Use of Microscopy for Identification of Complex MC, M2C, M7C3, M6C and M23C6 Carbides in High Speed Steels

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Abstract
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 features of HSS. Many types of carbides are present in these alloys, each having a different effect upon the final properties of HSS. As a result, nature, morphology and amount of these carbides are factors of important concern. Identification and characterization of HSS carbides are realized with optical microscopy combined with electron microscopy.

Introduction
Raw material is manufactured by vertical spin casting in the industrial conditions. This process leads to a bimetallic roll, with shell material (HSS) different from the core (Ferritic nodular graphite iron). The average composition of shell material is given in Tab.1. After casting, the roll is air-cooled, and double-tempered. Blocks are cut out of the shell part. Studied samples are then obtained from these blocks, and they are polished and etched, each sample showing the working surface of the roll at variable deepness within the shell material. SEM analyses are carried out to determine the nature of each type of carbide, with a great emphasis on EDX mapping. After electron microscopy, samples are examined using Groesbeck etching, which allows rapid optical identification of carbides by coloring them, leaving the matrix unetched. The grain size and the volume fraction of leading carbides are roughly assessed by image analysis.

Results of Microscopy Analysis
Shell microstructure is composed of tempered martensitic matrix containing a network of carbides mostly located at grains boundaries. Grain size increases with decreasing cooling rate from the shell to the core (Fig. 1). Colored etching allows rapid optical identification of carbides, after determining their nature by the means of SEM/EDX.
This appears to be of interest for image analysis prospects. Groesbeck reagent (KMnO4) colors differently each type of carbide, as shown in Fig. 2 and Tab. 2. **Five types of carbides can be found after SEM/EDX analysis** (Fig. 3): MC, M2C, M7C3, M6C, and M23C6. MC, M2C, M7C3, M6C types are eutectic carbides, which means that they precipitate from the liquid. MC is V-rich and its morphology is often globular. M2C are Mo/W-rich, with an acicular shape (cluster of rodlike particles). M7C3 are Cr-rich, and they are located at grains boundaries and distributed as a continuous network. M6C are Fe/Mo-rich, and they appear to be located only near the surface edge of the shell material (higher cooling rates), whereas others carbide types are present on the entire deepness of the shell. M23C6 are Cr-rich fine secondary carbides fully distributed inside the matrix. Hence, M23C6 appear during tempering.

Complex carbides cluster give an idea on the precipitation sequence of carbides. MCs that are located at the top of cluster branches appear to be the first eutectic carbide to precipitate. As the solidification goes ahead, the V content of the residual liquid is lowered, and that allows others carbides types such as M7C3, to precipitate in the cluster centre (Fig. 4).

**Discussion and Conclusions**

Overall distribution, nature and carbide size directly affect rolls mechanical properties. In fact, additional mechanical tests are achieved using samples coming from the shell. For a given HSS composition, various types of carbides are present in the microstructure, depending on the cooling rate and the heat treatment performed after casting. It is quite possible to determine the precipitation sequence of carbides while analyzing a mixed carbide cluster. Eutectic carbides precipitate mostly at grains boundaries, while secondary carbides are fully distributed inside the matrix. 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 are very fine secondary carbides, which 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.
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SEM micrographs have been obtained using ULg CATμ devices. Raw material is supplied by Marichal Ketin, Rolling mill rolls manufacturer located in Liege (Belgium).

References

Short CVs.
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