NEW TOOL STEEL FOR WARM AND HOT FORGING

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Abstract Currently there are few tool steels which are particularly suitable for warm forging. A number of hot work tool steels, high speed steels and even cold work tool steels are used. Compared to hot forging (>1050 °C) the loads required may be doubled. Compared to cold forging, the workpiece temperature is high (600 °C–900 °C), and therefore thermal stresses are imposed on tooling. Hot work tool steels are often used, but wear relatively quickly so that the tools soon become out of tolerance. High speed steel tooling may be employed to meet the extra hardness/strength requirements but is limited to use in particular parts (mostly punches) because of its inherent lack of toughness. Cold work tool steels have inadequate toughness levels, and lose their high hardness rapidly at warm forging temperatures.

A steel is required which has high hardness/strength to resist wear and deformation, adequate toughness to resist cracking, and which retains its hardness at temperature in a manner similar to hot work tool steels.

A new steel has been developed by Bohler Edelstahl, which can reach a hardness of 58 HRc when heat treated at 1050–1070 °C, and has a toughness at this hardness equivalent to that of standard hot work tool steels at 45 HRc. Thus the hardness of a cold work tool steel has been achieved at heat treatment temperatures typical for hot or cold work tool steels and the toughness and the retention of hardness at temperature of a hot work tool steel are retained.

Keywords: Hot work tool steel; warm forging

INTRODUCTION

The following paper outlines the background behind the development of a new hot work tool steel, Bohler W360, and the essential improvements
in mechanical properties which have been achieved in this steel. First, the demands placed on the steel during the warm forging process will be discussed. Next, the design, composition, manufacturing and characterisation of the new alloy will be outlined. Finally, the properties will be summarised in comparison to standard hot work tool steel grades.

WARM FORGING IN COMPARISON

The process of warm forging, or semi-hot forging as it is sometimes known, has been in continual development since its introduction in the 1970s. The process was first introduced in Japan and the far east, and later came to Europe. The differences between warm, hot and cold forging are summarised, after Sheljaskov [1], in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>Hot forging (Die forging)</th>
<th>Warm forging</th>
<th>Cold forging (Extrusion)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shape spectrum</strong></td>
<td>Arbitrary</td>
<td>Rotationally symmetrical if possible</td>
<td>Mainly rotationally symmetrical</td>
</tr>
<tr>
<td><strong>Used steel quality</strong></td>
<td>Arbitrary</td>
<td>Arbitrary</td>
<td>Low alloyed steels C&lt;0.45%</td>
</tr>
<tr>
<td><strong>Normally achievable accuracy</strong></td>
<td>IT 12 – IT 16</td>
<td>IT 9 – IT 12</td>
<td>IT 7 – IT 11</td>
</tr>
<tr>
<td><strong>Normally achievable surface quality R</strong></td>
<td>&gt; 100 µm</td>
<td>&lt; 50 µm</td>
<td>&lt; 10 µm</td>
</tr>
<tr>
<td><strong>Economic lot size</strong></td>
<td>&gt; 500 parts</td>
<td>&gt; 10 000 parts</td>
<td>&gt;3 000 parts</td>
</tr>
<tr>
<td><strong>Surface treatment of the slugs</strong></td>
<td>Generally none</td>
<td>Generally none or graphite layer</td>
<td>Annealing, phosphating</td>
</tr>
<tr>
<td><strong>Intermediate treatments</strong></td>
<td>None</td>
<td>Generally none</td>
<td>Annealing, phosphating</td>
</tr>
<tr>
<td><strong>Tool materials</strong></td>
<td>Hot work tool steels</td>
<td>Hot work tool steels, high speed steels, hard metals</td>
<td>Cold work tool steels, high speed steels, hard metals</td>
</tr>
<tr>
<td><strong>Tool life</strong></td>
<td>5 000 – 10 000 parts</td>
<td>10 000 – 20 000 parts</td>
<td>20 000 – 50 000 parts</td>
</tr>
<tr>
<td><strong>Material utilisation</strong></td>
<td>60 – 80%</td>
<td>Approx. 86%</td>
<td>85 – 90%</td>
</tr>
<tr>
<td><strong>Energy required per kg forged part</strong></td>
<td>46 – 49 J/kg</td>
<td>40 – 42 J/kg</td>
<td>40 – 42 J/kg</td>
</tr>
</tbody>
</table>
Warm forging accounts for only a small fraction of all forged products, however it is an important process for components with tight tolerance demands made from materials unsuitable for cold forging. The most common parts made in this way are axisymmetric parts for the automobile industry e.g. constant velocity joints, tripods and the like [2, 3].

