PROGRESSIVE STEELS USED FOR CENTRIFUGALLY CAST ROLLS
PROGRESÍVNÍ OCELI POUŽÍVANÉ PRO ODSTŘEDIVÉ LITÉ VÁLCE

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Abstract

The article deals with the progressive materials, used for the working layer of the state-of-the-art composite centrifugally cast rolls, intended mainly for the hot rolling mills. They are discussed the basic requirements for the working layer of the rolls made of the chromium steels and high-speed tool steels (of type HSS and SEMI HSS), the principles of their heat treatment, the microstructure characteristics and the basic properties. In the experimental part of the article the results of the laboratory simulation of heat treatment of SEMI HSS steel are presented. The influence of parameters of the heat treatment on the microstructure, the content of the retained austenite and the hardness of SEMI HSS steel was studied. The microstructure of the investigated steel was created by a mixture of the eutectic carbides, the tempered martensitic matrix with the secondary carbides and the retained austenite. The discontinuous skeleton of eutectic carbides was created by a mixture of carbides of type M$_6$C and M$_7$C$_3$. In the case of the investigated SEMI HSS, the hardness ca 85HShC after the high-temperature annealing and the two-stage tempering at temperature 480 °C was achieved. At this level of hardness, ca 10 % of the retained austenite was presented in the structure.

1. INTRODUCTION

Rolling belongs to the most important industrial technologies of forming of the metallic materials. The requirements for the rolls that are used in the hot rolling process are very high, with regard to the wide assortment of the rolled steels and increasing demands on the surface quality, mainly of sheets. Among the basic requirements are the following:

- high hardness at working temperatures,
- sufficient wear resistance,
- low friction coefficient,
- ability of creating the compact oxide layer with good adhesion,
- resistance to thermal fatigue,
- high fracture toughness,
- uniform surface quality (roughness) at maximum service life.

The stationary roll casting was progressively substituted by the two-stage casting of rolls, which enabled the production of composite (multilayer) rolls with a different composition of the working layer and the core of rolls. Introduction of the centrifugal casting process made it possible to improve dramatically quality of the surface layer of the composite rolls. The continuously increasing requirements for rolls intended for hot rolling led to the development and introduction of production of rolls with the working layer made of chromium steels and alloys, indefinite chilled cast iron, high-speed tool steels (HSS) and recently SEMI HSS materials [1-6]. All these materials show the high level of hardness, but also the other significant properties are important for use of particular types of materials in continuous rolling mills. In this article the basic requirements for the state-of-the-art steels, used for the working layer of the composite centrifugally cast rolls, are discussed. The experimental works were focused on the simulation of heat treatment of the SEMI HSS steel with the aim of achievement the maximum hardness level.
2. PROGRESSIVE STEELS USED FOR WORKING LAYER OF ROLLS

2.1 Chromium steels

The optimal microstructure of these steels is created by the skeleton of primary eutectic carbides of M7C3 type and the tempered martensitic matrix. The content of the retained austenite in the resulting microstructure should be minimal. The microstructure may be controlled by the selection of the conditions for the heat treatment and by the chemical composition of steels. Generally it is possible to say that in the case of the economical alloy-saving process in the steel production it is necessary to use more power-intensive modes of the heat treatment. The typical contents of chromium and carbon in the chromium steels used for the production of rolls are given in Table 1. In designing the type and quantity of other alloying elements in the chromium steels the following aspects have to be considered:

- types and composition of the primary and secondary chromium carbides, precipitation of special carbides during the solidification,
- transition of curves of the pearlitic decomposition of austenite in the direction to longer times,
- sufficient amount of the carbide-forming elements and silicon for avoiding the graphite origin,
- influence of elements on temperature Ms.

| Table 1. Chemical composition of Cr steels, wt % |
| --- | --- | --- | --- | --- |
| C | Cr | % carbides | Cr / C | % Cr matr. |
| 1 – 1.5 | 11 – 12 | 5 – 15 | 8 – 10 | 10 – 11 |

The heat treatment of rolls with the working layer of the chromium steels consists usually of the high-temperature annealing and the following tempering, or only the cast microstructure is tempered. The main benefits of the chromium rolls may be summarized as follows [1]:

- way of precipitation of the eutectic carbides enables to attain the high toughness,
- high hardness of carbides M7C3 increases the abrasion resistance,
- high hardenability enables to achieve the fully martensitic structure, also in the case of the large cross sections,
- high resistance to softening during tempering enables to use the high temperatures of tempering,
- chromium price is relatively low.

