ON THE APPLICATION OF HOT-WORK TOOL STEELS FOR MANDREL BARS

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Abstract
Since Mannesmann’s introduction of the first cross roll piercer and pilger mill approximately 100 years ago the production of seamless tubes and pipes has gained more and more importance. Various different manufacturing processes for seamless tubes and pipes have been developed of which many are still being used. In all of these processes mandrel bars - hot-work tools of large volume - are of particular significance.

The report describes the most relevant production processes for seamless tubes with focus on the various factors influencing the performance of the mandrels and gives a survey on the basic requirements on the applied hot-work tool steels. Based on these requirements special hot-work tool steels have been developed. After an explanation of their properties the paper finally reports about experience gained with different hot-work tool steels in this field of application.

Keywords: Mandrel bar, seamless tube, MPM mill, continuous tube mill, push bench, Assel mill, hot-work tool steel, carbide precipitation, service life, heat checking, chromium plating, scaling, lubricant

MANUFACTURING PROCESSES OF SEAMLESS STEEL TUBES
The development of the steel tube was given a decisive impulse with the invention by the brothers Max and Reinhard Mannesmann of a method of
making seamless tube by cross-rolling. Their invention was patented in 1885. Shortly after this, the two brothers developed the pilger mill process. Favoured by the sudden advance in technology at the turn of the century, the seamless steel tube was able to establish itself everywhere within a short period of time.

Due to the multiplicity of applications in the course of the years further manufacturing processes of seamless steel tubes were developed, but they did not all gain great significance [1]. The most important manufacturing processes for seamless tubes are as follow:

- MPM-mill
- Continuous tube mill
- Push bench
- Assel mill
- Hot pilger mill
- Extrusion press
- Plug mill

For the first 4 processes mandrel bars are necessary as inside tools.

The basic production steps for these 4 different manufacturing processes include:

- Heating of the billet in a furnace
- Piercing of the billet to form a round shell
- Rolling the shell into a tube on a mandrel
- Finishing the tube on a sizing or stretch-reducing mill

Since at least the operations of the 4 processes are different a description of the whole process is given as an example only for the manufacturing process of a continuous tube mill in Fig. 1.

Rolled or continuously cast rounds are used as starting material. These rounds, up to 5 m in length, are heated to the rolling temperature in the rotary hearth furnace, centered, and then pierced in the rotary piercing mill. To
enable the continuous rolling mill to operate with a single starting material size and to improve the diameter tolerance of the shells, continuous tube mills are sometimes also provided with a reducing mill, which is located behind the rotary piercing mill. The shell thus produced is brought to a precise position in front of the rolling mill via roller tables. A mandrel bar is then pushed through the shell. When the mandrel bar reaches a certain position, the bar and the shell are pushed into the rolling mill, where the shell is elongated between the two-high rolls and the mandrel bar, serving as the inside tool. A continuous rolling mill usually consists of 8 two-high stands, successively at right angles to each other and very closely spaced. The final two stands do not participate in the elongating process, but loosen the shell off the mandrel bar. After leaving the mandrel mill, the tube is again heated to the requisite rolling temperature in a re-heating furnace. On leaving the furnace, the surface is descaled with pressure water. Finally, the finished tube is obtained by rolling in a stretch-reducing mill. The stretch-reduced tubes pass over a cooling bed, after which they are cut to length [1].
Table 1 presents the size ranges of seamless tubes using various manufacturing processes.

<table>
<thead>
<tr>
<th></th>
<th>Minimum tube diameter</th>
<th>Maximum tube diameter</th>
<th>Minimum wall-thickness</th>
<th>Maximum wall-thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Push bench</td>
<td>17</td>
<td>168</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>Continuous tube mill</td>
<td>21</td>
<td>168</td>
<td>2</td>
<td>25</td>
</tr>
<tr>
<td>Assel mill</td>
<td>50</td>
<td>260</td>
<td>4.1</td>
<td>12.5</td>
</tr>
<tr>
<td>MPM 6 5/8”</td>
<td>21.1</td>
<td>114.3</td>
<td>4.2</td>
<td>18.5</td>
</tr>
<tr>
<td>MPM 16 3/4”</td>
<td>359.3</td>
<td>426.3</td>
<td>4</td>
<td>50</td>
</tr>
</tbody>
</table>

The Assel Mill is suited for the manufacture of thick-walled quality tubes such as anti-friction bearing race tubes as well as turned part tubes, which are later machined to obtain high precision.

