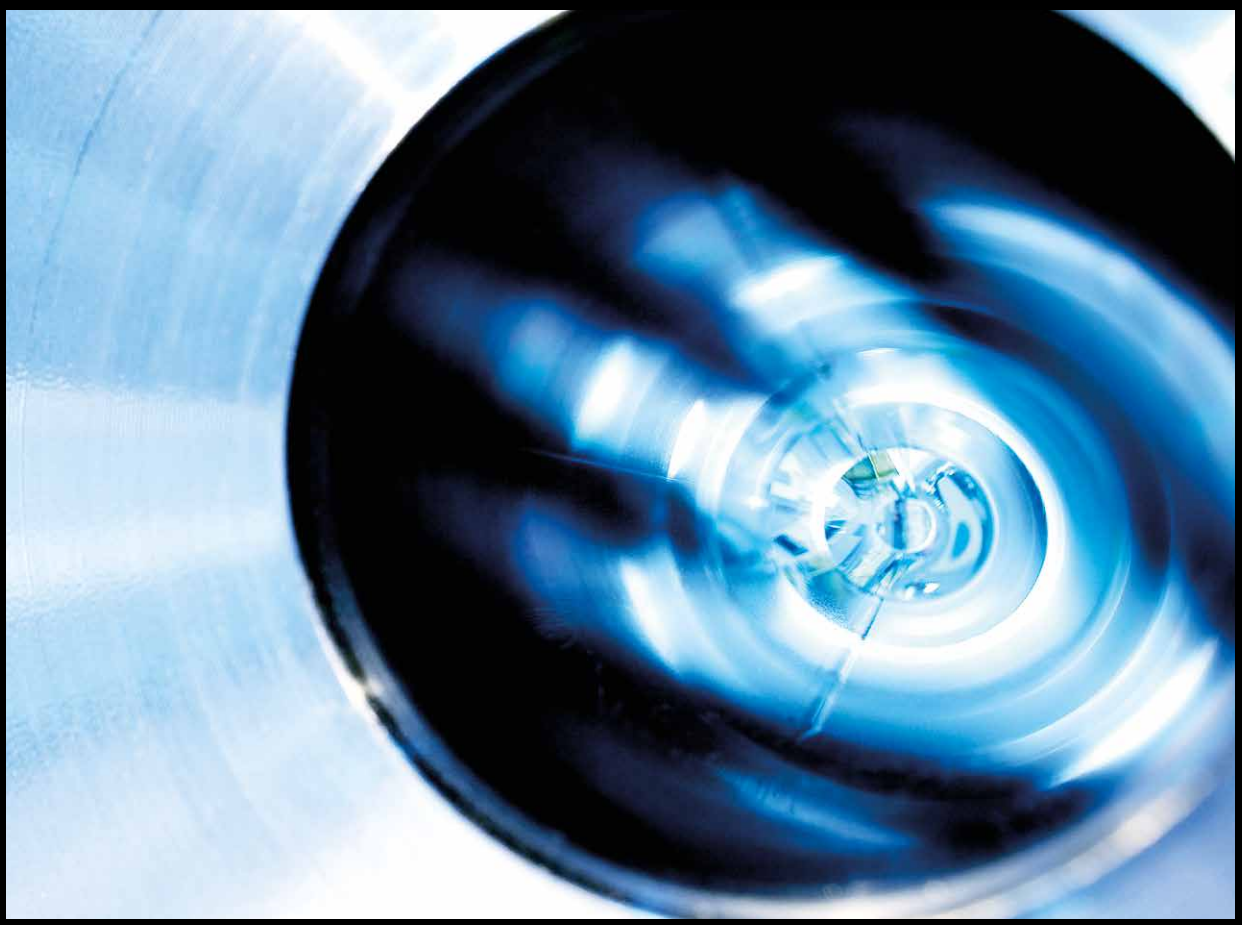
Magnadur®

Non-magnetic stainless steels



Deutsche Edelstahlwerke

Our technology and expertise in oil and gas field applications

The technology in oil and gas exploration is continuously developing. Using directional drilling, new oil and gas deposits - up to depths of 5 km and distances of 10 km away from the rig - can be tapped. This has the advantage that different deposits can be reached with only one rig.

