A NEW HIGH TENSILE STEEL
WITH HIGH TOUGHNESS

E. Wulfmeier

Abstract
On the basis of a special alloying concept, the new steel Thyrodur T for cold working applications was developed. Due to its favourable property profile, the steel is suited for applications as impact and wear strained tools, excavator teeth, shock tools or shear blades. In several cases, the steel has passed its praxis test already. The suitability for plastic moulding is investigated in the moment.

The characteristic feature of the new steel is an outstanding combination of a high strength and excellent toughness connected with a good wear- and impact-resistance and a high cutting durability. In the production process, the alloying and the manufacturing techniques have to be concertededly coordinated. By alloying techniques the toughness/strength-ratio can be varied in a limited range.

The main grade with about 0.25% carbon shows a tensile strength and a yield strength above 1570 N/mm² and 1150 N/mm² on a concurrent notch impact energy of 45 J at least. The favourable property profile is guaranteed by a mainly homogeneous martensitic microstructure with evenly distributed fine carbides and up to 5% of finest stable austenite. On account of its low carbon content, the steel is weldable without problems. A small content of copper gives the steel a corrosion resistance, which lies significantly higher than on usual high tensile, wear-resistant steels.

Keywords: Cold work steel, steel for plastic moulding, high toughness/strength ratio, applications with toughness demands, wear resistance

INTRODUCTION
Within the frame of investigations on toughness-improvements of high-strength steels at Edelstahl Witten-Krefeld, a new steel was developed, which turns out to be excellent suited for cold working applications. Edelstahl
Witten-Krefeld offers the steel under the designation Thyrodur T. At the first glance this steel bears resemblance to some steels for plastic moulding as 40CrMnMo7 (1.2311) or 40CrMnNiMo8-6-4 (1.2738). Thyrodur T mainly attracts attention by a lower carbon content and the absence of molybdenum. Due to its special property profile, however, it has initially found use in cold work applications. The suitability for plastic moulding is still approved at the moment.

**COMPOSITION AND MICROSTRUCTURE**

The basic grade of Thyrodur T contains 0.25% carbon (Table 1). The main alloying elements are manganese and chromium, but the total alloying content doesn’t exceed 5%. Other specific features are little contents of niobium, titanium and copper.

<table>
<thead>
<tr>
<th>Characteristic features of the steel Thyrodur T.</th>
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<tbody>
<tr>
<td>0.25% C</td>
</tr>
<tr>
<td>MnCr - steel</td>
</tr>
<tr>
<td>+Nb +Ti +Cu</td>
</tr>
<tr>
<td>lamellar-martensitic microstructure</td>
</tr>
<tr>
<td>carbides</td>
</tr>
<tr>
<td>stable residual austenite films</td>
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</table>

In the heat treated condition the steel shows a predominantly martensitic structure, which is formed lamellar due to the low carbon content and contains very evenly distributed fine carbides. On account of the concerted adjustment of the alloying — especially the manganese/chromium ratio and the "pinch" of copper —, however, very fine austenite films go right through the martensitic basic structure contrarily to the customary steels for cold work or plastic moulding. The austenite content lies at about 5%.

Figures 1a and 1b show the microstructure of Thyrodur T in two different magnifications. On examination under the light microscope in the upper photo, the steel appears homogeneously martensitic like other heat treated steels. The austenitic parts of the structure are so fine, that they are not discernible by means of light microscopy. Only on electron optical magnification in the lower photo, it becomes visible, that light austenitic films
go through the dark martensitic zones, respectively enclose the martensite zones.

![Microstructure of the steel Thyrodur T. Examination under light microscope. Magnification: ~ 600 : 1.](image1)

**Figure 1a.** Microstructure of the steel Thyrodur T. Examination under light microscope. Magnification: ~ 600 : 1.

![Microstructure of the steel Thyrodur T. Examination under electron microscope. Magnification: ~ 75000 : 1](image2)

**Figure 1b.** Microstructure of the steel Thyrodur T. Examination under electron microscope. Magnification: ~ 75000 : 1

The alloying concept leading to this martensitic-austenitic structure is not fundamentally new and was already the matter of investigations in Great
Britain and the United States between 1980 and 1990. As on other investigations, it took some time, as well, until the potential of this material type was realised and the "sophistication" concerning the application became possible. The steel Thyrodur T, offered by Edelstahl Witten-Krefeld, bases on this structure concept and has already successfully passed the first praxis tests.