2.2 HSS steels

The ever increasing demands on the rolls used in the hot rolling mills led in the nineties of the last century to development of rolls with the working layer of the high-speed steel. Quite a few of the production technologies of the HSS rolls were tested, the most widespread is the centrifugally casting, enabling to achieve the very fine-grained microstructure with the high level of micro-cleanliness. A prerequisite for the good properties of HSS rolls during rolling is maintaining the high wear resistance and hardness at the working temperatures.

The speech is about the multi-component Fe – C – X alloys, where X is represented mainly by chromium, tungsten, molybdenum, vanadium, and/or niobium. The cast structure of the HSS layer is created by the dendrites, surrounded by the more or less compact interdendritic network of eutectic carbides. The typical chemical composition of the HSS rolls is given in Table 2. The volume share of the carbides that have a crucial impact on the wear resistance of rolls is determined by the chemical composition and the heat treatment of HSS steels.
Table 2. Typical composition of the working layer of HSS rolls, wt%

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Cr</th>
<th>Mo</th>
<th>V</th>
<th>W</th>
<th>Nb</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.6 – 2.2</td>
<td>4 – 8</td>
<td>Max. 6</td>
<td>4 – 7.5</td>
<td>Max. 5</td>
<td>Max. 1.8</td>
</tr>
</tbody>
</table>

The following types of the eutectic carbides may occur in the working layer of the HSS rolls in relation to the chemical composition: MC, M₂C, M₆C and M₇C₃. The mutual comparison of typical hardness of these phase is given in Table 3.

Table 3. Hardness of carbide phases in HSS steels

<table>
<thead>
<tr>
<th>Phase</th>
<th>HV</th>
</tr>
</thead>
<tbody>
<tr>
<td>M₆C</td>
<td>1200-1800</td>
</tr>
<tr>
<td>M₇C</td>
<td>1600-2200</td>
</tr>
<tr>
<td>MC (VC)</td>
<td>2800-3000</td>
</tr>
<tr>
<td>M₇C₃</td>
<td>1400-1800</td>
</tr>
</tbody>
</table>

The optimization of the type and amount of particular carbide phases in the newly developing HSS steels is based on the following requirements [2, 4]:

- high wear resistance,
- temperature stability,
- good resistance to oxidation,
- high hardness.

The purpose of alloying the HSS steels consists in avoiding precipitation of the insufficiently hard and at the same time brittle carbides of M₃C type. A suitable representation of particular types of carbides in the resulting microstructure is obtained by the balanced ratios of vanadium, tungsten and molybdenum. It was verified that the wear resistance of the HSS rolls is very positively influenced mainly by fine carbides of VC type, which are very hard.

2.3 SEMI HSS steels

With regard to the fact that the high alloyed HSS steels are very expensive, the great effort is dedicated to the development of cheaper variants of steels with comparable properties. The solution represents so-called SEMI HSS steels with the “economical” chemical composition, when the mechanical properties are obtained by the optimized modes of the heat treatment.

The producers of rolls try to maximize the useful properties of the SEMI HSS rolls in such a way that they be near to the values typical for the HSS rolls. The SEMI HSS rolls are used in hot rolling mills, but it is supposed that they can be used also in cold rolling mills, where the decisive property is the level of hardness and the content of the retained austenite in the resulting microstructure is not so important [6].

The heat treatment intended for quality of the HSS and SEMI HSS steels generally consists of austenitizing and at the minimum two (2) cycles of tempering that follow after the sufficiently fast cooling [7]. The conventional high-speed steels are austenitized at temperatures 20-40°C below the solidus temperature [4]. In the case of higher carbon content the temperature range is 1120-1190 °C. However, the composite rolls with the working layer of HSS steels are usually treated in the temperature range only 980-1100°C, due to the low temperature of solidus of the core iron [1,6]. During austenitizing the microstructure of the discussed steels is created by a mixture of austenite, the eutectic and secondary carbides. The following cooling leads to a partial decomposition of the “destabilized” austenite to martensite, or cooling is interrupted when the
required temperature below $A_1$ is achieved. During the following tempering, the destabilization of the retained austenite and the binding of a part in the matrix solved atoms of molybdenum, tungsten, vanadium and niobium on the carbides occur.

