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Microstructure of two centrifugal cast high speed steels for hot strip mills applications

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ABSTRACT

High speed steels (HSS) present excellent hardness, wear resistance and high-temperature properties. These mechanical properties are due to the presence of a great amount of hard carbides in the martensitic matrix. In the last 10 years, Japanese rollmakers have developed HSS grades and introduced them into hot strip mills.

The Marichal Ketin society (Liège, Belgium) has developed two grades of HSS: Kosmos and Aurora. Both grades present interesting properties but Aurora shows overall better performance than Kosmos, mainly because of a better distribution of harder (MC and M_2C) carbides in the martensitic matrix. Moreover, the hardness of the Aurora grade stays constant in depth and can be strongly improved by heat treatment, due to secondary hardening.

The purpose of this work is to describe the microstructure and the mechanical properties of the Kosmos and Aurora grades by various techniques such as optical microscopy, scanning electron microscopy (SEM), and macrohardness measurements.

1. Introduction

Hot strip mill rolls are submitted to extreme wear and high temperature conditions through their use [1–3]. For this reason, development efforts are made to improve their performance by the use of alloys with the best possible properties under those conditions.

In this scope, high speed steels (HSS) have been developed by Japanese rollmakers since the 1980s and introduced in hot strip mills.

HSS are complex multi-component alloys whose microstructure is composed of blocks of primary carbides within a matrix of tempered martensite, with the presence of fine secondary carbides [4–9]. This structure is mainly formed during solidification and can only be modified in a limited manner by heat treatment or hot working [4], and is strongly influenced by alloy composition and solidification rate.

Due to this particular structure, HSS grades exhibit excellent wear resistance in high temperature operation [5–8]. They have been and still are the object of several studies [4–18].

The main alloying elements in HSS are carbon, vanadium, chromium, tungsten and molybdenum. Their role in the structure of HSS is the following: Carbon is of course needed for the formation of carbides. Moreover, the effects of carbon in unalloyed steel, which is well known, can also be observed in alloyed steels, such as HSS. Vanadium is a strong carbide-forming element. The formula of vanadium carbide is typically V_8C_7. They are usually called MC. Chromium is also a carbide-forming element. The chromium carbides are usually of the M_7C_3 or $M_{23}C_6$ type. Tungsten forms very hard carbides and allows secondary hardening of HSS. However, the high specific mass of its carbides is the origin of segregation problems. Molybdenum has a behaviour similar to tungsten but is less sensible to segregation. Both of those elements form carbides of the M_2C or M_6C type.

The various carbides present in HSS can be identified by their morphologies and their localization in the steel, as summarized on Fig. 1.

Marichal Ketin (Liège, Belgium) is a company specialized in the production of hot strip mills rolls. They have developed two HSS grade called Kosmos and Aurora, that are the object of the present work. Kosmos was first developed and lead to the replacement of the previously used High Chrome rolls by bi-metallic rolls with an external layer of Kosmos grade and a core of nodular cast iron. The Aurora grade was developed later as a mean to improve and optimise the mechanical properties of HSS for the use in hot strip mills.

Both grades are used in bi-metallic rolls that are produced by centrifugal casting. The external metal is poured first, then the core metal.

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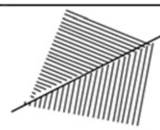
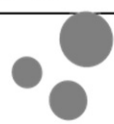
Carbide type		Morphology	Chemistry	Localization
MC		•Globular •Thick •Isolated or associated	•Mainly V •Secondary Mo, W, Cr	Centre of grains or grain boundaries (in association with M_7C_3)
M_2C		•Acicular (needles) or lamellar •Associated	•Mainly Mo, W •Secondary Cr, Fe, V	Interdendritic areas
M_6C		•Thin lamellae (fish bone) •Associated	•Mainly Mo, W •Secondary Cr, Fe, W, V	Areas of strong cooling (first 5 mm from surface)
M_7C_3		•Thick lamellae (fish bone) •Associated	•Mainly Fe, Cr •Secondary Mo, V, W	Interdendritic areas
$M_{23}C_6$		•Small globules •Isolated	•Mainly Cr, Fe •Secondary Mo, W, V	Homogeneously reparted in matrix

Fig. 1. Summary of carbide morphology and localization in HSS.

This study focuses on the determination of the microstructure and the mechanical properties of the Kosmos and Aurora grades by various techniques such as optical microscopy, chemical etching, scanning electron microscope (SEM) and macrohardness measurements.

2. Experimental details

2.1. Samples preparation

Two HSS grades were studied in this work. They are named Kosmos and Aurora. Both grades are variations on the AISI M2 HSS grade.

Their chemical composition is presented in Table 1. The Aurora grade differs from the Kosmos one by its higher Mo content, lower Cr content and by absence of W.

The microstructure of both grades was studied on 43 different samples obtained from bars (in as-cast and heat-treated conditions) cut in the shell of centrifugally cast rolls. These samples were divided into four batches: batches 1, 2 and 4 were cut at depth of 10 mm from the roll surface; batch 3 was cut along the diameter of the roll in order to study the microstructure as a function of the depth and to observe the influence of the cooling rate (Fig. 1).

Table 1
Chemical composition of Kosmos and Aurora grades (wt.%).

Grade	C	Cr	Mo	V	W
Kosmos	1.5–2	5.0–7.0	3.0–4.0	4.0–6.0	1.5–2.5
Aurora	1.5–2	3.0–5.0	5.0–7.0	4.0–6.0	–

Some of the specimens were heat treated as follow: the Kosmos grade was tempered to guarantee a shore hardness of 77/83. The Aurora grade needed a previous austenization flowed by air quenching before the tempering could be implemented.

Specimens were mounted, ground with an abrasive SiC paper (up to grade 4000) and finally polished with a diamond paste (1/4 μm).

Several etchants were used to determine the microstructure of Kosmos and Aurora grades by differential coloration of the carbides dispersed in the martensitic matrix [19–21]. Nital (10 wt.% HNO_3 in ethanol [22]) was used to reveal the grain boundaries in the martensitic matrix. Murakami etchant (3 g $K_3Fe(CN)_6$; 10 g NaOH;100 ml H_2O [8,22]) was used to colour the chromium containing M_2C carbides in black. Groesbeck etchant (4 g $KMnO_4$, 4 g NaOH, and 100 ml H_2O) enables to identify on a single sample M_7C_3 carbides (coloured in light brown), MC carbides (coloured in pink) and M_2C (coloured in black).

Another etchant (5 g $FeCl_3$; 10 ml HNO_3; 3 ml HCl; 87 ml ethyl alcohol [8]) was used to dissolve the martensitic matrix without any degradation of the carbides localized on the surface of the sample.

2.2. Analysis of the samples

Optical microscopy, coupled with image analysis was used to study the microstructure of the samples. A contrast image analysis of the etched specimens was carried out using the Paint Shop Pro Version 8.10 software, in order to evaluate the volume fraction of each type of carbides.

The microstructure was also studied using a Jeol JSM 5900 LV scanning electron microscope. Hardness of the samples was