MECHANICAL PROPERTIES

Some essential characteristic features of the property profile are:

- high wear resistance
- high hardness
- excellent toughness / strength ratio (quenched+tempered condition)
- good weldability
- improved corrosion resistance
- good machinability
- good grain coarsening resistance

The most striking surely is the outstanding toughness / strength ratio in the quenched and tempered condition. The hardness, strength and wear resistance lie on a surprising high level considering the comparably low carbon content. Due to the low carbon content, the steel is unproblematical weldable. Furthermore the machinability is very satisfying.

HARDNESS, STRENGTH AND TOUGHNESS

As Thyrodur T generally is used in the heat treated condition, the tempering behaviour shall get a special emphasis at first. Figure 2 characterises the dependence of the hardness on the tempering temperature. For reasons of comparison, some curves of usual cold work steels and steels for plastic moulding are additionally shown. Due to its adjusted contents of chromium and manganese and in spite of the low carbon content, the steel Thyrodur T shows a similar tempered hardness as the higher alloyed cold work steel
X45NiCrMo4 (1.2767) or the steels for plastic moulding 40CrMnNiMo8-6-4 (1.2738) and 40CrMnMo7 (1.2311). As will be discussed later, the toughness/strength ratio of Thyrodur T can be varied in a limited range by a modification of the alloying contents. The pointed line shows, that also the grade Thyrodur T mod has a sufficient tempered hardness, which is equivalent to the steel 35NiCrMo16 (1.2766).

Figure 2. Hardness in dependence on the tempering temperature, range of quenching temperature: 860 – 950 °C, test position: 12.5 mm under surface.

The dependence of the strength values on the tempering temperature is presented in Fig. 3. Here too, Thyrodur T shows almost the same curves as the steels 40CrMnNiMo8-6-4 (1.2738) and 40CrMnMo7 (1.2311). With view to the application, however, advantages result from the use of a low tempering temperature on Thyrodur T. The usual tempering temperature lies at 200 °C and it becomes clearly visible, that the strength and hardness values in the customary heat treated condition lie on a much higher level as on comparative steels, which are tempered at about 600°C. In this condition even the grade Thyrodur T mod shows significantly higher values than comparative steels tempered on higher temperatures.

But the most important property feature becomes visible in Fig. 4. This figure presents the notch impact energy values in dependence on the tempering temperature. Certainly the Thyrodur T shows a comparably wide range of temper brittleness, however, there is a very distinct impact energy maximum at about 200 °C tempering temperature. This exceptional strong maximum
Figure 3. Strength in dependence on the tempering temperature, range of quenching temperature: 860 – 950 °C, test position: 12.5 mm under surface.

Figure 4. Notch impact energy in dependence on the tempering temperature, range of quenching temperature: 860 – 950 °C, test position: 12.5 mm under surface.

enables the steel to be adjusted to an outstanding toughness/strength ratio by controlled tempering in a low temperature range at about 200 °C. As to be seen in the figure, impact energy values of 48 - 50 J are attained on the
A New High Tensile Steel With High Toughness

standard grade. This level is twice as high as on customary cold work steels
as X 45NiCrMo4 (1.2767) or 35NiCrMo16 (1.2766). On the grade Thy-
rodur T mod, even better impact energy values at about 90 J are attainable
by a controlled modification of the alloying contents in a small range. As
illustrated above, the strength then is on a merely little bit decreased level.
The characteristic properties of the standard and the modified grade in the
customary heat treated condition are summarized in Table 2 for the size 150
mm dia.

Table 2. Steel Thyrodur T
Characteristic properties in the heat treated condition, size: 150 mm ∅, test position: 12.5
mm under surface

<table>
<thead>
<tr>
<th></th>
<th>Thyrodur T</th>
<th>Thyrodur T mod</th>
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<tbody>
<tr>
<td>Hardness</td>
<td>48–50</td>
<td>44–46 HRC</td>
</tr>
<tr>
<td>$R_m$</td>
<td>1570 MPa</td>
<td>1430 MPa</td>
</tr>
<tr>
<td>$R_{p0.2}$</td>
<td>1150 MPa</td>
<td>1030 MPa</td>
</tr>
<tr>
<td>$A_5$</td>
<td>11 %</td>
<td>12 %</td>
</tr>
<tr>
<td>$Z$</td>
<td>55 %</td>
<td>60 %</td>
</tr>
<tr>
<td>$A_V$ (Charpy-V)</td>
<td>48 J</td>
<td>90 J</td>
</tr>
</tbody>
</table>

Complementarily, Fig. 5 shows the notch impact energy values in depa-
dence on the proof temperature. Opposite the customary cold work steels,
the steel Thyrodur T has a distinct transition range and higher impact energy
values in the upper shelf. At room temperature the values lie narrowly below
the upper shelf.

