Production of maraging steel grades and the influence of specified and nonspecified elements for special applications

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The material properties of maraging steels are greatly affected by the alloy and inclusion content and hence by the production route. This paper describes various past and current production routes at Böhler Edelstahl GmbH and the effect of these routes on the specified element (alloy) and non-specified element (inclusion) contents. Non-metallic inclusions were investigated by EDX analysis. The effects of various alloying and tramp elements on the material properties are presented as a statistical evaluation of previous melts. Nitrogen solubility was calculated with Thermo–Calc for maraging steel Mat.-No. 1.6354 and the precipitation of nitrides is discussed. A proposal is made for the production of melts with improved properties. © 2004 Kluwer Academic Publishers

1. Introduction
The development of maraging steels began in the research laboratories at INCO at the end of the 1950s. With the invention of maraging steels, a type of alloy was found whose properties are significantly different from those of other steels [1–3]. Maraging steels are distinguished by their combination of high strength and high toughness. At strengths up to 2500 N/mm², these materials also offer good ductility and resistance to crack propagation. Maraging steels can be used successfully at temperatures up to 500 °C. Their simple heat treatment, low dimensional change following heat treatment, good machinability and weldability and the advantage that these materials do not decarburise, all made these alloys attractive for tool steel manufacturers with vacuum melting capabilities right from the start. Table I presents an overview of maraging grades produced by Böhler.

2. Manufacture
In the past, Böhler Edelstahl GmbH made maraging steels via two production routes. The first followed the traditional route: melting in an electric arc furnace followed by ladle metallurgy. The electrodes were remelted in a vacuum arc furnace. The second was the double vacuum melting route meaning vacuum melting followed by vacuum remelting (Fig. 1).

2.1. EAF melting/vacuum remelting
Maraging steel electrodes can be produced in the EAF, mainly for tool steel grades. Cheaper raw materials and back scrap with a composition similar to the steel to be produced can be processed by this route. No complicated scrap preparation is necessary. Our own experiences have shown that this method can, however, also be problematic. The high affinity of titanium and aluminium for oxygen and nitrogen causes a significant increase in the inclusion level and an unsatisfactory electrode surface when these alloys are cast in air. The apparent advantages of low cost raw materials and the cheaper production route provided by open melting must be offset against the increased tendency to form cracks in the electrode and the VAR-ingot. Hot forming problems and reduced yield are caused by poor ingot quality. For this reason this production route was replaced by the double vacuum route in 1997. Scrap is still melted in the EAF, however, and used for the production of charge material for the vacuum induction furnace.

2.2. Vacuum melting/vacuum remelting
For more demanding applications, where toughness or increased cleanliness are of primary importance, maraging steels were melted under vacuum in the ROTEL plant and further remelted in the vacuum arc furnace. Double vacuum melting helps to reduce the problems described above. Although double vacuum melting led to high cleanliness levels the ROTEL facility was not specified for highly demanding uses like aircraft applications. In 2000 the ROTEL plant was replaced by a modern vacuum induction melting furnace (VIM) of the VIDP (vacuum induction degassing and pouring) type with two 8 tonne and one 16 tonne crucible.

3. Metallographic investigations
The most problematic inclusions in maraging steels are elongated non-metallic inclusions (NMI). The length of
TABLE I Maraging steels/Boehler grades

<table>
<thead>
<tr>
<th>Böhler grade</th>
<th>C</th>
<th>Mo</th>
<th>Ni</th>
<th>Co</th>
<th>Ti</th>
<th>Al</th>
<th>Mat.-Nr.</th>
<th>DIN</th>
<th>AMS/MIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>V720</td>
<td>max. 0.030</td>
<td>5.30</td>
<td>18.50</td>
<td>9.00</td>
<td>0.60</td>
<td>0.10</td>
<td>1.6354</td>
<td>~1.6358</td>
<td>AMS 6514 MIL-S-46850 (Grade 300)</td>
</tr>
<tr>
<td>V721/V723</td>
<td>max. 0.030</td>
<td>4.90</td>
<td>18.00</td>
<td>8.00</td>
<td>0.55</td>
<td>0.13</td>
<td>1.6359</td>
<td>1.6359 X2NiCoMo1885 AMS 6512 MIL-S-46850 (Grade 250)</td>
<td></td>
</tr>
<tr>
<td>V725</td>
<td>max. 0.030</td>
<td>4.20</td>
<td>18.00</td>
<td>12.30</td>
<td>1.70</td>
<td>0.15</td>
<td>1.6356</td>
<td>1.6356 MIL-S-46850 (Grade 350)</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 1* Production routes for maraging steels.

These inclusions and especially their three-dimensional extension are easily recognisable at fracture sites. Fig. 2 shows an inhomogeneous band at the fracture surface of a notched impact test specimen. In an evaluation of the inclusion content, for example according to ASTM E45, this band would be classified as a type B inclusion. In the scanning electron micrograph the defect is easily identified as an inhomogeneous conglomerate of matrix material and fine non-metallic inclusions. The geometry of inclusions is, of course, also influenced by...

*Figure 2* SEM—investigation of steel Mat.-No. 1.6356 (Böhler V725).