IMPROVEMENT IN HSS ROLLS FOR EARLY STANDS OF HOT STRIP MILLS[1]

Metallurgical Features and Mechanical Properties Assessment

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Abstract

Aurora and Kosmos grades are HSS alloys belonging to the complex Fe-Cr-C-X system, where X is a strong carbide former element of the V, Mo or W type. Both alloys were metallurgically characterised prior to their comparison. Metallurgical analyses involved phases identification and carbides quantification by using Scanning Electron Microscopy and Energy Dispersive X rays. Differential Thermal Analysis was performed to allow a better understanding of the solidification sequence of studied alloys while mechanical tests performed were compressive at room temperature and bulk hardness at usual service temperatures. An attempt was made in order to connect experimental results to the good behaviour in operation of Aurora grade. In fact Aurora grade appeared to exhibit strong metallurgical differences when compared to Kosmos grade, especially as concern in nature and amount of carbides.

Key words: HSS; Carbides; DTA; Residual and intrinsic delta ferrite; Compression tests; Hot hardness

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INTRODUCTION

The so-called Kosmos grade is the standard HSS grade manufactured by Marichal Ketin for the early finishing stands of Hot Strip Mill (HSM). The chemical composition of Kosmos grade optimises the precipitation of three kinds of eutectic carbides: MC, M_2C, M_7C_3. [1,2]

A sufficient amount of very hard MC eutectic carbides strongly improves wear resistance while a too large amount of the same carbides lead to an increase of the friction coefficient and even chattering.

Although M_2C eutectic carbides are also wear resistance enhancers, their morphology has a great influence on toughness and mill incidents resistance. In fact when precipitating in flake-like particles M_2C eutectic carbides lead to a brittle material with a weak resistance to mill incidents.

M_7C_3 eutectic carbides may have an improving effect on roll oxidation behaviour due to their high Chromium content. However M_7C_3 carbides exhibit a lower hardness when compared to MC and M_2C carbides.

The new HSS alloy namely Aurora grade had been manufactured four years ago in order to yield performances better than those of Kosmos grade without modifying the vertical spin casting process. For that time about fifty rolls of Aurora grade have been in operation in various HSM.

This paper illustrates alloying elements setting (choice and content) in the new Aurora grade. By using sophisticated laboratory examination technique such as Differential Thermal Analysis (DTA), Scanning Electron Microscopy (SEM), Energy Dispersive X rays (EDX) and Image Analysis, metallurgical parameters of Aurora grade will be determined and compared to those of Kosmos grade. An attempt will also be made in order to connect experimental results to the good behaviour of Aurora grade in operation.

EXPERIMENTAL PROCEDURE

Studied Materials

Raw materials that were vertically spun cast originated from the complex Fe-Cr-C-X system, where X is a strong carbide element former of the V, W or Mo type. These materials represent the shell of a compound rolling mill roll with a core material made of spheroidal graphite iron.

Average chemical compositions (% -wt) of Kosmos and Aurora grades are given in Table 1.

Table 1. Average chemical compositions of Kosmos and Aurora (% -wt.)

	C	Cr	W_{eq}	Mo/(Mo+W)	V
KOSMOS	1.5/2.0	5.0/7.0	7.0/10.0	0.6/0.7	4.0/6.0
AURORA	1.5/2.0	3.0/5.0	11.0/14.0	0.9/1.0	4.0/6.0

Major differences between Kosmos and Aurora grades are set in chromium content, tungsten equivalent parameter (W_{eq}) and Mo/(Mo+W) ratio. In fact, Kosmos grade had a higher Cr content than Aurora with related lower Weq and Mo/(Mo+W) parameters.

By decreasing Cr content a lower amount of M_7C_3 chromium eutectic carbides could be expected while the higher W_{eq} parameter could lead to an increase of M_2C carbides.(1,2)
For Kosmos grade which exhibited martensite and retained austenite in the as-cast conditions, tempering was performed to obtain a fully martensitic matrix.
As Aurora grade contained a mixture of bainite and retained austenite in the as-cast conditions, hardening was set by quenching from a defined temperature to get expected martensite. Tempering was then performed to transform most of the retained austenite into martensite.
Heat treatments temperature ranges were set in order to achieve bulk hardnesses between 78 and 83 ShC for both grades.