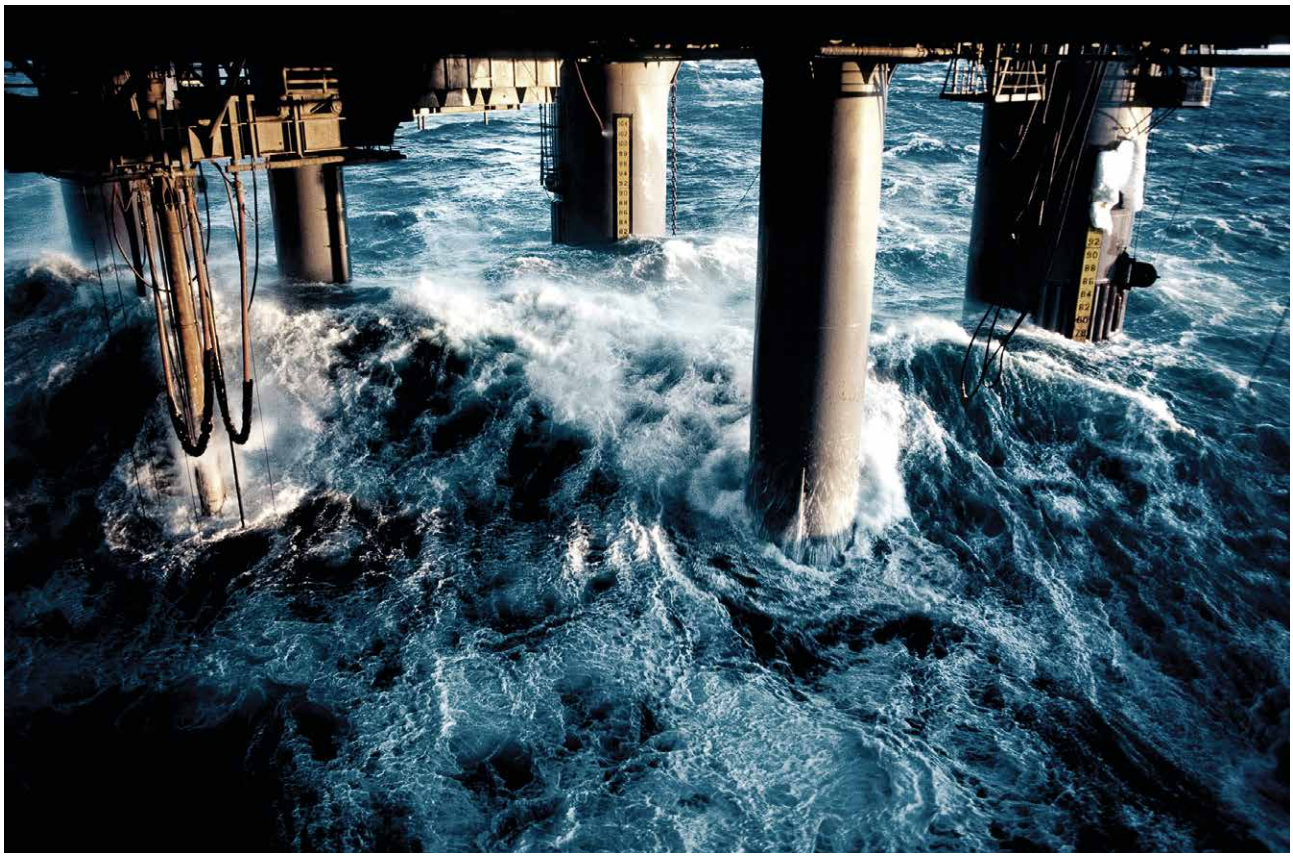
With the help of extremely sensitive measurement tools near the drill bit, the current position of the drill bit can be determined. These measuring tools can be distinguished into two methods:
– MWD (Measuring While Drilling)
– LWD (Logging While Drilling)

MWDs use the earth's magnetic field to define the three-dimensional position of the drilling tool as well as the drilling direction, whereas LWDs determine information about the geological structure of the formation.

