Effect of Heat Treatment on the Microstructure of Spray Formed AISI M2 High-speed Steel

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ABSTRACT. The effect of heat treatment on the microstructure of spray formed AISI M2 high-speed steel is under evaluation. The objective was to optimise heat treatments allowing further mechanical working. The M2 steel used in the present work was obtained in a spray forming plant in Brazil, built for processing billets preforms of light alloys and steels. The typical microstructure of spray formed materials, i.e., fine and equiaxial grains, allowed the optimisation of the M2 spheroidization heat treatment. The heat treatment at 1166 °C for 12 hours was effective in producing microstructure and hardness suitable for further mechanical working.

INTRODUCTION

High-speed steels can be obtained by three distinct methods, casting, powder metallurgy and spray forming. The casting route usually leads to a microstructure with segregation and poor carbide size distribution. This may affect the material performance, but can be minimised by post thermal mechanical treatments, at a cost penalty. Powder metallurgy methods can overcome such problems. The result is the obtention of materials with improved performance. Nevertheless, the removal of any remaining porosity can be highly expensive, e.g. by hot isostatic pressing. In the early 70, the development of spray forming introduced a new process. One of the outstanding features of this process is the capability to produce alloys that are normally difficult to cast by conventional techniques. This is due to the rapid solidification phenomenon involved in the process. The technique is very useful for the production of alloys with extensive freezing range, which impairs solidification and microstructure control during casting.

Tool steels are characterised by long freezing range and complex eutectic reactions, resulting in alloying elements segregation and formation of several different types of carbides during solidification [1-5]. The spray forming process minimises these effects and is effective as a powder metallurgy process, having the advantage of obtaining material in one single fabrication step. Therefore, it may offer substantial cost reduction [2].

Regarding high-speed steels, the more often observed carbides are MC, M2C and M6C, depending on the cooling rate and alloy composition [2,4,5]. The mechanical properties of the high-speed steels are affected by the carbides type, size and distribution [2]. For molybdenum high-speed steels obtained by continuous casting, the M2C carbide formation by eutectic reaction impairs hot workability and toughness [2].

The carbide formation and microstructure changes after reheating M2 high-speed steels, obtained by casting in sand and chill moulds have been presented in the literature [6]. This work shows that M2 steel solidification leads to coarse precipitation of M2C particles at the centre of the dendrites resulting from a peritectic decomposition of δ-ferrite. Subsequent enrichment of solute atoms around the growing austenite dendrites leads to MC, M3C and M6C formation. Further cooling, below the solidus line, results in the precipitation of small M2C and MC carbides, but
reheating leads to rapid dissolution of the ultrafine carbides. The $\text{M}_2\text{C}$ particles decompose rapidly to form $\text{MC}$ and $\text{M}_6\text{C}$ in less than 1 h at temperatures between 1150 °C and 1200 °C. Further reheating causes spheroidization of $\text{M}_6\text{C}$ eutectic carbide and coarsening of $\text{M}_6\text{C}$ and $\text{MC}$.

Literature results indicate that the microstructure of M2 casting obtained in chill moulds is slightly finer than that obtained in sand-cast [7]. Consequently, reheating at high temperatures show faster reaction kinetics. The aim of the present work was to evaluate the spheroidization heat treatment of a much-refined M2 high-speed steel microstructure, i.e., those obtained by the Osprey spray forming process.

**EXPERIMENTAL**

**Material**

The material under evaluation is spray formed AISI M2 high-speed steel. The burden charger for the spray forming processing was standard commercial cast steel. The chemical composition (wt. %) of the spray formed M2 high-speed steel is shown in Table 1 in comparison to nominal composition [8].

<table>
<thead>
<tr>
<th>AISI M2</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>W</th>
<th>V</th>
<th>P</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal</td>
<td>0.78 - 0.88</td>
<td>0.15 -</td>
<td>0.20 -</td>
<td>3.75 -</td>
<td>0.30</td>
<td>4.50 -</td>
<td>5.50 -</td>
<td>1.75 -</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>0.95 - 1.05</td>
<td>0.40</td>
<td>0.45</td>
<td>4.50</td>
<td>max</td>
<td>5.50</td>
<td>6.75</td>
<td>2.20</td>
<td>max</td>
<td>max</td>
</tr>
<tr>
<td>Spray formed</td>
<td>1.03</td>
<td>0.18</td>
<td>0.22</td>
<td>3.29</td>
<td>0.29</td>
<td>4.98</td>
<td>6.19</td>
<td>1.87</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

... Not measured.