Metallurgical Features

Metallurgical features involved identification and quantification of carbides as the matrix is supposed to be fully martensitic.
Carbides nature was investigated by means of SEM, EDX. DTA trials performed allow to determine on one hand the nature of phases which exist in the raw material (industrial conditions) and on the other hand the solidification sequence of the studied materials while considering cooling from the liquid at given cooling rates. In fact, DTA was used to determine the carbides precipitation.
And finally carbides volume fraction were determined in the as-polished conditions while using Image Analysis.

Mechanical Tests

Mechanical tests involved compression at room temperature and hot hardness.

RESULTS

Carbides Characterisation in the Industrial Conditions

Carbides identification in Kosmos and Aurora was made by SEM combined with EDX microanalyses. Figures 1 and 2 illustrate their related microstructure.
Three types of similar carbides were identified in both grades, namely MC, M_2C, $M_{23}C_6$ (Figures 1 and 2), while M_7C_3 carbide type was found in Kosmos grade in addition (Fig 1a and 1b).(3)
MC, M_2C, M_7C_3 are eutectic carbides which means that they precipitate from the liquid while $M_{23}C_6$ are very fine secondary carbides fully dispersed within the matrix.(4)

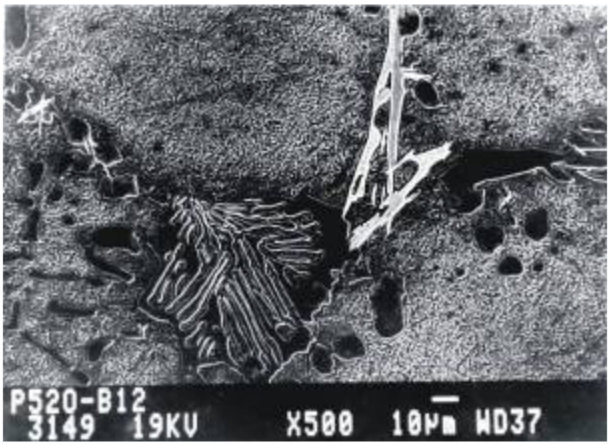

Figure 1a. Cluster of MC (black lobules), M_2C (platelike) and M_7C_3 (black fan-shape) in Kosmos grade (martensitic matrix)

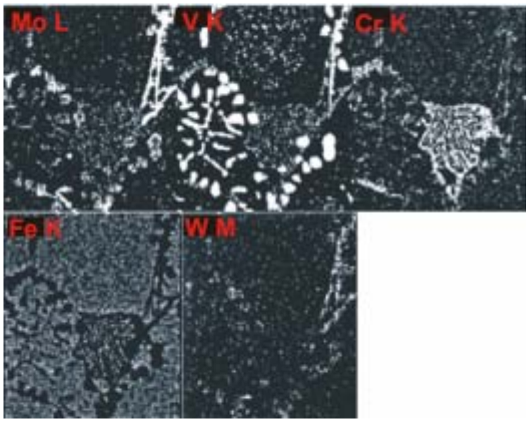

Figure 1b. Related EDX map from figure 1a Fine $M_{23}C_6$ (V,Mo-rich) inside matrix grains

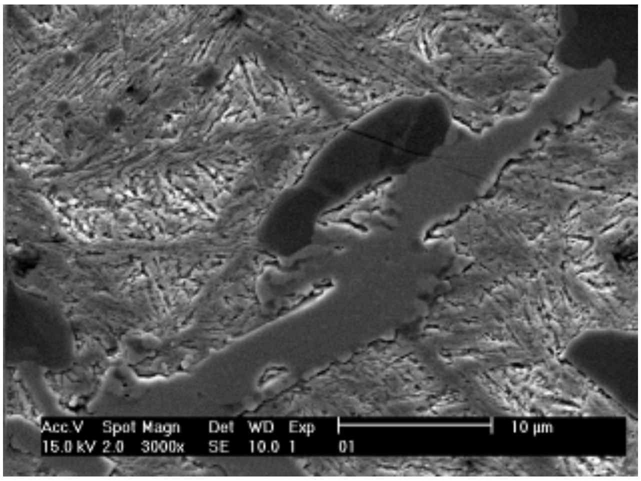

Figure 2a. Complex MC (dark grey) and M_2C (light grey) in Aurora grade with a martensitic matrix