3. LABORATORY SIMULATION OF HEAT TREATMENT OF SEMI HSS STEEL

In the framework of the experiment the simulation laboratory heat treatment of the specimen made of the SEMI HSS material was performed. The chemical composition of this material (wt%) was as follows:

- 0.86%C
- 7.6%Cr
- 0.48%(Nb + V)
- 3%Mo$_{eqv}$(Mo$_{eqv}$=%Mo+0.5%W)

The heat treatment of given type of the material consists in general of the high-temperature annealing and the successive multi-stage tempering. The share of the solved secondary carbides can be influenced during the high-temperature treatment by the austenitizing temperature. The usual austenitizing temperature is ca 1000°C. In the framework of the laboratory simulation treatment, the influence of annealing at temperature 1070°C on the degree of solution of secondary carbides and on the level of hardness of products of the decomposition of austenite after cooling to the room temperature was studied. The used cooling speed from the austenitizing temperature was chosen in such a way that the origin of troostite was suppressed.

The metallographic analysis confirmed that the austenitizing at temperature 1070°C influenced the morphology of the skeleton of eutectic carbides presented in the initial cast microstructure and at the same time made it possible the dissolving of a significant part of secondary carbides. The high content of carbon in austenite led to its partial decomposition during cooling, which resulted in the origin of plate martensite. The presence of a significant portion of the retained austenite in the resulting structure resulted in the lower level of hardness, compared to the austenitizing temperatures 1020 and 1050°C, where the share of the dissolved secondary carbides during austenitizing and the content of retained austenite in the resulting structure were lower. The mean value of hardness after the high-temperature annealing at temperature 1070°C reached 852 HV50. The microstructure after the high-temperature treatment consisted of a mixture of eutectic carbides, secondary carbides, martensite and retained austenite. The following two-stage tempering of specimens was performed at temperature 480°C. In the course of tempering a partial decomposition of martensite and destabilizing of a part of the retained austenite occurred, due to precipitation of carbide particles. The content of retained austenite in the microstructure after the complete mode of the laboratory heat treatment amounted to 11.7%. The resulting hardness of the material amounted to 719 HV50, i.e. 83.3 HShC.

![Microstructure after heat treatment simulation](image1.jpg)  ![Microstructure after heat treatment simulation](image2.jpg)

Fig. 1 and 2. Microstructure after heat treatment simulation
The typical microstructure of the evaluated specimen after the complete heat treatment is shown in Figs. 1 and 2. The discontinuous skeleton of the eutectic carbides and the tempered martensitic matrix with the fine secondary carbides may be observed. The retained austenite is not reliably distinguishable in the optical micrographs. The volume share of eutectic carbides in the SEMI HSS steel is markedly lower, due to the fact that the investigated SEMI HSS steel contains a smaller quantity of alloying elements and carbon than a typical HSS steel. Using the X-ray spectral microanalysis, only the following types of carbides were identified in the eutectic skeleton: M$_7$C$_3$ and M$_6$C. The results of the semi-quantitative analysis of these phases are given in Table 4.

**Table 4. Chemical composition of eutectic carbides, wt %**

<table>
<thead>
<tr>
<th>Phase</th>
<th>Si</th>
<th>P</th>
<th>Mo</th>
<th>V</th>
<th>Cr</th>
<th>Mn</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>M$_7$C$_3$</td>
<td>1</td>
<td>-</td>
<td>17</td>
<td>6</td>
<td>38</td>
<td>1</td>
<td>37</td>
</tr>
<tr>
<td>M$_6$C</td>
<td>4</td>
<td>2</td>
<td>51</td>
<td>3</td>
<td>6</td>
<td>1</td>
<td>33</td>
</tr>
</tbody>
</table>

Fig. 3 shows the network of the primary carbides on the image in reflected electrons – the white particles represent the M$_6$C phase and the grey particles the M$_7$C$_3$ phase. The distribution of selected elements in the carbide skeleton is documented by the X-ray maps of Cr and Mo in the enclosures Fig. 4.

**Fig. 3. Eutectic carbides, white particles: M$_6$C, grey particles: M$_7$C$_3$**

**Fig. 4. X-ray map of Cr**

**X-ray map of Mo**
Within some cells of the original austenite, the distinct needle formations of the plate martensite were present, Fig. 5. In the neighbourhood of the martensitic needles, an increased quantity of the retained austenite (the white contrast) can be expected. In the transition area between the working layer and the core iron, an increased share of the eutectic carbides was observed, a result of carburizing this area of the working layer.

Fig. 5. Martensitic needles in the final microstructure

4. CONCLUSION

In the article the basic requirements for the state-of-the-art steels used for the working layer of the composite centrifugally cast rolls are discussed. The laboratory simulation of the heat treatment demonstrated that in the case of the investigated alloy-saving SEMI HSS steel the hardness value ca 85HShC may be achieved. With this hardness level, ca 10% of the retained austenite was present in the tempered martensitic structure. The discontinuous skeleton of the eutectic carbides in the investigated steel was created only by a mixture of carbides of M₆C and M₇C₃ type.

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REFERENCES