The exploration of deposits located deep below seabed requires steels with excellent corrosion resistance and strength, especially for drill string components e.g. drill collars, internals and connections.

The non-magnetic stainless steels (non-mags) produced by Deutsche Edelstahlwerke are called Magnadur® which fulfill the increasing requirements of the oil and gas industry. Due to their special properties, such as high corrosion resistance against aggressive media, high strength and low relative magnetic permeability, these stainless steels are the best choice for components of MWDs and LWDs as well as drill collars.

Furthermore, using Magnadur®, the earth's magnetic field remains unaffected, allowing thus the highly sensitive measurement methods to deliver highly accurate results.



Magnadur®

High performance non-magnetic steels with defined mechanical, physical and chemical properties.

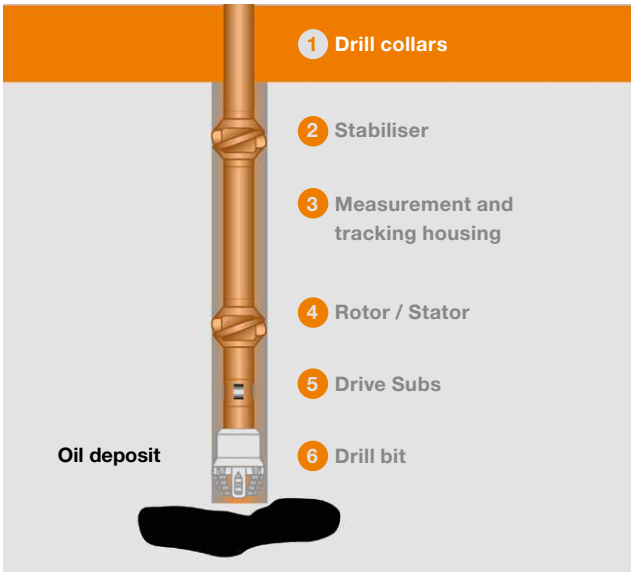
The non-magnetic stainless steels of the Magnadur® series are based upon a combination of high chromium, manganese, molybdenum and nitrogen content plus small amounts of nickel to ensure a stable austenitic microstructure. A homogeneous austenitic microstructure is the precondition to provide a specific magnetic permeability of $\mu_r < 1.01$. All our Magnadur® grades pass through special metallurgical processes, selective temperature control throughout the whole production as well as a demanding cold-working process.

Depending on existing stresses and application in the oil and gas exploration, Deutsche Edelstahlwerke supplies the non-magnetic stainless steel grades:
– Magnadur® 501
– Magnadur® 509
– Magnadur® 601

Magnadur® 501 can be used for drill collars, heavy weight drill collars, flex collars and stabilizers with low requirements on strength as per API 7-1.

Magnadur® 601 is recommended for application requiring a combination of highest corrosion resistance and high strength (UTS >= 150 ksi), e.g. housings of MWDs or MWDs/LWDs. These enhanced properties are among others the result of a higher nitrogen content and increased work-hardening ability.

Through specific and application-oriented development Deutsche Edelstahlwerke has expanded its portfolio of non-magnetic stainless steels with Magnadur® 509, which offers a compromise between Magnadur® 501 and Magnadur® 601. Due to a richer chemistry compared to Magnadur® 501, Magnadur® 509 performs better in more aggressive media. With the same strength level as Magnadur® 601, Magnadur® 509 achieves resistance to several types of corrosion comparable to Magnadur® 601. However, Magnadur® 601 exhibits superior resistance against stress corrosion cracking (SCC).



Construction of Drilling tools in the Oil and Gas Exploration

1. Drill collars
Thick-walled pipes to put pressure on the drill bit
– SAE 4145
– Magnadur® 501 / Magnadur® 509 / (Magnadur® 601)

2. Stabilizer
Stabilizing the thinner drill string within the hole
– Magnadur® 501

3. