

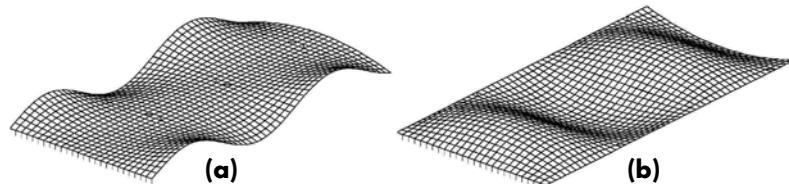
# ArcelorMittal Tubarão hot skin pass, flatness improvement in thin gauges

The main objective of ArcelorMittal Tubarão hot skin pass mill is to improve the flatness results in hot rolled strips. Since its start-up in 2002 a consistent evolution of quality and process control has been reached based on the domain of work roll profile behavior, especially roll wearing and bending. The implemented actions regard the production scheduling rules, definition of optimum target elongations and automation of bending forces control.

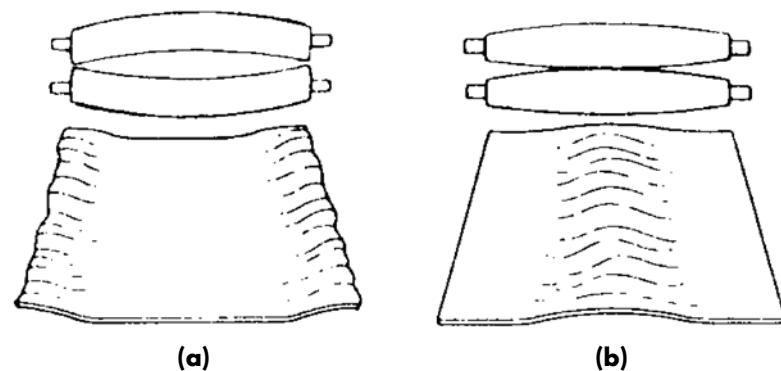
## ■ INTRODUCTION

Flatness is an intrinsic quality characteristic of flat rolled products clearly perceived and demanded in more and more restrictive tolerances by the customers. Mainly characterized by waves, raised with the accommodation of more elongated regions of the strip, flatness defects used to be present in the edges or in the center of the strip width, as shown in figure 1.

The waviness is commonly caused by differential elongations across the strip width during the rolling process, as shown in figure 2. Waves possibly formed during hot rolling can be corrected through a cold processing in a hot skin pass, a flattener or a leveller. In all these processes the strip is submitted to differential elongations across the width, higher in the tight regions and lower in the wavy regions.



**Fig. 1 - Examples of flatness defects: wavy edges (a) and center buckles (b).**  
Fig. 1 - Exemples de défauts de planéité : ondulations en rives (a) et centre long (b).



**Fig. 2 - Wavy edges due to roll bending (a) and center buckles due to high roll crown (b).**  
Fig. 2 - Ondulation en rives par flexion des cylindres (a) et centre long par bombé excessif des cylindres (b).

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## Skin pass à chaud d'ArcelorMittal Tubarão - Améliorations de planéité pour les faibles épaisseurs

La planéité est une caractéristique essentielle des produits plats en acier, avec des tolérances de plus en plus restreintes imposées par les clients. Elle est principalement altérée par la présence d'ondulations résultant de différences d'allongement de différentes zones, entre le centre et les rives des bandes.

Elles sont causées par un laminage non homogène au travers de la largeur de la bande et elles peuvent être corrigées par un skin pass ou une planeuse. Lors de cette opération, la bande est déformée en traction de manière différente au travers de la largeur, selon la présence des ondulations.

Grace aux technologies de dernière génération de contrôle de la planéité, le laminoir à chaud d'ArcelorMittal Tubarão est capable de produire une partie importante de son mix en bandes de faible épaisseur, à forte valeur ajoutée ( $21\% \leq 2.0\text{mm}$  en 2006). Le train finisseur est équipé de contre flexion, de translation et du CVC sur les cylindres de travail des six cages, avec un set-up calculé par un modèle de contrôle du profil thermique, usure et comportement élastique des cylindres. De plus, des mesures de planéité (tensiomètres loopers et rayons-X) assurent un feedback pour le contrôle des efforts de laminage et de flexion, ce qui permet un contrôle en ligne.

ArcelorMittal Tubarão possède aussi un skin pass dont le principal objectif est l'amélioration de la planéité sur des bandes de faible épaisseur, répondant ainsi aux exigences du marché. Ce laminoir possède aussi des ressources avancées, une cage 4-HI avec un effort de laminage maximum de 13.000 kN, des efforts de flexion et de contre-flexion, la mesure et le contrôle automatiques de l'allongement.

