Steels for Oil- and Gas-Exploration
In search of new oil and gas sources high performance steels with defined mechanical, physical and chemical properties are required.

New oil and gas fields have been identified in large depths under the sea. The tools for exploring these fields are exposed to various rock formations and aggressive media which react with the tools being used.

Depending on the ambient conditions special high strength steels with a high resistance to corrosion are required. Deutsche Edelstahlwerke possess more than 150 years of experience in the development and production of special steels and are thus ideally suited to be your partner in the supply of special steels.

This brochure provides information about the production routes for special oil tool steels and the products which we are able to deliver. Furthermore, mechanical and physical properties as well as the corrosion resistance properties of stainless grades are provided.

Our technology and experience – your guarantee for premium quality

The purity and homogeneity of our special steels stem from producing them in our modern steelworks. We fulfill our clients, predefined demands by means of precision alloying and optimized process specifications for melting, shaping and heat treating.

Our state of the art melting and combination of ingot and vertical continuous casting allow bars of various dimensions to be hot rolled or forged. Usually an optimized vertical continuous casting method is used, but for large forging sizes, ingot casting is employed.

Our combination of processing facilities are unique worldwide and allow us to produce all forms of long products required by the market.

With our electroslag and vacuum remelting facilities we are also an important player in other special steel markets, for example the aerospace industry.

Providing special steel solutions

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Finishing
Peeling and grinding machines as well as modern non-destructive testing lines, to ensure ultimate quality, are available for rolled and forged products and steel bars. Our Machining division, which is equipped with deep hole drilling, milling, turning and grinding facilities, is also capable of producing finished or semi-finished components (drive subs and drill collars).

For deep drilling of drill collars and bars up to 12 m (35 feet) length, 4 special drilling machines are available. This equipment has been specially developed in cooperation with the machine manufacturer.

In order to guarantee an improved fatigue life and better resistance to stress corrosion cracking (SCC) in operation, a new work hardening process has been developed in which two ceramic balls rotate in contact with the inner surface of the collar (roller burnishing) to produce defined residual compressive stresses.

Steel grades and applications
Based on its extensive production facilities Deutsche Edelstahlwerke is able to supply the entire portfolio of steel grades required for oil- and gas-exploration. This includes the low and high alloyed engineering steels, ferritic and martensitic as well as high alloyed austenitic and duplex stainless steels. Specialties as hot cold deformed nonmagnetic steels play a major role in the detection of new oil and gas sources.

Low alloyed steels of the types SAE/AISI 41xx and 86xx series are based on the alloying elements Cr-Mo and Cr-Ni-Mo with carbon contents between 0.25 and 0.50 %. After quenching and tempering hardness according to NACE specifications and impact toughness values (Charpy-V) at low temperatures are required.

Specific metallurgical procedures and heat treatments are necessary to obtain these properties in combination with a homogeneous fine grain microstructure. Typical applications for these grades include flanges, valves, blow out preventer feeders and manifolds. High strength engineering steels like SAE 4340 or 4330 V with yield strength levels > 1100 MPa (160 ksi) are more highly alloyed with Nickel-, Molybdenum- and Vanadiumcontents. These grades must exhibit enhanced toughness properties even at low temperatures and sometimes also in the transverse direction.
Martensitic stainless grades

Martensitic stainless grades with 13% Cr (AISI 410 and 420) are used if the corrosion resistance of the low alloyed engineering steels is not sufficient and the required strength level is similar. Details of the Specification NACE MR 0175 with a narrow tolerance of hardness and strength have to be respected. A reliable process control in all steps of production is necessary to secure these properties.

For applications like drive components (drive trains) for the drill bit within the drill string (down hole motors) precipitation hardening martensitic stainless steels with low carbon contents are used. The most common grade is the steel 17-4 PH (AISI 630) with 15-17% Cr, 5% Ni and 3% Cu. Since components of this grade also have to comply with the NACE specification, only the condition DH 1150 is allowed (approved). In addition to an excellent combination of strength and toughness, the pitting resistance of these steels is also good.

Austenitic stainless grades

Environmental media are often contaminated with aggressive chloride ions and since austenitic steels are susceptible to stress corrosion cracking (SCC) these grades are rarely used.