**TOOL STEELS IN WARM FORGING**

The demands made of tooling in warm forging are high: the loads required may be double those in hot forging and the workpiece temperature is high (600 – 900 °C) compared to cold forging. Severe mechanical loading and thermal stresses are the result.

Schmoeckel and Speck [4] summarised the properties necessary in a tool steel for warm forging as:

- Retention of shape (resistance to deformation)
- Safety against fracture
- Wear resistance
- Temper resistance
- Thermal shock resistance

Hot work tool steels are often used, but these may wear or deform relatively quickly so that the tools soon become out of tolerance. High speed steel tooling may be employed to meet the extra hardness/strength requirements but is limited to use in particular parts (mostly punches) because of its inherent lack of toughness and therefore thermal shock resistance. Cold work tool steels have inadequate toughness levels, and are not temper resistant, losing their high hardness rapidly at warm forging temperatures. Currently there are few tool steels which are particularly suitable for warm forging. A number of hot work tool steels, high speed steels and even cold work tool steels are used [5, 6]. A number of proprietary tool steels have been developed for this application, however most of these have at least one of two disadvantages: either austenising must be carried out at a high temperature to achieve the high hardness, or the high hardness has been achieved at the expense of toughness, meaning that thermal shock can cause the material to crack.
DEVELOPMENT AIMS

From the description above it becomes apparent that a steel is required which has high hardness/strength to resist wear and deformation, adequate toughness to resist cracking, and which retains its hardness at temperature in a manner similar to hot work tool steels. This became the aim of our development work. A goal was set to achieve a hardness of 58HRc at a hardening temperature of 1050–1070 °C. The temperature was chosen with typical hardening temperatures for cold and hot work tool steels in mind. Additionally, the steel should retain the typically high toughness levels of hot work tool steels, and a similar softening behaviour to these steels.

ALLOY DESIGN AND COMPOSITION

In order to achieve the high toughness target, the new hot work tool steel Böhler W360 was developed with only very few, finely-dispersed carbides. Two important factors influencing the toughness – the homogeneity of the microstructure and the cleanliness of the steel – are ensured by remelting. The hardness has been achieved by finely adjusting the composition of the matrix. The nominal composition of the new hot work tool steel is given, in comparison to standard grades, in Table 2.

<table>
<thead>
<tr>
<th>Steel</th>
<th>Grade</th>
<th>C</th>
<th>Mn</th>
<th>S</th>
<th>Cr</th>
<th>Mo</th>
<th>V</th>
<th>W</th>
<th>Co</th>
</tr>
</thead>
<tbody>
<tr>
<td>W303 ISOBLOC</td>
<td>1.2367</td>
<td>0.38</td>
<td>0.40</td>
<td>0.40</td>
<td>5.0</td>
<td>2.8</td>
<td>0.65</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>W321 ISOBLOC</td>
<td>~1.2885</td>
<td>0.39</td>
<td>0.30</td>
<td>0.35</td>
<td>2.9</td>
<td>2.8</td>
<td>0.65</td>
<td>—</td>
<td>2.9</td>
</tr>
<tr>
<td>S600</td>
<td>1.3343</td>
<td>0.90</td>
<td>0.90</td>
<td>0.90</td>
<td>1.8</td>
<td>6.4</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>W360</td>
<td>—</td>
<td>0.50</td>
<td>0.20</td>
<td>0.20</td>
<td>4.5</td>
<td>3.0</td>
<td>0.55</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

CHARACTERISATION AND BENCHMARK

Typical hot work tool steels currently used in warm forging are 1.2367 and 1.2885, often at a hardness level of 50–52 HRc and sometimes higher. The high speed steel 1.3343 is also used for punches at 60–62 HRc. These benchmark steels, and the new hot work tool steel Böhler W360 were characterised with respect to:
HARDENING AND TEMPERING BEHAVIOUR

Figure 1 shows the hardening and tempering behaviour of W360 compared to that of the two standard hot work tool steels W303 (1.2367) and W321 (~ 1.2885). It is clear that the achievable hardness of W360 lies significantly higher. This offers one of two advantages: the steel can be used at the higher hardness to provide resistance to wear or deformation, or, when used at the usual hardness of 50–52 HRc for warm forging, to provide temper resistance.

For the investigations described here the steel was hardened to 57 HRc by austenitising at 1070 °C and tempering three times at 540 °C. For the hot hardness investigation a hardness of 51 HRC was also examined. This was achieved by austenitising at 1070 °C and tempering three times at 630 °C.
TOUGHNESS

Figures 2 to 4 illustrate the toughness level of the new steel. Figure 2 shows the toughness at room temperature measured as notched impact energy using Charpy-U specimens. Figure 3 shows the same values measured at 500 °C—this is a typical die surface temperature during warm forging.