**Heat treatments**

The conditions of the heat treatments used in this work (annealing, austenitization and spheroidization) are presented in Table 1. All samples were cooled inside the furnace.

<table>
<thead>
<tr>
<th>Heat treatment</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>annealing</td>
<td>880 ± 5 °C for 1 h</td>
</tr>
<tr>
<td>austenitization</td>
<td>1220 ± 10 °C for 2 h</td>
</tr>
<tr>
<td>spheroidization</td>
<td>annealing + austenitization + 1166 ± 10 °C for 12 h</td>
</tr>
</tbody>
</table>

**Microstructural characterisation and mechanical testing**

Samples of M2 high-speed steel after spray forming, annealing, austenitization and spheroidization were prepared for microstructural characterisation and hardness testing. The samples for metallographic examination were mounted in resin, polished and etched (Nital 3 %) for further optical microscopy analysis (MO). The samples for hardness testing were milled from both sides for a better settling in the hardness machine.

**RESULTS AND DISCUSSION**

**Hardness testing**

The material hardness gives an insight of the mechanical workability of the material. The hardness testing results are shown in Table 3. The spray formed tool steels in the as fabricated
condition showed high hardness that can result in difficult machining operations such as sawing. The literature hardness of M2 steel in the as annealed condition values vary from 16 to 23 HRC [8,9]. The results obtained in this study were similar to the literature-reported values. Austenitization heat treatment however, leads to high hardness similar to the as spray formed material. The spheroidization heat treatment produced very soft spray formed M2 steel.

Table 3. Hardness values after different thermomechanical treatments for the M2 high-speed steel.

<table>
<thead>
<tr>
<th>Condition</th>
<th>HRC</th>
<th>HRB</th>
</tr>
</thead>
<tbody>
<tr>
<td>as spray formed</td>
<td>41 ± 5</td>
<td>...</td>
</tr>
<tr>
<td>annealing</td>
<td>25 ± 2</td>
<td>...</td>
</tr>
<tr>
<td>austenitization</td>
<td>44 ± 2</td>
<td>...</td>
</tr>
<tr>
<td>spheroidization</td>
<td>(10)</td>
<td>92 ± 2</td>
</tr>
<tr>
<td>annealing [8,9]</td>
<td>16 - 23</td>
<td>-</td>
</tr>
</tbody>
</table>

... Not measured. Value in parenthesis is approximated.

Microstructural characterisation

M2 high-speed steel samples after proper polishing and etching were observed by optical microscopy. The spray forming of the M2 high-speed steel resulted in a fine microstructure with equiaxial grains, mean size of 57 µm, see figure 1.

The heat treatment of the spray formed M2 steel at 1166 °C for 12 h produced a microstructure with characteristics typical of strong destabilisation of the carbides plates, i.e. spheroidization, see figure 2. The literature indicates that carbides spheroidization and ferritic matrix is adequate for further mechanical working [8].

Literature showed that carbide spheroidization stops after 100 hours, due to the impingement mechanism of the already spheroidized carbides [7]. For M2 casting in sand moulds, the impingement mechanism starts after 10 hours at 1200 °C and the amount of spheroidization of the grain boundaries eutectic carbides type M₆C, is around 60 %.

![Fig. 1. Optical micrograph of M2 high-speed steel as spray formed. Nital etch.](image)
Fig. 2. Optical micrographs of the M2 high-speed steel after spheroidization at 1166 °C for 12 hours.

The spray forming process is characterised by a finer microstructure of equiaxial grains in comparison to casting in sand and chill moulds. Therefore, this fine microstructure may lead to faster spheroidization kinetics. A preliminary analysis suggests that the amount of carbides spheroidization of spray formed M2 steel in 12 hours heat treatment, is superior to that of the same material obtained by sand-cast.

CONCLUSIONS

The high cooling rate intrinsic of the spray forming process led to a partial hardening of the tool steels obtained. Annealing of the preforms, before any further cutting operation, is therefore necessary.

The fine spray formed microstructure lead to a rapid carbide spheroidization in the M2 high-speed steel. The heat treatment sequence (annealing, austenitization and spheroidization) was effective in the production of microstructure and hardness adequate to mechanical working.

The fine microstructure, homogeneity, equiaxial grain structure and the short spheroidization times are striking characteristics that makes the spray forming process very attractive in relation to other fabrication techniques.

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REFERENCES


