IN SERVICE BEHAVIOR OF SPUN CASTING WORK ROLLS IN HOT FLAT ROLLING OF STEEL[1]

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Abstract
The evolution of work roll performance involved an increased amount of alloying elements and the following increase of costs. It has become very important to evaluate the behavior of new grades, since the initial stages of development, in order to tune the content and type of alloying elements as a function of the specific application on the rolling mill. One of the most important damage phenomena which strongly influences the roll performance is thermal fatigue. A new test was recently developed to reproduce a similar kind of damage to which the roll is subjected during rolling. In any case, research and development must be always considered in the frame of the industrial use of rolls, thus considering typical rolling practice, possible accidents and turning operations. This work describes by means of some examples a work methodology used to evaluate the in-service behavior of rolls in some mills, paying special attention to thermal fatigue damage.
Key words: Hot rolling; Spun casting roll; Thermal fatigue; Roll performance.

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1 INTRODUCTION

The demand for increasing strip quality and mill productivity leads to a continuous development of roll grades. On one side better performance have been achieved introducing High Speed Steels (HSS) in place of more conventional High Chromium Steel (HCrS) and High Chromium Irons (HCrI). Currently, tests are ongoing to replace indefinite chill cast irons in the last finishing stands with high performance materials of suited composition.[1,2] On the other side, the higher cost of HSS contributed to slow down this process. The specific features and the production mix of a given rolling mill make the selection of the most proper roll grade quite complicate and, in any case, not straight.

Centrifugal casting remains the most convenient way for the fabrication of rolls, whose properties are largely affected by the solidification structure. The final heat treatment does not significantly affect the microstructure, constituted by a tempered martensite matrix surrounded by a network of eutectic carbides.[3] Properties as hardness, wear[4] and thermal fatigue resistance are strictly correlated to the amount and type of carbides (M_7C_3, MC, M_6C, M_2C, M_3C) and to the hardness of the metallic matrix, as well. Past studies, also of present authors, correlate the microstructure of different roll grades to their performance, evaluated on small samples.[5-9]

A quite interesting point of interest for roll manufacturers remains the possibility to evaluate the roll performance by means of small scale laboratory tests. Wear, thermal fatigue tests and even tests combining both kinds of solicitations were developed to predict the in service behavior of different roll grades using a much less expensive approach compared to field tests, also in view of the length of rolling campaigns and the long time to get results from the rolling plants. Wear resistance generally increases by increasing hardness, particularly if promoted by hard and evenly distributed MC carbides. On the other side a large amount of interconnected carbides often results in deeper cracks which allow more severe machining operation to recover the surface integrity of the roll. This dramatically reduces the yield of the roll, calculated as rolled tons/mm roll.

The reliability of laboratory tests results lies in their capability to correctly reproduce the damage mechanism observed during service. In this way, continuous efforts are being spent to approach the service conditions. In recent times, a new thermal fatigue test was proposed to produce the bidirectional thermal fatigue cracking (heat checking) of rolls in place of the unidirectional cracking observed with the previous test configuration.[10]

Results of newly developed thermal fatigue tests will be presented together with some practical case studies related to this damage mechanism. Moreover some recent development of roll grades made by Innse Cilindri are shown.

2 NEW THERMAL FATIGUE TEST

A customary thermal fatigue (TF) tests was used to reproduce the is service damage of rolls. A surface portion of a disc specimen (40mm external diameter, 10mm width), corresponding to about one third, was induction heated up to 670°C over its whole width. The hot surface is then rapidly cooled down by a controlled water jet (2l/min). In this way thermal gradient and related stresses developed in tangential direction only, inducing the initiation of unidirectional axial cracks propagating in radial direction (Figure 1). On the other side, the heat checking damage of roll usually provides bidirectional cracking, suggesting the action of multiaxial thermomechanical stress. The width of the specimen was thus increased to 20mm, so to introduce a thermal gradient also in the axial direction (Figure 2). The different thermal profile in the two cases is confirmed by the microhardness profiles measured on a metallographic cross section. While the microhardness profile is almost homogeneous across the width of the 10mm sample, it shows a marked softening in the central region of the 20mm samples, with no softening in the outer lateral regions (Figure 3). This results in the initiation of tangential crack as well, giving rise to a bidirectional cracking similar to that of rolls. The size of the thermal fatigue mesh of the 20mm samples is not much different from that of the roll. Moreover, on a microscopic scale, a secondary finer mesh can be observed along the eutectic carbides network, confirming the detrimental influence of carbides on crack initiation and propagation (Figure 4).