Il est important pendant le laminage, de maîtriser le comportement du profil des cylindres afin de contrôler l'allongement différent au travers de la largeur, garantissant ainsi un bon résultat de planéité. Le profil du cylindre résulte de la flexion, de l'usure et du bombé thermique, ce qui peut être mis en équations

Une analyse du profil d'usure des cylindres de travail à la fin des campagnes a montré que l'usure est concentrée près des rives de la largeur moyenne laminée, formant ainsi des rainures qui peuvent atteindre une profondeur de 60  $\mu\text{m}$ . Ce profil d'usure provoque un bombé positif au centre qui ne peut pas

être compensé quand on lamine des bandes larges en fin de campagne, introduisant ainsi des défauts sur les bords.

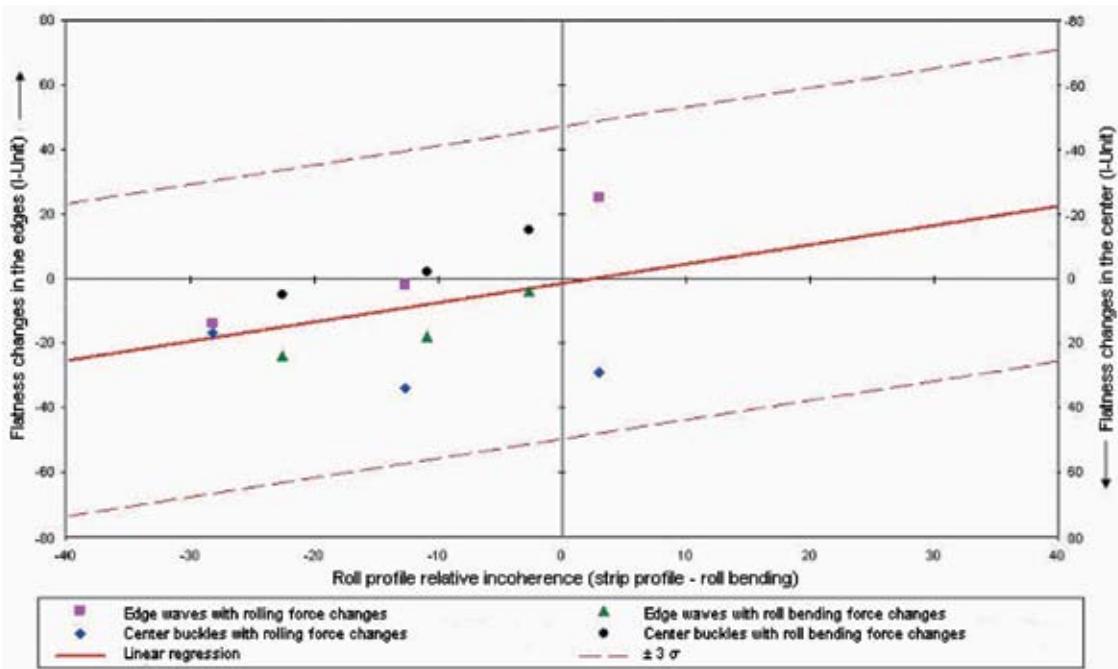
Pour résoudre ce problème les séquences de laminages prévoient que les bobines soient laminées par largeur décroissantes, au cours d'une campagne de cylindres de travail. De cette manière, l'usure peut être compensée par flexion.

La correction de la planéité au skin pass dépend aussi de l'utilisation d'un effort suffisant pour allonger de manière différente la largeur de la bande. L'allongement dépend de la planéité initiale et pour les dimensions critiques, bandes étroites en particulier, les allongements visés doivent être plus élevés. Des efforts de laminage différents sont aussi appliqués sur la bande selon les allongements visés. Des efforts de laminage différents produisent des profils différents de flexion des cylindres, et ces flexions doivent être compensées pour garantir la planéité finale des bandes. On peut utiliser des ensembles de cylindres avec des bombés différents ou en utilisant la flexion. La première solution est délicate en production et la deuxième peut être limitée par la capacité de l'équipement. La définition des allongements visés doit être faite en analysant les valeurs suffisantes pour corriger la planéité mais en gardant les efforts les plus constants possibles.

Selon les variations des paramètres de process, principalement la vitesse, l'effort de laminage nécessaire pour atteindre la valeur visée de l'allongement varie aussi. Ce réglage de l'effort de laminage est fait de manière automatique par référence à l'allongement mesuré.

