Study of Complex Carbides obtained after Solidification and Thermal Treatment in High Speed Steels

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Introduction

High-speed steels (HSS) rolls are used in front finishing stands of hot strip mills. Good wear resistance and hardness at high temperature are defining characteristics of HSS.

Many carbides are present in these alloys, each having different effects upon the final properties of HSS. As a result, the nature, the morphology and the amount of these carbides are factors of important concern.

Optical microscopy combined with electron microscopy lead to quicker identification and characterization of HSS carbides.

Raw material

The rolls are elaborated from centrifugal vertical casting process. The final roll is bimetallic, with a shell material (HSS) different from the core material (Ferritic nodular graphite iron).

Chemical analysis of HSS – %Wt (Shell material) - The Balance is Fe*

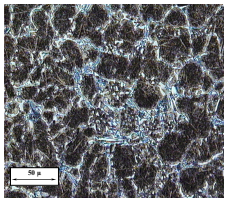
C	Si	Mn	Ni	Cr	Mo	P	S	V	W
1.0/2.5	0.1/0.5	0.5/1.5	1.0/2.5	4.0/8.0	2.0/8.0	<0.05	<0.015	3.0/9.0	2.0/8.0

Microscopic characterisation of HSS microstructure

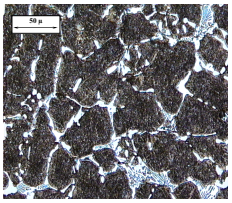
Optical microscopy for microstructural characterisation

The shell material is composed of a fully martensitic matrix (dark), with a network of eutectic carbides (light) mostly located at grains boundaries.

Grain size increases from the shell to the core.



Raw material – 5 mm Depth
3% Nital etched



Raw material – 50 mm Depth
3% Nital etched

Microscopic characterization of HSS carbides *(SEM/EDX)*

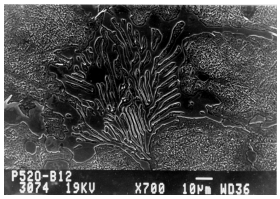
Electron microscopy for carbides identification

SEM is combined with EDX to determine the shape and the nature of carbides.

Results of rough observations:

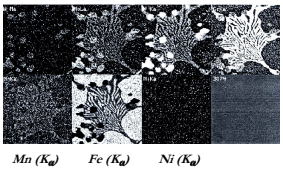
- **MC**: Cluster of Globular or Rod-like particles – V rich *(Eutectic carbides located inside grains)*
- **M_2C**: Cluster of Acicular particles – Mo rich *(Eutectic carbides located at grains boundaries)*
- **M_7C_3** : Fan-shaped or Plate-like Network of particles – Cr rich *(Eutectic carbides located at GB)*
- **M_6C**: Fish-bone like – Fe rich *(Eutectic carbides – Rare, and often associated with M_7C_3)*
- **$M_{23}C_6$**: Fine Globular particles – Cr rich *(Secondary carbides fully distributed inside the matrix)*

The chemical composition of each type of carbide is a combination of various elements with a leading one, which atomic concentration is highly over the others.



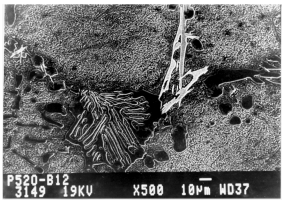
Raw material *(Shell, 50 mm depth)*
Fan-shaped carbide
SEM (SE)

W (M_α) *Mo (L_α)* *V (K_α)* *Cr (K_β)*



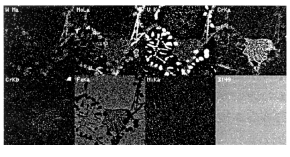
Mn (K_α) *Fe (K_α)* *Ni (K_α)*

Fan-shaped carbide **composition** *(Shell, 50 mm depth)*
EDX



Raw material *(Shell, 50 mm depth)*
Cluster of carbides *(Fan-shaped, Acicular and Coral-like)*
SEM (SE)