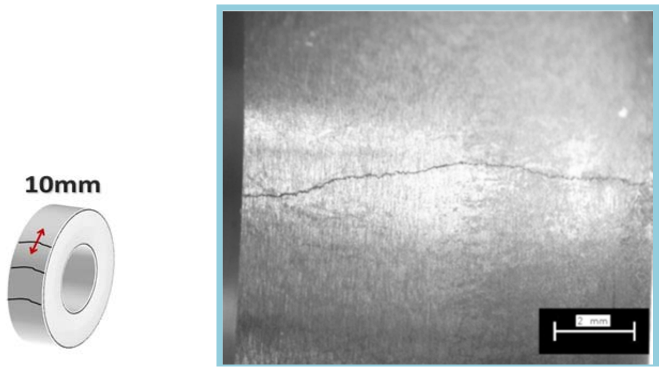

Figure 1. 10 mm width TF specimens for unidirectional cracking.

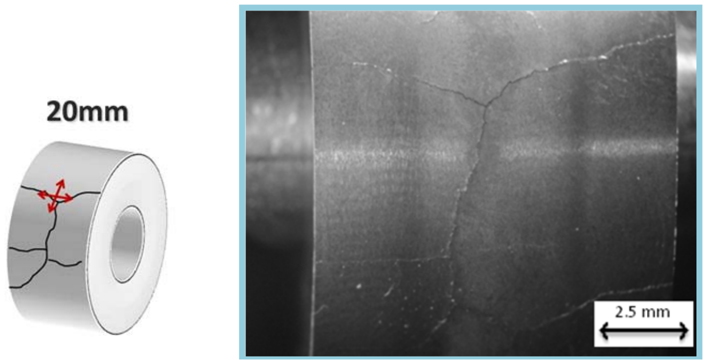

Figure 2. 20mm width TF specimens for bidirectional cracking.

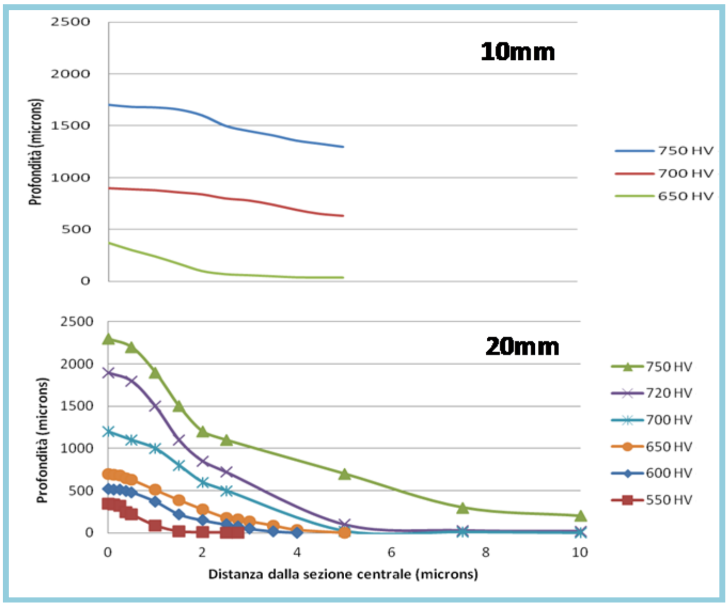

Figure 3. Microhardness profiles of TF specimens.