Duplex- and super duplex steels

Duplex and super duplex stainless steels, like F 51 and F 55 (1.4462/1.4501), are specified for applications where best corrosion resistance is required. These grades combine the advantages of ferritic and austenitic steels thus providing high strength, improved fatigue and corrosion resistance and better resistance to SCC.

Requirements for non mag steels:

- High strength > 900 MPa (130 ksi)
- High corrosion resistance to aggressive media (high Chloride concentration)
- Low magnetic permeability without any “hot spots”.

In oil and gas field applications, particular emphasis is placed on nonmagnetic steels (non mags). These steels rely upon the combination of high chromium, manganese and nitrogen contents in addition to small amounts of nickel to ensure a stable austenitic microstructure. These non mags can be work hardened to increase yield and tensile strength corresponding to the requirements of the API 7.

A homogeneous austenitic microstructure is the precondition to guarantee the specified magnetic permeability of $\mu_r < 1,01$.

Since no magnetic inclusion or local ferritic microstructure is allowed within the material, a particular clean steel production and stringent temperature control in the subsequent hot forming process is necessary. Non mag steels are used to house the extremely sensitive measuring instruments contained near the drill bit. MWDs (Measuring While Drilling) use the magnetic field of the earth to determine the precise position of the drilling tools and then control the direction of drilling, while LWDs (Logging While Drilling) gather information about the geological formation being drilled. Typical tools are MWDs (Measuring while drilling) and LWDs (Logging while drilling).

Depending on their application, low and high strength steels are specified. For simple drill collars, heavy weights, flex collars and stabilizers with a low strength level according to API 7 the non mag grade Magnadur 501 can be used.

For more demanding applications like MWDs with increased strength and corrosion resistance we recommend the use of the superior grade Magnadur 601. Beside the higher strength (> 150 ksi) which is obtained by a higher nitrogen content and work hardening, the resistance to corrosion is also superior.

Since the corrosion resistance of these non mag grades decreases slightly with increasing strength (work hardening), it is possible to improve the corrosion properties even further by specifying a lower strength Magnadur 601 variant. This lower strength grade is also available upon request.
Corrosion properties

In oil and gas field applications, the materials used are always subjected to corrosive conditions of varying severity. In fact the dwindling reserves are forcing exploration in ever increasingly harsh environments which are sour and/or contain high levels of chlorides. In addition to this, the combination of materials used and the high strengths which are required lead to a host of different forms of corrosion which have to be avoided. Some of the most common forms of corrosion which are encountered include:

Pitting corrosion resistance

This form of corrosion occurs when the protective passive film on stainless steels is locally damaged, allowing the corrosive environment to come into contact with the unprotected surface of the metal. The passive film is capable of regenerating itself, provided that oxygen is present in the environment, but in the presence of high concentrations of chloride ions, it is possible that the rate of destruction of the passive film is faster than the regeneration and this then results in localised corrosion or pitting. Once pits have formed, they continue to grow at an ever increasing rate until in extreme cases the metal is perforated.

The resistance of an alloy to this, unfortunately common, form of corrosion can be estimated empirically by using the so-called pitting resistance equivalent number or PREN. PREN = %Cr + 3,3 x %Mo + 16 x %N.

Further differentiation is given by the Critical Pitting Temperature (CPT) which is determined by following the ASTM G61 and G150.

Galvanic corrosion

It is almost impossible to avoid this type of corrosion which arises due to potential differences which arise when two dissimilar metals are placed in contact with one another in an electrolyte (corrosive environment). This essentially results in the formation of a battery in which one of the metals, the less noble, corrodes preferentially to protect the more noble metal. This form of corrosion can be reduced by ensuring that the potential difference between two contacted metals is as small as possible and by insulating the metals so that they are not in electrical contact with one another. Tests to determine the susceptibility of metals to this form of corrosion include visual examination after immersion in an electrolyte (140,000 ppm chloride, 71°C, 14 days).

Stress corrosion cracking (SCC)

This form of corrosion arises when a susceptible material is placed in a chloride or other halide containing environment and then subjected to tensile stresses. These stresses can either be residual or applied. The removal of any one of these conditions result in the avoidance of SCC. From this we can see that the residual and applied stresses must be kept as low as possible or that steps are taken to ensure that only compressive stresses are present. The latter requirement is the reason for the pursuitful deformation of the inner surface of the hollow bars to produce high compressive residual stresses. High nickel contents are also known to promote stress corrosion cracking and it is for this reason that high grade non mags are not alloyed with Ni.