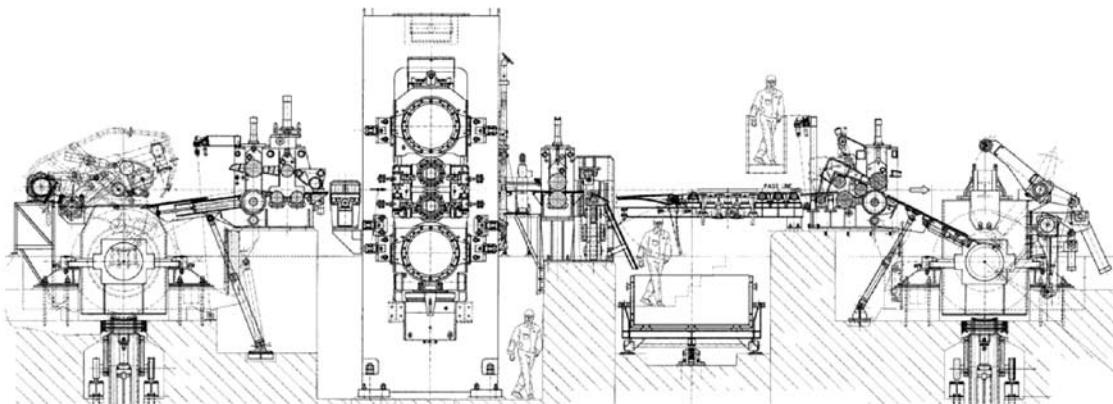
Si l'effort de laminage évolue en cours de laminage, la flexion du cylindre doit être compensée par l'effort de flexion pour conserver la planéité. A partir des équations de la flexion des cylindres, vérifiées expérimentalement, une correction automatique de l'effort de flexion a été introduite, pour garder constant le profil des cylindres malgré les variations de l'effort de laminage.

Les actions mises en place, pour permettre de contrôler l'usure et la flexion des cylindres, ont permis une évolution significative de la qualité et du contrôle du processus au skin pass d'ArcelorMittal Tubarão. Il est ainsi possible d'exploiter tout le potentiel du laminoir et d'améliorer les résultats de la planéité des bandes pour répondre aux demandes des clients.



**Fig. 3 - Experimental results of flatness changes according to the incoherence between the strip profile and the roll bending.**

Fig. 3 - Résultats expérimentaux d'évolution de la planéité selon l'écart entre le profil de la bande et la flexion des cylindres.



**Fig. 4 - Side view of ArcelorMittal Tubarão hot skin pass mill.**

Fig. 4 - Vue latérale du skin pass d'ArcelorMittal Tubarão.

In rolling processes, the domain of the work roll profile behavior is essential to control the differential elongations across the strip width, ensuring a good flatness result. The roll profile is function of the roll bending, wearing and thermal crown, which can all be predicted by mathematical equations. The effect of roll bending in flatness changes was evaluated through industrial experiments in the ArcelorMittal Tubarão skin pass mill, gradually changing the rolling forces and the roll bending forces and observing the initial and the final flatness compared to the relative incoherence between the strip profile and the predicted roll bending. The results, as shown in figure 3, confirmed the relationship between roll bending and flatness, practically without flatness changes when the cross section of the strip and the roll bending was coherent and with flatness changes increasing with the increase of this incoherence (1).

Thanks to the state-of-the-art technologies in matter of flatness control, the ArcelorMittal Tubarão hot strip mill is able to produce a significant part of its mix in high added value thin gauges strips ( $21\% \leq 2.0 \text{ mm}$  in 2006). The finishing mill counts on work roll bending, shifting and CVC profile in all six stands, with the set-up performed by a control model mainly based on thermal crown, wear and elastic behavior of the rolls. Furthermore, flatness measurements (tension-meter loopers and X-ray) provide feedback to rolling and bending forces control, assuring an effective in-bar control.

In its downstream facilities, ArcelorMittal Tubarão has a hot skin pass mill whose main purpose is to improve the flatness of these thin gauges hot rolled strips, reaching the restrictive market requirements. The skin pass mill, shown in figure 4, features such high-tech resources as a 4-HI stand with

maximum rolling force of 13,000 kN, positive and negative work roll bending and automatic elongation measurement and control.

Since the start-up in 2002, several actions have been implemented and a consistent evolution of quality and process control has been reached in the skin pass. The proposal of this paper is to present some of these actions, as follows:

- The philosophy of production scheduling along the rolls campaign to minimize the effect of roll wear;
- The definition of optimum target elongations to permit flatness correction keeping the rolling forces as constant as possible;
- The automation of bending forces control according to rolling force changes.