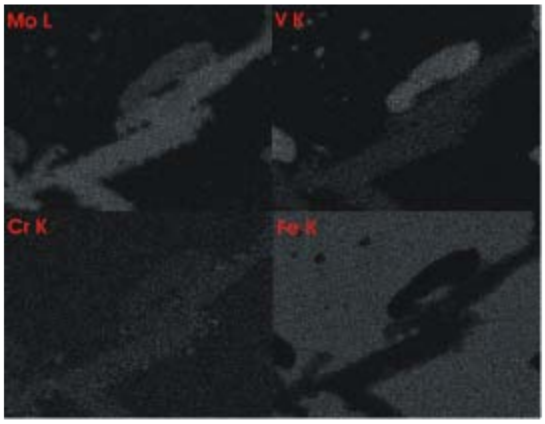

Figure 2b. Related EDX map from figure 2a Fine $M_{23}C_6$ (V,Mo-rich) inside matrix grains

Eutectic carbides have the same morphology in Kosmos and Aurora grades.
Divorced MC are characterised by a idiomorphic morphology as isolated massive crystals (Figures 1 and 2), while irregular M_2C are plate-like as they precipitated in an acicular shape made from a cluster of larges needles particles (Figures 1a and 2a).[4]
Complex-regular M_7C_3 founded in Kosmos lead to a continuous network of fan-shaped carbides mostly located at grains boundaries (Figures 1a and 1b). (4)
Results of ZAF quantification (EDX microanalyses) of MC, M_2C, M_7C_3 and the martensitic matrix are given in Table 2. Three parameters namely $\mathbf{W_{eq}}$, $\mathbf{Cr_{eq}}$ and $\mathbf{W_{eq}/Cr}$ ratio were set in addition to single elements X ray results.
W_{eq} (2Mo+W) which is assessed in the matrix is related to the solid solution hardening effect.
Cr_{eq} (Cr+1.5Si+Mo) which is also related to matrix content gives the matrix alphagen behaviour (austenite stability).
W_{eq}/Cr ratio that is related to eutectic carbides is an own-concept parameter set in order to characterise hardening effect of alloying elements in MC and M_2C eutectic carbides.

Table 2.ZAF quantification (wt-%)

Element X ray	KOSMOS				AURORA		
	MC	**M_2C**	**M_7C_3**	**Matrix**	**MC**	**M_2C**	**Matrix**
Mo L	18	39	12	2	34	68	6
V K	52	12	9	2	58	14	1
Cr K	7	16	33	5	6	11	5
Fe K	4	8	39	85	2	7	84
W L	19	25	7	2	-	-	-
Si K	-	-	-	1	-	-	1
Mn K	-	-	-	1	-	-	1
Ni K	-	-	-	2	-	-	1
Additional parameters for Qualitative analyses							
W_{eq}	-	-	-	6	-	-	12
Cr_{eq}	-	-	-	8.5			12.5
W_{eq}/Cr	7.9	6.4	-	-	11.3	12.4	-

Following observations were made on Aurora grade when comparing its metallurgical features (carbides nature and composition, matrix content, etc.) with those of Kosmos.