![Figure 2. Charpy-U notched impact energy of W360 measured at room temperature in comparison with other common tool steels used in warm forging.](image)

Note that the toughness of each steel has been measured at a different hardness level. The hardness levels chosen represent typical hardness levels at which each steel is used in warm forging. Particularly at the working temperature, Fig. 3, it can be seen that the new Böhler hot work tool steel W360 has a very high toughness. It shows the same toughness level at 57 HRc as W303 shows at 51 HRc, and lies above the toughness achieved by W321 at 51 HRc.

Toughness was also investigated by measuring the impact energy of un-notched toughness specimens and Charpy-V notch specimens. Although the steel was designed with a high hardness for warm and hot forming applications, the biggest challenge for toughness is in die casting applications. For die casting, toughness is of advantage to combat heat checking, and so a recommendation of 8ft.-lbf. min measured using Charpy-V notch specimens is made by NADCA (The North American Die Casting Association) for tool steels to be used in die casting [7]. This corresponds to almost
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Figure 3. Charpy-U notched impact energy of W360 measured at 500 °C in comparison with other common tool steels used in warm forging.

11J, and is expected to be achieved at a hardness of 44–46 HRc. Similarly, NADCA specifies an unnotched impact energy of 170 J at 45 HRc. These specifications were used as a further benchmark of toughness, and W360 was compared to them.

Figure 4(a) shows the impact energy of Charpy-V notch specimens of W360 at 57 HRc. It has an average Charpy-V notched impact energy of almost 13 J, exceeding the toughness specification set by NADCA for a much lower hardness.

In Fig. 4(b) it can be seen that W360 achieves an average unnotched impact energy of 184 J, again exceeding the stringent NADCA criteria. Figure 4 illustrates well the very high toughness achieved for a steel with a hardness of 57 HRc.

HOMOGENEITY

Due to the remelting process used, W360 shows good homogeneity. This is illustrated in Fig. 5, where the toughness, as Charpy-U notched impact energy is shown for specimens at 57 HRc taken from 18 different positions/orientations covering bottom to top, centre to edge in the ingot and both the transverse and longitudinal orientations. It can clearly be seen that
there is very little variation in toughness measurements over the ranges of positions and orientations tested.

HOT HARDNESS

The hot hardness and its dependency on time at working temperature was investigated using the hot hardness testing facility at the Materials Centre Leoben (MCL). The methodology has been described in detail elsewhere [8]. The specimen is held at temperature, in this case 600 °C, and the hardness is measured at temperature over a period of time. Figure 6 shows the steel W360 at two hardness levels in comparison to the standard hot work tool steel W303 (1.2367).

The hot hardness of W360 with a nominal hardness of 57 HRc is, as would be expected, much higher than that of W303 at 51 HRc. However as can be clearly seen from the diagram, the hot hardness of W360 at 51 HRc is also much higher, and holds for longer, than that of W303 at 51 HRc. This is because the improved hardening and tempering behaviour of the new
Figure 5. Toughness values (notched impact energy, Charpy-U) for W360 in three different orientations and at various positions along the bar length and across the cross-section.

Figure 6. Hot hardness, measured at temperature, as a function of time spent at temperature for W360 at two hardness levels and for W303 (1.2367).
steel W360 can be used effectively as described earlier: W360 has a higher tempering temperature to achieve the same hardness level, giving it a distinct hot hardness advantage.

**FURTHER INVESTIGATIONS**

The results presented above are from preliminary investigations. Naturally it is necessary to also investigate the physical properties of the material such as thermal conductivity and thermal expansion, as well as carrying out pilot trials to determine wear resistance, tool life etc in practice. These tests are currently underway.

**CONCLUSION**

The new hot work tool steel Böhler W360, has been developed for warm forging applications. It is characterised by a peak hardness of 58 HRC at an austenitising temperature of 1070 °C, with an excellent toughness e.g. of over 180 J (unnotched specimens) at 57 HRC. Due to this combination of properties the steel can be used without danger of catastrophic cracking or fracture due to thermal shock at a high hardness to combat wear and deformation or for its improved temper resistance at the usual hardness temperature for warm forging.

Böhler W360 was designed with warm forging in mind, but its excellent properties mean that it could also be used in some hot forging applications where hardness, wear resistance or temper resistance are needed. Use in toughness-critical cold work applications is also a possibility.

**ACKNOWLEDGMENTS**

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**REFERENCES**