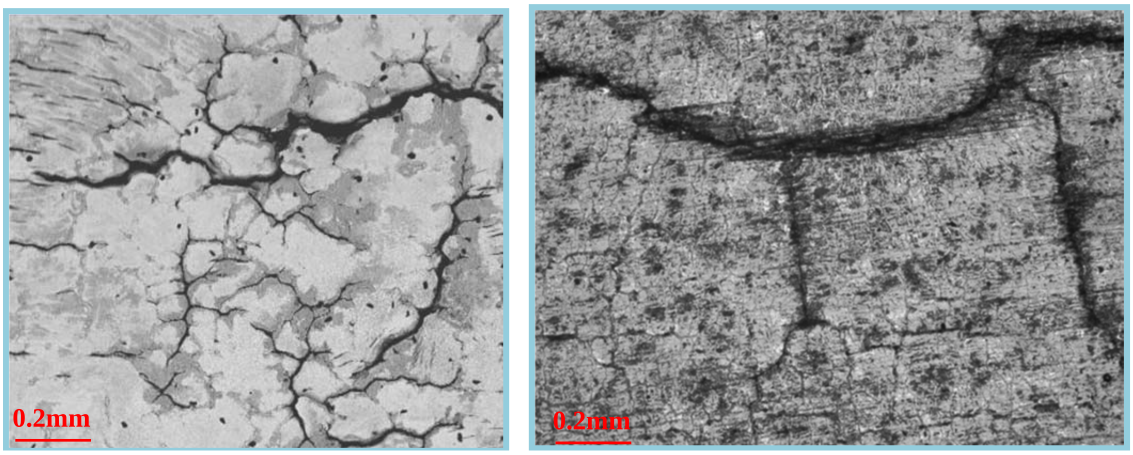

Figure 4. TF cracking on the 20mm lab specimen (a) and the roll (b).

3 THERMAL FATIGUE DAMAGING ON WORK ROLLS

Thermal fatigue damage is found in almost all stands of an hot strip mill. In the case of roughing stands the degradation is more severe due to the lower speed of the strip and the higher surface temperature. The cracks may propagate over 1mm in depth. In the case of finishing stands the damage becomes less severe even in front of the higher number of thermal fatigue cycles, because the contact time between roll and strip is lower and the roll temperature lower, as well.
The heat checking mesh strongly affect the yield of the roll, for two distinct reasons:

- thermal cracking promoting micro-detachments of roll surface so the wear resistance can be negative affected;
- the depth of cracks can affect the roll redressing at the machine shop.

The positive influence of an improved thermal fatigue resistance on the roll performance is thus quite evident.
Laboratory tests still evidence some important aspects related to the microstructure and thermomechanical properties but, in some cases, these required features are not compatible with other important function related demands of the roll.

Thus, it is usually very important to attain a stable equilibrium for the normal working regime of the mill. In this sense, the daily experience learns that a correct analysis of the rolling procedures on a specific mill is really strategic looking at the optimization of roll performance.
In the following paragraph some case studies will be shown in order to highlight how TF damage may assume very different form and extent in different mills. This suggests that a detailed evaluation of damage is a fundamental requirement looking at optimum mill productivity and roll performance.

3.1 Roughing Stands

Example 1 – Stand R3 (continuous) of HSM – HCrSteel after 220000 ton.

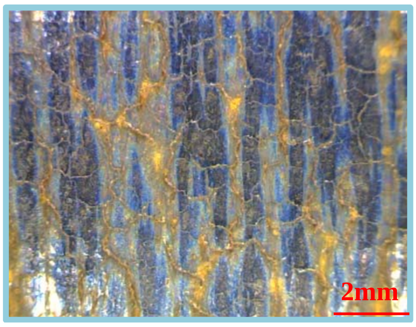

Figure 5. Heavy pattern of firecracks.

Example 2 – Stand R1 (continuous) of a MiniMill – HSS after 3000 ton.