- There are no M_7C_3;
- MC and M_2C are Mo-rich but doesn't contain as many Cr and W than M_7C_3 ones;
- W_{eq}/Cr ratio is higher;
- The matrix contents more Mo and its W_{eq} parameter is higher;
- Cr_{eq} parameter is higher

Furthermore eutectic carbides of the same type exhibit different composition depending on the initial chemical composition of the related alloy. Besides MC and M_2C carbides seem to dissolve variable amount of the same elements as there are more Mo and V in Aurora carbides than in Kosmos ones.[2,4,5]

Carbides Characterisation Towards DTA Experiments

Experimental conditions involved heating from room temperature up to 1620°C with a 300°C/h rate. The temperature upper limit of DTA tests was set by the maximum of DTA "Netsch" device.

Different peaks have been observed from DTA curves, each one corresponding to a defined phase transformation. Figure 3 and Table 3 compare behaviour of Kosmos and Aurora grades.

Following observations could be inferred from DTA heating curves (Figure 3):

- Residual austenite transformation in martensite, additional secondary carbides precipitation with martensite relaxation (peak 1);[6]
- Reverse austenitic transformation from the tempered and relaxed martensite (peak 2);[6]
- Secondary carbides dissolution (peak 3);
- Reverse eutectic transformations with carbides dissolution (peaks 4, 5 and 6);
- Reverse peritectic transformation (peak 7);
- Complete fusion of delta ferrite and the possible remaining austenite (peak 8);
- Starting of the reverse peritectic transformation (uncompleted peaks 9 and 9', only for Aurora with end of the fusion reported by a dashed line)

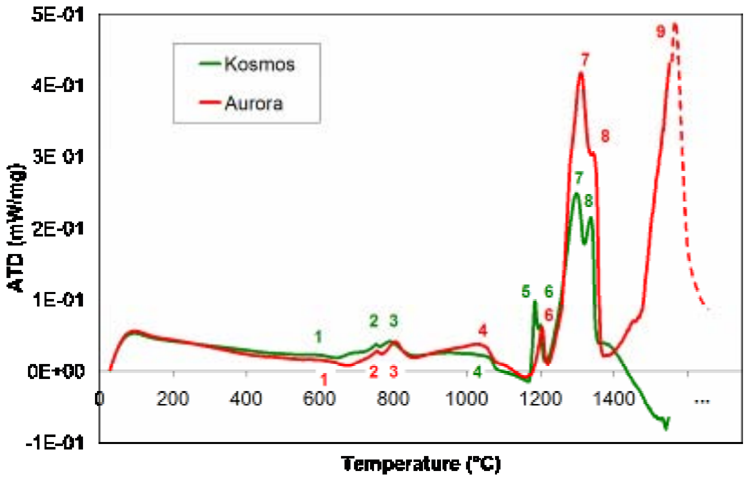

Figure 3. DTA curves during heating

Table 3. Peaks and related phase transformations in Kosmos and Aurora during heating

KOSMOS			***AURORA***		
Peak n°	T° peak max (°C)	Related Phase transformation	Peak n°	T° peak max (°C)	Related Phase transformation
1 (7)	595	$\gamma_{res} \rightarrow \alpha'$ $\alpha' \rightarrow \alpha'' + SC$	1 (7)	610	$\gamma_{res} \rightarrow \alpha'$ $\alpha' \rightarrow \alpha'' + SC$
2 (7)	752	$\alpha'' \rightarrow \gamma$	2 (7)	755	$\alpha'' \rightarrow \gamma$
3	790	$M_{23}C_6 \rightarrow \gamma$	3	805	
4	1090	$\gamma + M_2C \rightarrow L$	4	1095	$\gamma + M_2C \rightarrow L$
5	1186	$\gamma + M_7C_3 \rightarrow L$	5	---	---
6	1201	$\gamma + MC \rightarrow L$	6	1205	$\gamma + MC \rightarrow L$
7	1298	$\gamma \rightarrow \delta + L$	7	1344	$\gamma \rightarrow \delta + L$
8	1338	$\delta \rightarrow L$	8	1311	$\delta \rightarrow L$
-	-	-	9'	1450	$\gamma'' \rightarrow \delta'' + L$
-	-	-	9	> 1550	$\delta'' \rightarrow L$

Carbides Quantification

The amount of every single type of eutectic carbide and the total volume fraction of eutectic carbides depend mainly on the chemical composition, the effect of the cooling rate being less significant.[2,4]

The total volume fraction of eutectic carbides in High Speed Steels (HSS) is one of their main features. For HSS rolling mill rolls this value ranges from 9 to more than 15%.[4]

Figure 4 gives the overall volume fraction of the MC, M_7C_3 and M_2C eutectic carbides in Kosmos and Aurora as obtained from Image analysis examinations.