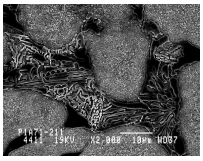
W (M_α) *Mo (L_α)* *V (K_α)* *Cr (K_α)*



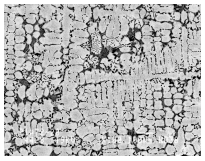
Cr (K_β) *Fe (K_α)* *Ni (L_α)*

Carbides **composition** *(Shell, 50 mm depth)*
EDX

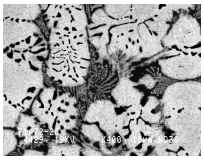
Microscopic characterization of HSS carbides *(SEM/EDX)*



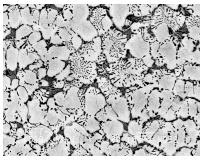
Complex M_7C_3 (grey) and M_6C (light grey) – Roll surface



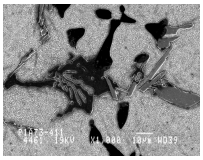
Dendritism (Solidification directions) - 20mm Depth



M_7C_3 (grey), MC (black) and M_2C (light grey) – 20mm depth



Dendritism (Solidification directions) From 20 to 40mm



Complex M_7C_3, MC and M_2C carbides 40mm depth

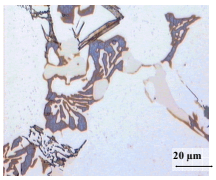
Bonding zone – From 60 to 70mm

Carbides identification with Optical microscopy

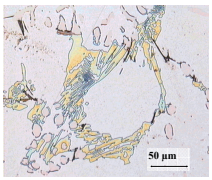
GROESBECK reagent ($KMnO_4$) as specific colouring etching, to allow optical identification of HSS carbides

- MC : Pink, with Dark outlining
- M_2C : Brown to Dark
- M_7C_3/M_6C : Blue to Yellow *(Rainbow coloured)*
- $M_{23}C_6$: Dark *(fine precipitates in the matrix)*

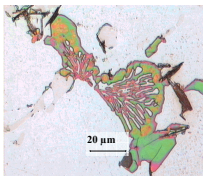
There could be a variation in the colour of the carbide, depending on the holding time in the reagent while etching.



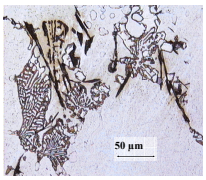
Raw material + 1 Tempering (580°C) Etching (Instant)



Raw material + 1 Tempering (580°C) Etching (3 sec)

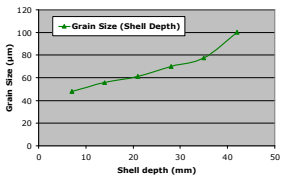


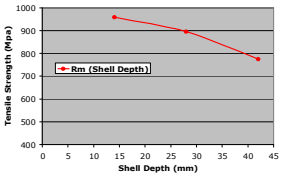
Raw material + 1 Tempering (580°C) Etching (10 sec)

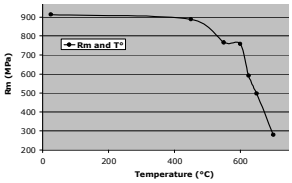


Raw material + 1 Tempering (640°C) Etching (60 sec)

Correlations between Microstructure (Grain Size and Secondary Carbides) and Mechanical Properties (Tensile Strength)







Conclusions

Coloured etching allows rapid identification of HSS carbides, while using optical microscopy. Before running optical identification, it is quite important to determine the nature of each type of existing carbides, by the means of SEM and EDX.

HSS Rolls for Hot Strip Mills contain different types of carbides, each having specific effect on mechanical properties. Overall distribution, nature and carbides size directly affect rolls mechanical properties. Vanadium forms very hard MC eutectic carbides mainly inside grains, improving hardness and wear resistance. High content of Cr causes formation of M7C3 eutectic carbides mainly at grains boundaries, improving hardness and preventing oxidation phenomenon. Both Mo and W lead to the formation of M2C eutectic carbides, which lower the secondary hardening effect during tempering. M23C6, which are very fine secondary carbides precipitate in the matrix during tempering at high temperatures. This second hardening effect seems to improve the ultimate tensile strength in temperatures around 600°C.ork is still in progress to study transformations that occur between carbides themselves, during heat treatments of HSS.

Acknowledgements : **MARICHAL-KETIN Group**