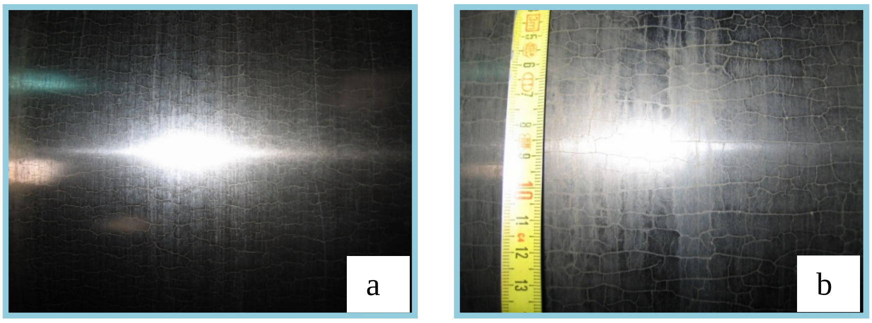

Figure 6. Roll surface (a – Top Roll; b – Bottom Roll).

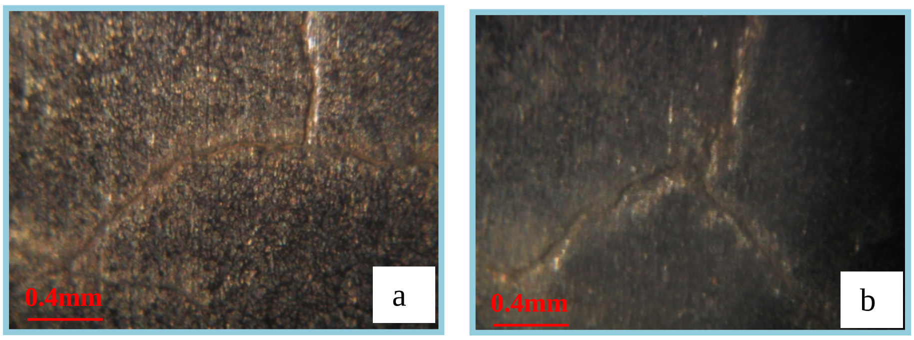

Figure 7. Zoom on main cracks of Figure 6 (a – Top Roll; b – Bottom Roll).

Example 3 – Stand R1 (continuous) of a MiniMill – HSS after 5000 ton.