**SELECTION OF HOT-WORK TOOL STEELS FOR MANDREL BARS**

Mandrel bars are subjected to a wide variety of stresses. A balanced combination of material properties is necessary in order to achieve maximum service lives, and thus a high output per mandrel bar. The key properties in this context are high temperature wear resistance and toughness. Experience in the field and consistent further development work have shown that two main material groups are most suitable for use as mandrel bars. The first one is nickel alloyed hot-work tool steels which have generally balanced properties and offer particularly advantages in terms of their toughness. The second group is highly alloyed chromium-molybdenum hot-work tool steels which possess particularly good high-temperature wear resistance. The chemical composition of the hot-work tool steels used for mandrel bars is shown in Table 2.
### NICKEL-ALLOYED HOT-WORK TOOL STEELS

Free floating mandrels in a push bench need a good high-temperature wear resistance during the rolling process. These tools are cooled in a water tub after the rolling process in order to obtain a temperature, which is suitable for the application of the lubricant. Therefore, the other important property for the mandrel steel is a good thermal conductivity.

One set of mandrel bar consists of approximately 28 pieces. The number of mandrels required for push benches per annum is very high. Therefore the cost of the steel becomes an issue. The steel used in tub mills not only needs to fulfil the required properties but also to be cost effective. Usually the mandrel bars are supplied in the finish machined condition and they have to be scaled in order to prevent a welding with the tube material during operation. The medium alloyed hot-work steel 28NiCrMoV10 (1.2740) provides the required properties and a sufficient through-hardenability for the diameters between 100 and 165 mm.

Mandrel bars for Assel Mills are also made of 28NiCrMoV10 if the design of these tools is without a bore hole inside.

26NiCrMoV5 is a medium-alloyed hot-work steel with outstanding toughness. The primary field for application of this steel is piercers, but it is also used for mandrel bars in single cases.

### HIGH-ALLOYED HOT-WORK TOOL STEELS

X38CrMoV5-1 (1.2343) and X40CrMoV5-1 (1.2344) are hot-work tool steels for universal use. Due to a good high-temperature wear resistance and toughness the steel X38CrMoV5-1 is preferably used for mandrel bars in continuous tube mills.
A comprehensive comparison of the properties is given in Table 3.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Hot cracking resistance</th>
<th>High-temp. wear resistance</th>
<th>Toughness</th>
<th>Scale adhesion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thyrotherm 2726</td>
<td>++</td>
<td>+</td>
<td>+++</td>
<td>+</td>
</tr>
<tr>
<td>Thyrotherm 2740</td>
<td>+</td>
<td>++</td>
<td>+++</td>
<td>++</td>
</tr>
<tr>
<td>Thyrotherm 2342</td>
<td>++</td>
<td>+++</td>
<td>++</td>
<td>+++</td>
</tr>
<tr>
<td>Thyrotherm 2343</td>
<td>++</td>
<td>+++</td>
<td>+</td>
<td>+++</td>
</tr>
<tr>
<td>Thyrotherm 2344</td>
<td>++</td>
<td>++++</td>
<td>+</td>
<td>+++</td>
</tr>
</tbody>
</table>

+ to ++++ (ascending)

**BEST SUITED HOT-WORK TOOL STEEL FOR MPM-MANDREL BARS**

In a conference in Bochum 13 years ago a new hot-work tool steel for tools of big volume was introduced by Ingolf Schruff. Since then Thyrotherm 2342 has been proven to be the most suitable grade for mandrel bars used in a Multistand-Pipe-Mill process.

What was the background for this development? In high alloy steels carbide precipitations on the grain boundaries reduce toughness considerably, causing cracking and breakage. Based on the hot-work steel X40CrMoV5-1 (H 13) the basic influences of the carbide forming elements such as carbon, chromium, molybdenum and vanadium were investigated. The results led to decreased contents of these elements and thereby to the new hot-work steel which was called Thyrotherm 2342. The lower carbide content of the new grade led to only slight precipitations of carbides on the grain boundaries. The hardened and tempered structure in the transition zone of a mandrel bar having a diameter of 220 mm is shown in Fig. 2.