Intergranular corrosion

Although this form of corrosion is readily avoidable by accurate control of the chemical analysis and by performing adequate heat treatment, many customers require proof that the steels supplied are free from intergranular corrosion (IGC). The most common tests to determine freedom from IGC are performed according to ASTM A 262, Practice A and E.
### AISI 4330V mod/1.6562, Firmodur 6562

<table>
<thead>
<tr>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
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<td>0,70</td>
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<td></td>
</tr>
<tr>
<td>Max</td>
<td>0,35</td>
<td>0,40</td>
<td>1,00</td>
<td>0,015</td>
<td>0,010</td>
<td>1,10</td>
<td>0,50</td>
<td>1,60</td>
</tr>
</tbody>
</table>

Diameter OD range: 80 – 250 mm/3 1/8 – 9 1/2 inches

0.2 % Offset-yield strength $R_{p0.2}$ in MPa (ksi): 1035 – 1210 (150 – 175)

Tensile strength $R_m$ in MPa (ksi): 1105 – 1290 (160 – 185)

Elongation $L_0 = 4d$ (A4) in %: ≥ 15

Reduction of area (2) in %: ≥ 45

Impact toughness (Charpy-V at 23°C) in J: ≥ 60

Impact toughness (Charpy-V at -40°C) in J: ≥ 27

Hardness in BHN: 340 – 400

Ultrasonic soundness: ASTM A 388, API 6A PSL 3 or 4

Specimens taken 31.8 mm (1 1/4 inch) below surface in longitudinal direction.

### AISI 4340/1.6595, Firmodur 6595

<table>
<thead>
<tr>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
<th>V</th>
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<tbody>
<tr>
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<td></td>
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<tr>
<td>Max</td>
<td>0,43</td>
<td>0,40</td>
<td>1,00</td>
<td>0,020</td>
<td>0,015</td>
<td>1,00</td>
<td>0,30</td>
<td>1,50</td>
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</table>

Diameter OD range: 80 – 250 mm/3 1/8 – 9 1/2 inches

0.2 % Offset-yield strength $R_{p0.2}$ in MPa (ksi): 1000 – 1150 (145 – 167)

Tensile strength $R_m$ in MPa (ksi): 1100 – 1250 (160 – 185)

Elongation $L_0 = 4d$ (A4) in %: ≥ 15

Reduction of area (2) in %: ≥ 45

Impact toughness (Charpy-V at 23°C) in J: ≥ 60

Impact toughness (Charpy-V at -40°C) in J: ≥ 27

Hardness in BHN: 320 – 380

Ultrasonic soundness: ASTM A 388, API 6A PSL 3 or 4

Specimens taken 25.4 mm (1 inch) below surface in longitudinal direction.

### AISI 8630/8630 mod/1.6591 (API 6A/ NACE MR 01.75), Firmodur 6591

<table>
<thead>
<tr>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
<th>V</th>
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<tbody>
<tr>
<td>Min</td>
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<tr>
<td>Max</td>
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<td>0,005</td>
<td>0,005</td>
<td>1,50</td>
<td>0,66</td>
<td>1,00</td>
</tr>
</tbody>
</table>

Mechanical properties in quenched and tempered condition

0.2 % Offset-yield strength $R_{p0.2}$ in MPa (ksi): ≥ 517 (75)

Tensile strength $R_m$ in MPa (ksi): ≥ 655 (95)

Elongation $L_0 = 4d$ (A4) in %: ≥ 18

Reduction of area (2) in %: ≥ 35

Impact toughness (Charpy-V at 23°C) in J (ft-lbs): ≥ 80 (59)

Impact toughness (Charpy-V at -60°C) in J (ft-lbs): ≥ 27 (20)

Hardness in BHN (HRC): 207 – 234 (10 – 22)

Ultrasonic soundness: ASTM A 388, API 6A PSL 3 or 4

Specimens taken 31.8 mm (1 1/4 inch) below surface in longitudinal direction.
### Stainless steels

**AIISI 410 (API 6A), Corrodur 4006**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Dimension in mm (inch)</th>
<th>QT650</th>
<th>QT650</th>
<th>QT (NACE)</th>
</tr>
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<tbody>
<tr>
<td>Min</td>
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<tr>
<td>Max</td>
<td>0,15</td>
<td>1,00</td>
<td>1,50</td>
<td>0,040</td>
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</table>