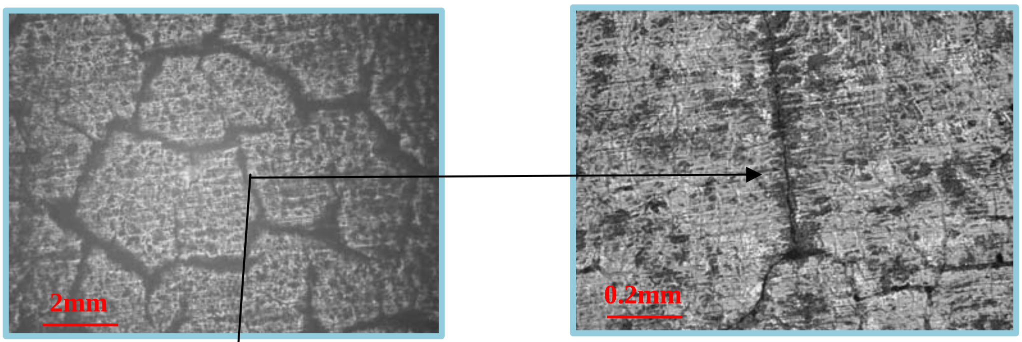

Fig. 8 Damaging on the roll surface

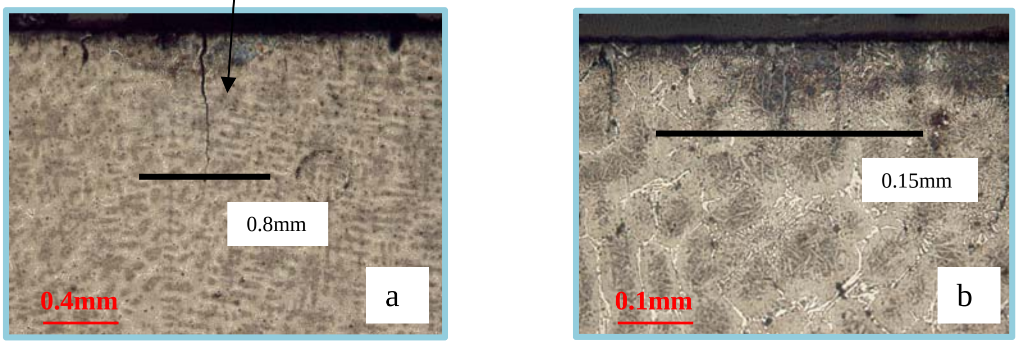

Figure 9. Section view (a – main firecracks network; b – secondary firecracks network).

Example 4 – Stand R5 (continuous) of HSM – Semi HSS after 200000 ton.

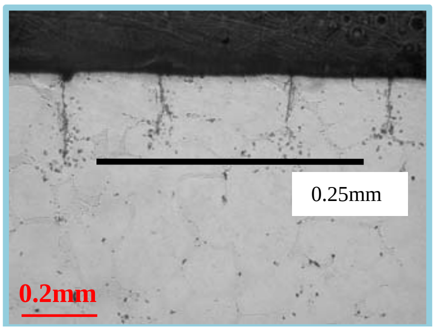

Figure 10. Section view of main firecracks network.

3.2 Finishing Stands

Example 1 – Stand F1 of HSM - bottom roll – HCrIron after 2600ton.

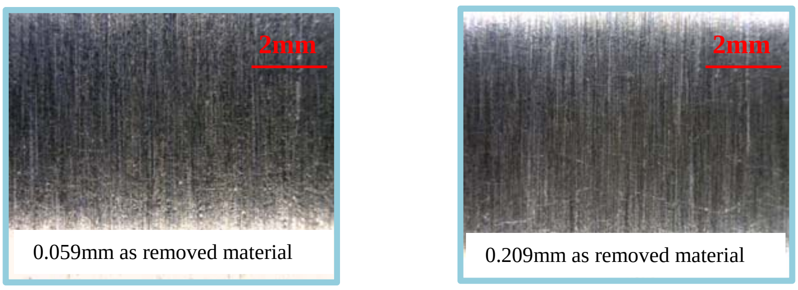

Figure 11. Roll surface during grinding operations.

Example 2 – Stand F2 of HSM - top roll – HCrIron after 2000ton.

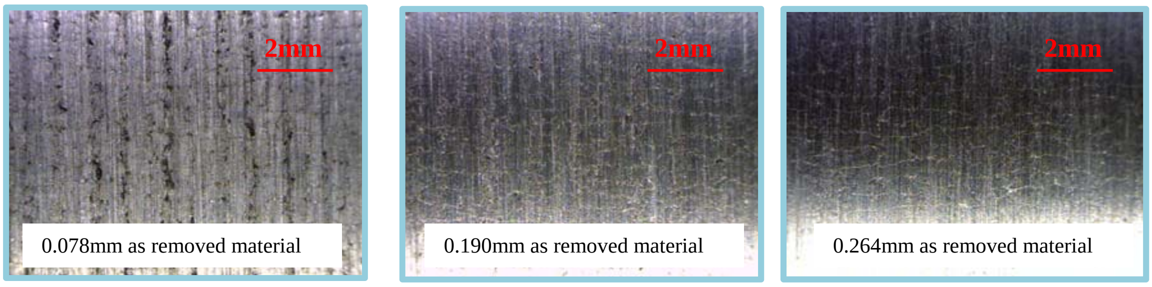

Figure 12. Roll surface during grinding operations.

Example 3 – Stand F4 of HSM - bottom roll – HCrIron after 2600ton.