Although MC and M_2C amounts are higher in Aurora (8.5%) than Kosmos (6.9%), the total volume fraction of eutectic carbides is higher in Kosmos. In fact additional M_7C_3 of Kosmos (7.4%) that are not present in Aurora contribute to raise the total carbides volume fraction up to 14.3% in Kosmos.

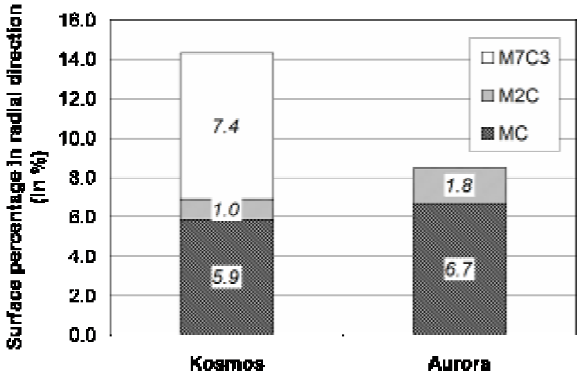

Figure 4. Surface percentage of carbides in radial direction for Kosmos and Aurora

Mechanical Tests

Figures 5 and 6 indicate the properties of Aurora compared to Kosmos for compression test and hot hardness.

The maximum compressive strength is higher in Aurora (3203 N/mm²) than Kosmos (2440 N/mm²) (Figure 5) and so does the hardness at temperature range between 500 and 600°C (Figure 6).

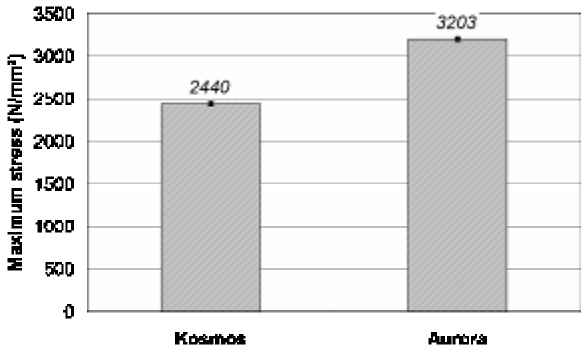

Figure 5. Compression test results

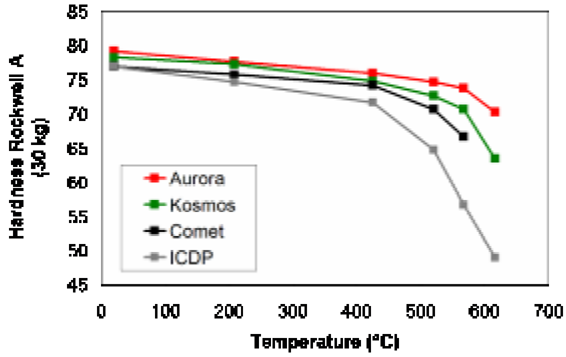

Figure 6. Hot hardness tests results

Industrial Results

Figure 7 illustrates both grades performance in stand 2 of a CSP (Compact Strip Mill). Outputs are expressed in kilometres of tons rolled in the stand per millimetre of stock removal. The performance of Aurora is 14% higher (2606 km/mm for Aurora and 2282 km/mm for Kosmos).

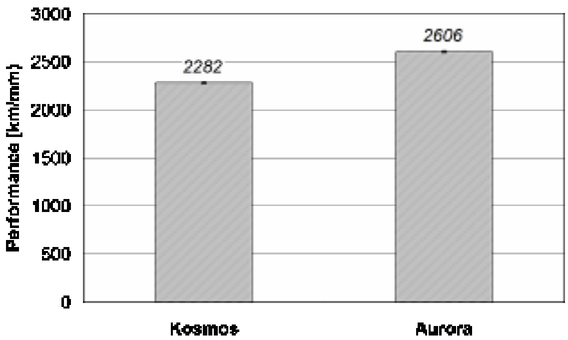

Figure 7. Performances of Aurora and Kosmos in stand 2 of a CSP

DISCUSSION

While comparing DTA heating curves (Figure 3 and Table 3), following observations were made on Aurora grade:

- There are no eutectic carbide M_7C_3;
- There is an increase of the peak maximum temperature of the dissolution of eutectic carbide MC;
- There is a reverse peritectic transformation.

The lack of eutectic carbide M_7C_3 in Aurora grade can be explained by the decreasing of the Chromium content, the principal element forming the carbide M_7C_3.
The reverse peritectic reaction is the transformation that occurs during the heating, starting from a solid austenite phase and leading to a mixture of solid delta ferrite and a residual liquid. The presence of intrinsic ferrite delta at the end of heating could be allowed by the presence alpha stabilising elements (Si, Mo, Cr).
Generally speaking, during solidification, two types of delta ferrite can be observed:

- the *“intrinsic” delta ferrite* which appears as the result of the beginning of solidification sequence and is transformed completely by peritectic reaction into austenite ($L+ \delta \rightarrow \gamma$);
- the *“residual” delta ferrite* which remains at room temperature due to the uncompleted peritectic transformation.

“Residual” delta ferrite can be identified in the DTA heating mode, as the inversion of DTA curve slope in the temperature range of 1050°C to 1300°C.(7)
Aurora contains “intrinsic” delta ferrite and no “residual” delta ferrite, as Aurora heating curve does not show the slope inversion corresponding to residual delta ferrite.
The presence of “intrinsic” delta ferrite in Aurora and not in Kosmos is due to the presence of higher Molybdenum content in Aurora. As Mo is a ferrite stabilising element(3) it could also be expected that Aurora will contain more carbides resulting from eutectoid decomposition of delta ferrite.
Results obtained after mechanical tests are in good agreement with all the previous observations.
In fact W_{eq} in Aurora matrix is twice higher than Kosmos one while related Cr_{eq} is one and half time higher. Thus matrix in Aurora appears more resistant as it contains more hardening elements.
Although Aurora contains less eutectic carbides than Kosmos, Aurora carbides appear to keep a higher hardness in operation as shown in hot hardness tests results. Moreover, MC and M_2C carbides in Aurora exhibit a composition which is slightly different from that of the same carbides in Kosmos grade. In fact the related W_{eq}/Cr ratio of MC and M_2C carbides is always higher in Aurora than Kosmos (see Table 2). So for a given V content, both W and Mo could be set as major elements for good hardness behaviour in the temperature range of 500/600°C as these elements enhance MC and M_2C carbides hardness.
Overall observations are in good agreement with previous studies.

CONCLUSIONS

The Aurora grade presents strong differences compared to Kosmos grade:

- there are no eutectic carbides M_7C_3;
- a decrease of the total amount of carbides but an increase of MC and M_2C carbides amount;

- harder MC and M_2C carbides connected to higher parameter W_{eq}/Cr;
- a more alloyed and more resistant matrix with higher W_{eq};
- a high hardness level at temperature in the 500/600°C range;
- a higher maximum strength in compression.

The decrease of Cr content together with the increase of W_{eq} parameter in HSS, lead to a more resistant matrix and harder eutectic carbides. The matrix is more resistant due to higher Weq content. The eutectic carbides present in the structure are harder due to the fact that the amount of soft carbides such as M_7C_3 is small or equal to zero and that the amount of hard carbides such as MC or M_2C is high. Moreover, these carbides are harder due to the higher content of Weq and decreasing content of Cr. This explains the better mechanical properties of grades containing low Chromium and high W_{eq} content.

The Aurora grade gives better performance than Kosmos in operation. That result is in good agreement with both mechanical and metallurgical features.

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