Mechanical properties in QT condition according to DIN EN 10088-3 or QT condition according NACE MR0175

<table>
<thead>
<tr>
<th>Condition</th>
<th>Dimension in mm (inch)</th>
<th>QT700</th>
<th>QT800</th>
<th>QT (NACE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Max</td>
<td>0,25</td>
<td>1,00</td>
<td>1,50</td>
<td>0,040</td>
</tr>
</tbody>
</table>

### 17-4 PH – AISI 630, Corrodur 4542

<table>
<thead>
<tr>
<th>Condition</th>
<th>Dimension in mm (inch)</th>
<th>H900</th>
<th>H925</th>
<th>H1025</th>
<th>H1075</th>
<th>H1100</th>
<th>H1150</th>
<th>H1150D</th>
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<tr>
<td>Min</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>15,0</td>
<td>-</td>
<td>-</td>
<td>5,0</td>
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<tr>
<td>Max</td>
<td>0,07</td>
<td>0,50</td>
<td>1,50</td>
<td>0,030</td>
<td>0,030</td>
<td>17,0</td>
<td>0,60</td>
<td>5,0</td>
</tr>
</tbody>
</table>

Mechanical properties after age hardening heat treatment according to ASTM A564/ASGAM

#### Surface condition
- **Pealed**

#### Straightness
- Max. 2,0 mm per meter (0,07 per ft), 1,0 mm per meter (0,03 per ft) upon request

#### Availability
- Hot-rolled + Pealed: round 20 – 200 mm (0.79 – 7.87"")
- Forged + Pealed: round 150 – 520 mm (5.91 – 20.47"")
  
- [1.4542/Type 630 up to 350 mm (13.78"")]

### AISI 420, Corrodur 4021

<table>
<thead>
<tr>
<th>Condition</th>
<th>Dimension in mm (inch)</th>
<th>QT700</th>
<th>QT800</th>
<th>QT (NACE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>0,16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max</td>
<td>0,25</td>
<td>1,00</td>
<td>1,50</td>
<td>0,040</td>
</tr>
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</table>

Mechanical properties in QT condition according to DIN EN 10088-3 or QT condition according NACE MR0175

<table>
<thead>
<tr>
<th>Condition</th>
<th>Dimension in mm (inch)</th>
<th>QT700</th>
<th>QT800</th>
<th>QT (NACE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>0,16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max</td>
<td>0,25</td>
<td>1,00</td>
<td>1,50</td>
<td>0,040</td>
</tr>
</tbody>
</table>

### Corrodur 4006 – AISI 410 (API 6A)

<table>
<thead>
<tr>
<th>Corrodur 4006 – AISI 410</th>
<th>Corrodur 4021 – AISI 420</th>
<th>Corrodur 4542 – 17-4 PH – AISI 630</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface condition</td>
<td>Pealed</td>
<td>Hot-rolled + Pealed: round 20 – 200 mm (0.79 – 7.87&quot;&quot;)</td>
</tr>
</tbody>
</table>

### Ultrasonic soundness
- ASTM A 388, API 6A PSL 3 or 4

### Notes
- Specimens taken 12,5 mm (1/2 inch) below surface in longitudinal direction.
- Specimens taken midradius in longitudinal direction.
Quality Assurance
All products meet API7 specified properties and conditions as a minimum standard. Furthermore, Deutsche Edelstahlwerke are certified and approved by independent authorities and significant customers of the oil tool industry.

All over the world
Deutsche Edelstahlwerke are part of the SCHMOLZ + BICKENBACH group which operates all over the world. The distribution companies are present in all important regions.

The unique corporate concept with its three pillars of production, processing and distribution and service qualify us as solution provider and technology driver – and above all as a reliable and quality-conscious partner to our customers worldwide.

As a single-source provider of solutions, know-how and service for steel, we want to constantly further expand and strengthen our global position. The SCHMOLZ + BICKENBACH distribution companies help us to be close to our customers – all over the world.