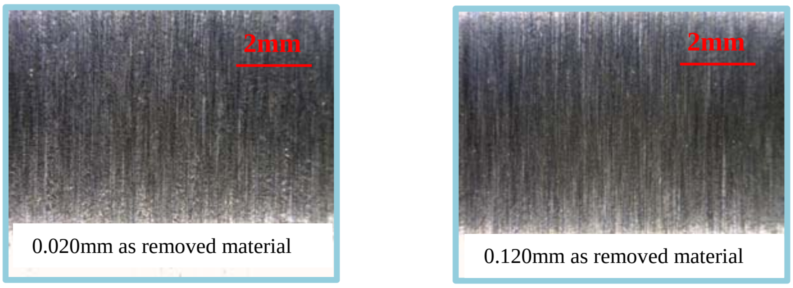

Figure 13. Roll surface during grinding operations.

Example 4 – Stand F5 of HSM - bottom roll – ICDP after 2600ton.

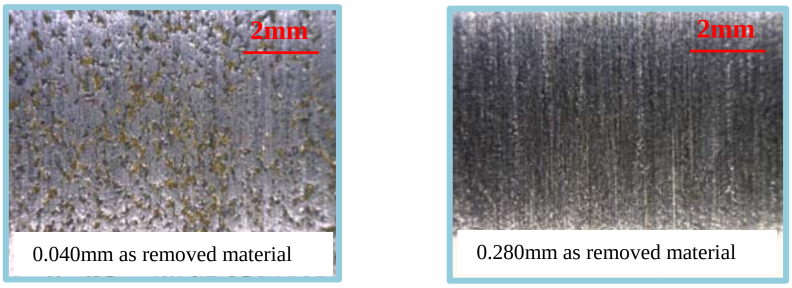

Figure 14. Roll surface during grinding operations.

Example 5 – Comparison stand F3/F4 – top roll – HCrIron after 3000 ton.

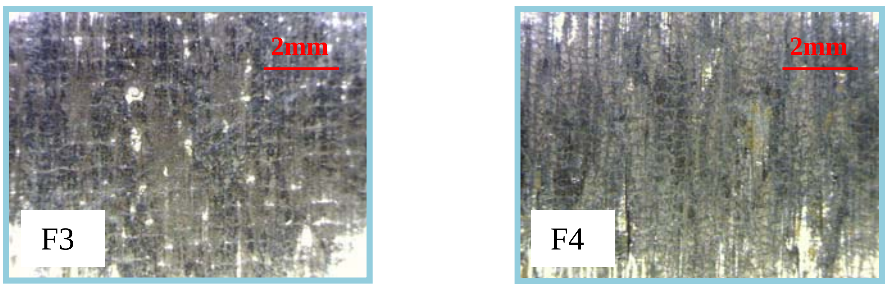

Figure 15. Comparison of roll surface damaging between F3 and F4.

Example 6 – Comparison stand F1/F2 – bottom roll – HSS after 5500 ton.

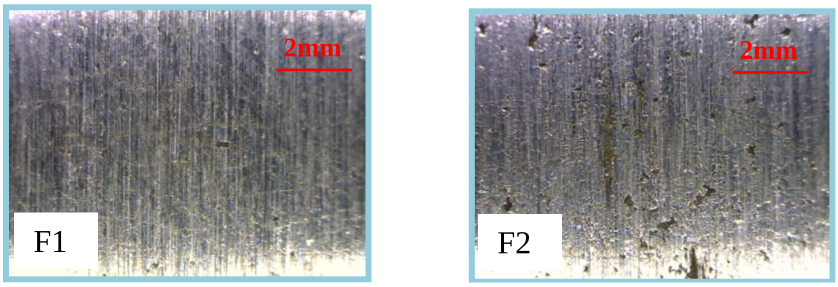

Figure 16. Comparison of roll surface damaging between F1 and F2 after a stock removal of 0.1mm.

4 NEW ROLL GRADES

During the last three years Innse Cilindri has invested a lot in the production process and now some restrictions in the chemical analysis to avoid quality problems during centrifugal casting are disappeared.
In the class of HSS roll material it's possible now to produce a series of grades with an amount of carbides around 15% without segregation phenomena through the shell. Also the properties of the matrix appear better due the high content of alloying elements that are present.
The main target of these new products is to improve the abrasion resistant of this class of roll material to allow longer campaign in the mill in particular for the front stands of finisher. The results coming from the trials in several mills are very satisfactory also about the thermal fatigue resistance. Figure 17 shows an example of microstructure of one of these new material.