## ■ PROCESS DEVELOPMENT

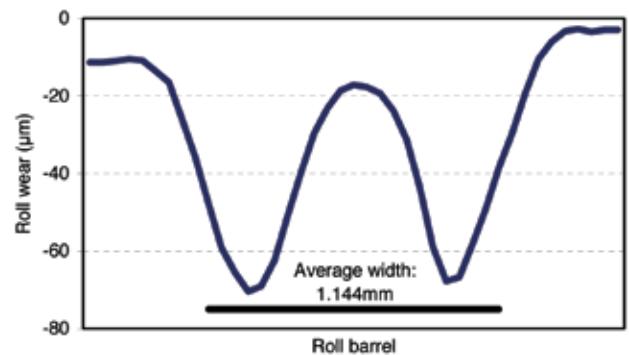
### Production scheduling

An analysis of the work roll wear at the end of the campaigns shows that the wear is concentrated near the edges of the average rolled width, forming "wear channels" that usually reaches more than 60 µm in diameter (2), as shown in figure 5. According to Salimi and Forouzan (3) this loss of material near the strip edges is due to numerous type of wear that combines the local tensile stresses in the roll body with shear stresses in the same area.

This wear profile forms a positive crown in the center of the roll barrel length. If rolling wide materials in the end of campaigns, this wear crown can't be compensated and causes wavy edges.

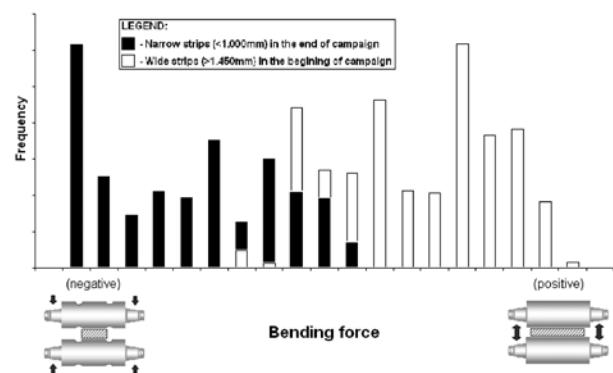
To overcome this problem, the scheduling rules are adjusted in such a way that the coils are processed in a sequence from the wider to the narrower ones along the work roll campaigns. In this manner, the wear crown can be compensated by the use of negative bending forces.

Actual results illustrating this procedure are presented in figure 6. The graph shows the frequency of bending force use for wide strips in the beginning of the work roll campaign and



**Fig. 5 - Example of a work roll wear profile after a 326 km campaign.**

Fig. 5 - Exemple du profil d'usure d'un cylindre de travail après une campagne de 326 Km.



**Fig. 6 - Frequency of bending force use for wide strips at the beginning of the work roll campaign and for narrow strips at the end of the work roll campaign.**

Fig. 6 - Fréquences d'efforts de flexion des cylindres de travail pour les bandes de grande largeur en début de campagne et pour les bandes plus étroites en fin de campagne.

for narrow strips at the end of the work roll campaign. In the beginning, it is more common to use positive bending forces to compensate the roll bending and to correct wavy edges, which is a tendency in wide strips.

On the other hand, negative bending forces are more common at the end of the roll campaign to compensate for the wear crown.

## Target elongations

The flatness correction in skin pass depends on the application of a sufficient rolling force to promote different elongations across the strip width. These elongation levels depends on the initial conditions of flatness, in such a way that in critical dimensions to obtain a good flatness in hot strip mill, as thin gauges, the elongation should be higher.

For example, a 1.5 mm strip usually has flatness defects around 40 l-units, while in a 3.0 mm strip the flatness rarely goes beyond 20 l-units. Theoretically the elongation required in the skin pass to correct the flatness in the 1.5 mm strip should be twice the value of the 3.0 mm strip.

On the other hand, different rolling forces will be imposed to the strip according to these required elongations. Different rolling forces result in different roll bending profiles, and the roll bending profiles should be compensated for in order not to be reflected in the final flatness of the strips.

These compensations can be done by using different sets of rolls with variations of grinded crowns or by using the roll bending forces. The first option results in disturbances for the operational routine and the second one can be limited by the mill capabilities.

So the set-up of target elongation values is done aiming at permitting the flatness correction while keeping the roll forces as constant as possible (4).