HARDENABILITY

With view to the applicability of the new steel Thyrodur T, further posi-
tive aspects of the property profile become visible on an inspection of the
hardenability. The upper part of Fig. 6 compares the results from Jominy
tests on Thyrodur T and the already mentioned customary cold work steel
and the customary steel for plastic moulding. Due to the lower carbon con-
tent, the hardenability curve of Thyrodur T lies a bit lower than that one of
the steel X45NiCrMo4 (1.2767). But the through hardenability, which is
mainly depending on the chromium content in this case, is as good as on
Figure 5. Notch impact energy in dependence on the proof temperature, range of quenching temperature: 860 – 950 °C, tempered: 200 °C, test position: 12.5 mm under surface.

the comparative steel. And in comparison to the steel 40CrMnMo7 (1.2311) the through hardenability is significantly better. On top of this, advantages follow from the fact, that the hardness of Thyrodur T on tempering at the usual temperature (about 200 °C) changes next to nothing (Fig. 6, lower part). As is known, the customary steels, especially the steels tempered at about 600 °C as 40CrMnMo7 (1.2311), contrarily show decreasing hardness values after the tempering. The tempering of Thyrodur T is done for reasons of toughness and to attain homogeneous properties in the cross section. Positive results concerning consistent hardness, strength and toughness properties on the levels summarized in Table 2 have been given from the first praxis tests on bars up to sizes of about 200 mm dia. Investigations on sizes between 60 and 200 mm dia. show a slight tendency to better properties with decreasing sizes, but the upper size limit for the praxis applicability is expected above 200 mm dia. The good through hardenability together with the combination of a high strength and a remarkably toughness on static strain surely is the most striking feature of the new steel Thyrodur T. On assessing the suitability of a steel for a certain application, other properties are of importance, of course. Some of these properties are presented in the following with help of examples.
Figure 6. Hardenability, Jominy test, range of quenching temperature: 860 – 950 °C.

FATIGUE STRENGTH

Figure 7 shows the behaviour of Thyrodur T on dynamic strain. The values were determined in the rotating bending test on plain polished specimen. As expected, the high strength level results in a high fatigue strength, too. Thyrodur T shows almost the same fatigue strength than the cold working steel X45NiCrMo4 (1.2767). The endurance strength is a little bit lower than on the comparative steel.
Figure 7. Fatigue strength, rotating bending test, range of quenching temperature: 860 – 950 °C, tempered: 200 °C.

GRAIN COARSENING BEHAVIOUR

Figure 8 illustrates the grain coarsening behaviour. Even if questions of grain coarsening on the steels under review are of less importance than on hot-work tool steels, i.e., the figure shows nevertheless, that the use of some higher needed hardening temperatures is possible without causing detrimental grain coarsening effects on the properties. Furthermore, in case of carburizing the tools made of Thyrodur T, fine grains are guaranteed up to highest carburizing temperatures. With this, the steel is well suited for direct hardening too, which today is done from higher and higher temperatures for reasons of economic efficiency. The term "fine grains" means grain numbers of 5 and higher according to DIN 50601.

MACHINABILITY

Not least the machinability is an important property for a lot of applications. Investigations on the behaviour of Thyrodur T in turning, drilling and milling tests are still going on. The first results let expect a very satisfying machinability behaviour, which in spite of the higher strength seems to come close to the machinability of the steel 40CrMnMo7 (1.2311). Presumably the low carbon content and the fine austenite films (better chip breaking) have a positive effect. Further improvements should be in reach by adding sulfur.
APPLICATIONS

Below some examples for applications are presented, in which the new steel Thyrodur T already has passed its praxis test or is in test at the moment:

- impact and wear strained tools
- tools with high toughness demands
- cutting tools
- drill bits
- imprint and bending tools
- excavator blade teeths
- armors
- nitrided tools
- . . .

First of all the steel is applied for wear strained as well as tension and pressure strained tools with concurrent high demands on the toughness.
The new steel Thyrodur T is well suited for cold work applications in which the occurring temperatures don’t exceed a maximum of about 150 °C. The hardness, strength and wear resistance are on a high level, which reliably meets the demands resulting from common practical uses. Concurrent very high toughness values give the steel an outstanding property profile and make it superior to conventional cold work steels. A possible further suitability for plastic moulding is still in test. Basis of the favourable property profile is an adjusted control of the chemical composition within narrow limits. This is guaranteed by a precisely controlled manufacturing process.