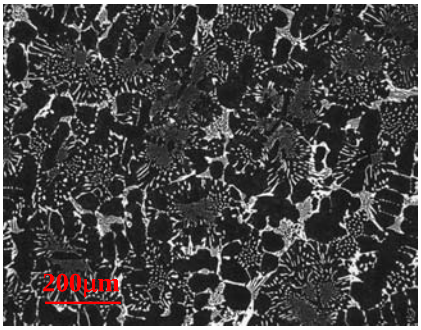

Figure 17. Microstructure of an high carbon HSS (C = 2,2% - ∑ Carbide Former Elements = 20%).

Thinking to the last finishing stands it's now under testing a new hybrid material to try to replace the indefinite chill iron rolls. This material show characteristics of a tool steel and of an indefinite chill iron therefore give it a "name" seems to problematic. The tests in laboratory are very promising. Figure 18 shows a microstructure of this material (graphite ~2% - carbides ~20%).

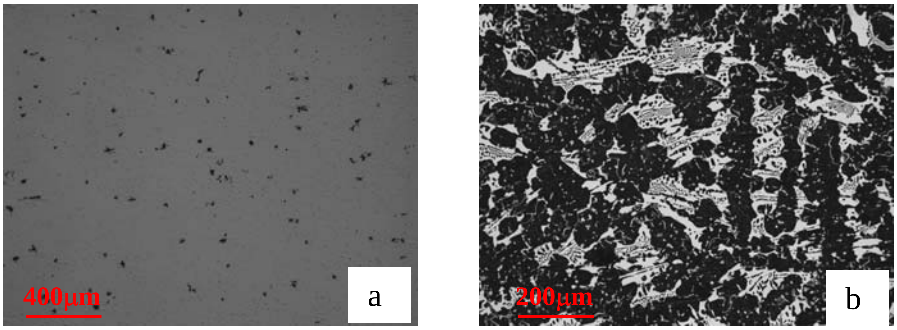

Figure 18. Microstructure of hybrid material (C_{eq} = 3,5% - ∑ Carbide Former Elements = 8%). (a) distribution of graphite; (b) distribution of carbides.

5 DISCUSSION

The damaging due to thermal fatigue is very different through the stands but let's try to fix some common ideas.
The thermal cycle produces on the roll surface 2 kind of damaging:

1. A heavy network of firecracks. The severity of this type of damage is mainly influenced by the mill operating conditions and secondarily by the stand. In this case the roll material plays a marginal role and it's possible to appreciate different situation only among different class of roll material.
   Regarding the depth of this type of cracks we can consider what follows as a reference situation:
   - from 0,25mm to 2mm for rougher;
   - from 0,05mm to 0,5mm for early finishing stands (F1-F4);
   - negligible for rear finishing stands (F5-F7).
2. A light network of firecracks that involves a depth below 0.20mm. In this case the microstructure of the material is very important. To limit this phenomena a material with a low amount of carbides is preferred; besides the presence of dissociated MC carbides instead of interdendritic carbides like M_7C_3 or M_2C can help to reduce the problem.

6 CONCLUSION

This work has faced the damaging of work rolls due to thermal fatigue. The present test configuration in the laboratory gives a type of damaging on the specimen very similar to the real one that characterized the rolls after the rolling campaign in the mill.
The thermal fatigue affects the roll surface and so its degradation during rolling. Clarify the level of this damaging becomes so an essential issue when we try to optimize the grinding operations mainly for the work rolls of early finishing stands. In this case the roll often restarts working with a residual damaging that could have negative influence for the incoming campaign.
To improve the roll thermal fatigue resistance from our side and to optimize the redressing procedures it's imperative to define what means thermal fatigue because, like underlined in this paper, the matter is absolutely not so simple.

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