 9 Eddy Current testing of crack and bruise at the surface of a VICTURA™ roll measured by Customer

Recently, most mills are equipped with eddy current equipment to monitor the roll surface after roll grinding. The results of eddy current scanning may vary between different roll grades. Figure 9 shows the eddy current results of a VICTURA™ roll, which is measured by using the LISMAR (2015 model) roll inspection equipment. The same threshold is used as for normal ICDP and eICDP rolls (0.2).

4 Industrial Results

Close relationships with its customers enables UEÅ to acquire a good knowledge of their applications. The studies performed on any rolls after rolling allow highlighting the main damage mechanisms involved in the considered rolling process and the roll properties to be adapted to improve roll performance.

Currently, VICTURA™ rolls are being used around the world. A significant improvement in performance has been attained. Figure 10 shows the results from conventional HSM, DSP/CSP and Steckel mills with mill incidents. In all cases, the VICTURA™ roll outperforms eICDP MICRA™/APEX™ rolls by at least 40% and up to 100%. It also performs better than, or as well as similar type of rolls from competitors. More and more mills are now discussing and implementing VICTURA™ rolls for double campaigns.

Moreover, it is very important to see from Figure 11 that rolls present a very good and uniform surface aspect, smooth and clear after rolling.

Figure 12 shows the replicas taken from the barrel surface after the roll usage.

This topography study of Sz, distance between the highest peak and the lowest valley, for customer A, also indicate a better wear resistance of VICTURA™ grade to MICRA™/APEX™ grade. (Sz VICTURA™ = 25 µM / 1000 ton; Sz MICRA™ = 35 µM / 1000 ton)

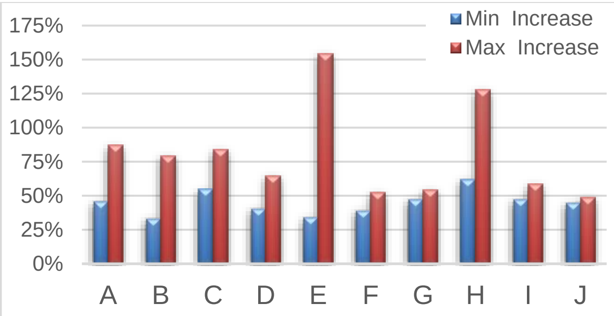

Fig. 10 UEÅ VICTURA™ Roll Performance versus APEX™/MICRA™ at different customers globally

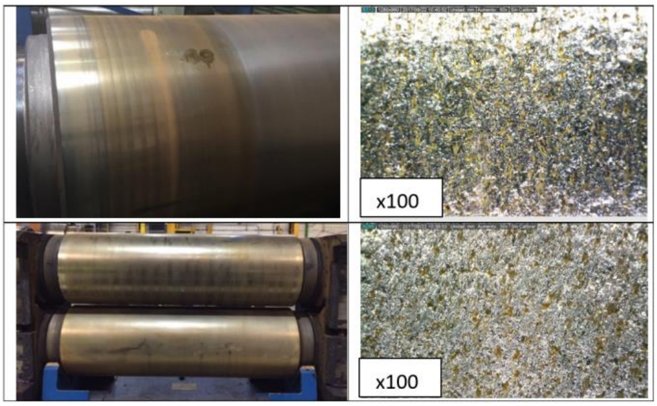

Fig. 11 Roll surface conditions after rolling in the last stand (top: customer E; bottom: customer F)

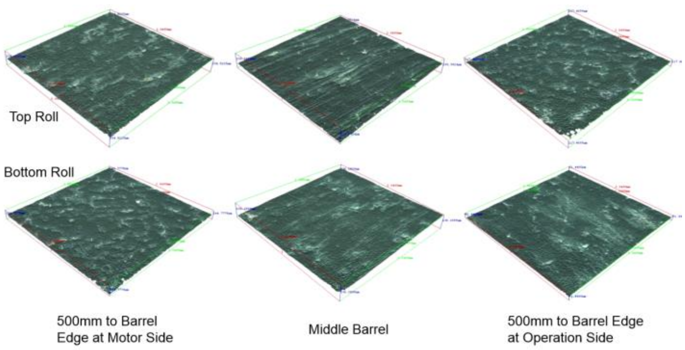

Fig. 12 Three-Dimensional replicas of barrel surface after rolling

5 Total Cost of Ownership

Total Cost of Ownership (TCO) is based on the concept that the true cost involves many factors in addition to the actual price. For late stand finishing mills, the major factors can include the roll performance (T/mm), quality costs (surface defects etc.), failure costs and downtime costs due to failures and scheduled and unscheduled roll changes.

Since VICTURA™ is a plug and play roll, there will be no difference in quality costs and failure costs. The main reduction in TCO is due to the reduced wear resulting in improved roll performance (T/mm) and the longer campaigns resulting in increased Mill availability. The largest reduction in TCO is achieved by mills that can take advantage of longer campaigns by increasing production. Increased sales due to the extra tons rolled are usually substantial.

6 Conclusions

The Union Electric Åkers TwinAlloy™ Steel VICTURA™ is a new generation of roll that provides a major improvement in performance while maintaining excellent product surface quality. This enables mills to lower roll costs while also improving the productivity of the mill by extending rolling campaigns. By adapting high speed tool steel-based carbides to an iron-based graphite morphology, the campaign lengths of entry (HSS) and delivery stands can be matched more closely.

REFERENCES

1 Ron Webber, Analysis of Total Cost of Ownership Models for Mill Rolls, AISTech 2017 Proceedings, AIST

2 Mitsuo H., Seizi O., Kouichiro Y., Kazuo K., Ryurou K., Tamotsu K., Takahiko K., Development of High-

performance Roll by Continuous Pouring Process for Cladding, ISIJ International, 1992 Volume 32, Issue 11, P. 1202-1210