It shows clearly a very fine grain size (ASTM: 8 and finer) and slight precipitations of carbides on the grain boundaries. Regarding its hot tensile strength Thyrotherm 2342 is at least equivalent to steels X38CrMoV5-1 and X40CrMoV5-1. The toughness however is that much improved that it is superior to the two standard hot-work tool steels. Results of testings carried out on samples taken from mandrel bars made from Thyrotherm 2342 and
On the Application of Hot-Work Tool Steels for Mandrel Bars

Figure 2. Microstructure of hardened and tempered tools of hot-work tool steel Thyrotherm 2342, diameter: 220 mm, transition zone.

X40CrMoV5-1 with similar tensile strength of 1000 N/mm² show that the toughness of Thyrotherm 2342 is higher, Fig. 3 [2].

![Bending energy comparison](image)

**Figure 3.** Comparison of toughness of Thyrotherm 2342 and X40CrMoV5-1.

All MPM-mandrel bars which are manufactured at EWK-works are made from Thyrotherm 2342. MPM-mandrels are the most sophisticated mandrel
bars. In the finish machined and chromium plated condition one piece can have a selling price like a luxury limousine.

**SERVICE LIFE OF MANDREL BARS**

The life of a mandrel bar depends on many different factors. The first factor is selection of a suitable steel grade. With a proper heat treatment carried out by the steel manufacturer the mandrels are well equipped with the necessary mechanical properties which are usually prescribed by the customers specifications. Furthermore the surface finishing of the mandrel bars has a significant influence on the service life.

The main life limiting factor for mandrel bars is heat checking. It is caused by the cyclic temperature variations in the mandrel surface. These variations cause stresses large enough to induce plastic deformation. This plastic deformation leads to a network of fatigue cracks in the surface of the mandrel. The cracks can be seen in Fig. 4.

- Heat-checking on a mandrel bar applied in a push bench
- Notch effect due to peeling grooves

*Figure 4. Heat-Checking on a Mandrel Bar*
In addition to the heat checking, machining grooves are responsible for the deeper cracks. Machining grooves which are remains from peeling have favoured this appearance of failure. A costly re-conditioning and a waste of material is the consequence.

The steel selection for the different tube manufacturing processes is revealed in Table 4.

<table>
<thead>
<tr>
<th>Tube manufacturing process</th>
<th>Grade</th>
<th>Tensile strength [N/mm²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPM-Rolling Mill</td>
<td>Thyrotherm 2342</td>
<td>1000–1275</td>
</tr>
<tr>
<td></td>
<td>Thyrotherm 2344</td>
<td></td>
</tr>
<tr>
<td>Continuous Rolling Mill</td>
<td>Thyrotherm 2342</td>
<td>900–1275</td>
</tr>
<tr>
<td></td>
<td>Thyrotherm 2343</td>
<td></td>
</tr>
<tr>
<td>Push Bench</td>
<td>Thyrotherm 2740</td>
<td>1000–1200</td>
</tr>
<tr>
<td></td>
<td>Thyrotherm 2726</td>
<td>900–1100</td>
</tr>
<tr>
<td>Assel Mill</td>
<td>Thyrotherm 2740</td>
<td>1000–1200</td>
</tr>
</tbody>
</table>

The most suitable steel grade and a proper heat treatment is not all needed to obtain a good life of the mandrels. The mandrel bars need to be protected against welding and the material flow has to be favoured. The mandrel bars are scaled or chromium plated or scaled and reeled before the use. This surface treatments are necessary in order to prevent the mandrel bar to weld during the first 48 hours of operation which is critical. In addition to this measure the mandrel bars cannot be put into operation without a suitable lubricant which has to be applied throughout the life time of the mandrels. Quite often it is sufficient to build an intensive separating phase in order to prevent a welding. High temperature lubricants based on a mixture of phosphates with other additives form a low viscosity molten film on the surface of the mandrel bar. This film is extremely stable to weights and is mobile. It protects during the hot forming process against welding and reduces friction. A continuous co-operation between the tube mills and
the manufacturers of lubricants led to new developed lubricants adjusted to the many different requirements in a seamless tube mill. Nowadays a lot of special lubricants are available. The type of lubricant depends on the tube-rolling method.

REFERENCES