Table I shows the results of elongations and rolling forces for different low carbon strips processed at the skin pass. In spite of the significant differences in dimensions, the actual rolling force changes less than 300 kN between the strips, thanks to the adjustments of the target elongations.

**TABLE I: Examples of elongation and rolling force results.**  
TABLEAU I: Exemples d'allongements et d'efforts de laminage.

Coil ID	Thickness (mm)	Width (mm)	Target Elongation (%)	Actual Elongation (%)	Actual Force (kN)
9340	1.5	1215	1.0	1.025	2350
7425	3.0	1113	0.9	0.904	2050
8451	6.5	1515	0.4	0.323	2150

## Bending force control

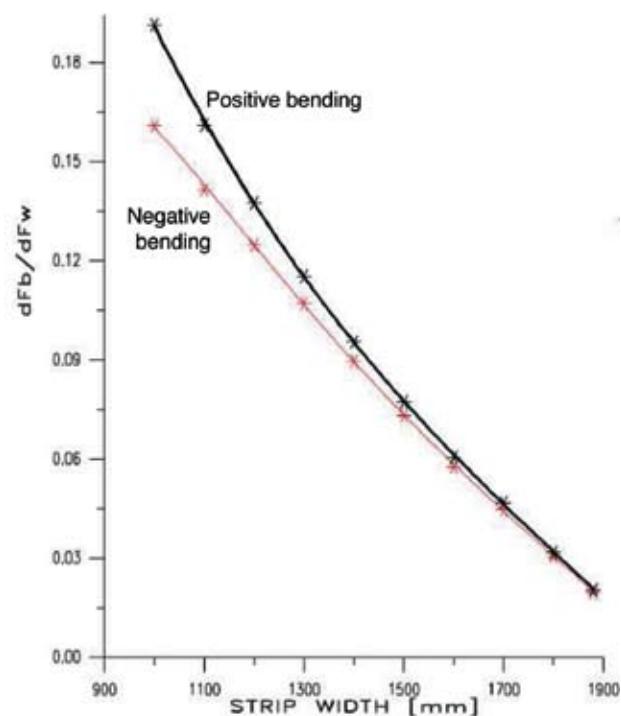
According to the changes along the strip processing, especially in rolling speed, the needed rolling force to achieve the target elongation also varies. These rolling force adjustments are automatically done by a single loop control based on the measured elongation.

If the rolling force changes, the roll bending profile should be compensated for by the use of roll bending forces, otherwise the final flatness of the strip will be affected.

Based on roll bending predictive equations, accordingly validated in practical experiments (1), an automatic correction of the bending forces were implemented aiming at keeping constant the roll profiles even with rolling force variations. Figure 7 shows the graphic representation of the control equation.

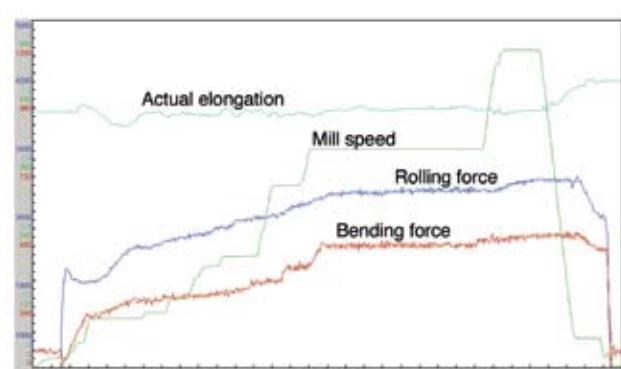
An actual result is shown in figure 8 that displays the rolling force changing automatically along the processing according the actual speed.

The resultant elongation is almost constant. The roll bending force automatically changes with the rolling force, aiming at keeping constant the roll profile and the flatness condition.



**Fig. 7 - Relation between the necessary bending force (Fb) and rolling force (Fw) to compensate the roll profile variation according to the strip width (5).**

Fig. 7 - Relation entre l'effort de flexion (Fb) et l'effort de laminage (Fw) nécessaires pour compenser la flexion des cylindres, selon la largeur de la bande (5).



**Fig. 8 - Process parameters variations along the strip processing.**

Fig. 8 - Variation des paramètres de process le long de la bande.

## ■ CONCLUSION

The domain of the work roll profile behavior is essential to obtain a good flatness result in any rolling process. In this way, the knowledge of roll wearing and bending behaviours in the hot skin pass mill of ArcelorMittal Tubarão was essential to establish the actions to be implemented in order to develop the process control.

The development achieved in the skin pass process has enabled the exploration of the equipment's great potential, resulting in significant improvements of flatness results and attainment of the market requirements.

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