Please do not hesitate to contact our competent sales and technical team should you require any additional information or assistance: oiltool@dew-stahl.com

Environmental Management System – ISO 14001:2004
Aircraft material approval – Nadcap (AC 7102)

Providing special steel solutions
Sales Network SCHMOLZ + BICKENBACH
Production, processing, distribution and services

Non-Magnetic Steel Grades

### Magnadur 501

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
<th>N</th>
<th>PREN</th>
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<tbody>
<tr>
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<td>0.03</td>
<td>0.005</td>
<td>13.0</td>
<td>0.36</td>
<td>0.32</td>
<td>0.40</td>
<td>15</td>
</tr>
<tr>
<td>Max</td>
<td>0.04</td>
<td>0.60</td>
<td>22.0</td>
<td>0.03</td>
<td>0.005</td>
<td>15.0</td>
<td>0.50</td>
<td>0.50</td>
<td>0.40</td>
<td>23</td>
</tr>
</tbody>
</table>

Mechanical properties in the forged and strain-hardened condition:
- Diameter in mm (inch): 80 – 175 (3 1/2 – 6 7/8"
- Tensile strength Rm in MPa (ksi): 930 (135), 770 (112)
- Elongation LA = 4 (A) in %: 25
- Reduction of area (2) in %: 50
- Impact toughness (Charpy-V at 25° C) in J (ft-lbs): 150 (100)
- Hardness in BHN: min. 277
- Ultrasonic soundness: ASTM A 388, API 6A PSL 3 or 4

Specimens taken 25.4 mm (1 inch) below surface in longitudinal direction.

### Magnadur 601 HS/LS

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
<th>N</th>
<th>PREN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>0.05</td>
<td>0.30</td>
<td>20.0</td>
<td>0.03</td>
<td>0.005</td>
<td>17.5</td>
<td>2.8</td>
<td>5.0</td>
<td>0.50</td>
<td>35</td>
</tr>
<tr>
<td>Max</td>
<td>0.05</td>
<td>0.60</td>
<td>22.0</td>
<td>0.03</td>
<td>0.005</td>
<td>18.0</td>
<td>2.8</td>
<td>5.0</td>
<td>0.50</td>
<td>35</td>
</tr>
</tbody>
</table>

Mechanical properties in forged and strain-hardened condition:
- Diameter in mm (inch): 80 – 241.3 (3 1/2 – 9 1/4"
- Tensile strength Rm in MPa (ksi): 965 (140), 900 (130)
- Elongation LA = 4 (A) in %: 20
- Reduction of area (2) in %: 50
- Impact toughness (Charpy-V at 25° C) in J (ft-lbs): 100 (74)
- Hardness in BHN: min. 290
- Ultrasonic soundness: ASTM A 388, API 6A PSL 3 or 4

Specimens taken 25.4 mm (1 inch) below surface in longitudinal direction.

**Non-Magnetic Steel Grades**

<table>
<thead>
<tr>
<th>Magnadur 501</th>
<th>Magnadur 601</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approvals</td>
<td>Schlumberger, Halliburton, Baker Hughes, Schlumberger, Halliburton</td>
</tr>
<tr>
<td>Surface condition</td>
<td>polished</td>
</tr>
<tr>
<td>Straightness</td>
<td>max. 2.0 mm per meter (1/16&quot; per 5 ft), 0.5 mm per meter (1/64&quot; per 5 ft) upon request</td>
</tr>
<tr>
<td>Availability</td>
<td>solution annealed or forged and strain-hardened, round 80 – 250 mm (3 1/2 – 9 3/4&quot;)</td>
</tr>
</tbody>
</table>

### Specimens taken 25.4 mm (1 inch) below surface in longitudinal direction.

### Quality Assurance

All products meet API7 specified properties and conditions as a minimum standard. Furthermore, Deutsche Edelstahlwerke are certified and approved by independent authorities and significant customers of the oil tool industry.

All over the world
Deutsche Edelstahlwerke are part of the SCHMOLZ + BICKENBACH group which operates all over the world. The distribution companies are present in all important regions.

The unique corporate concept with its three pillars of production, processing and distribution and service qualify us as solution provider and technology driver – and above all as a reliable and quality-conscious partner to our customers worldwide.

As a single-source provider of solutions, know-how and service for steel, we want to constantly further expand and strengthen our global position. The SCHMOLZ + BICKENBACH distribution companies help us to be close to our customers – all over the world.

Please do not hesitate to contact our competent sales and technical team should you require any additional information or assistance: oiltool@dew-stahl.com
General note (liability)

All statements regarding the properties or utilisation of the materials or products mentioned are for the purposes of description, only. Guarantees regarding the existance of certain properties or a certain utilisation are only valid if agreed upon in writing.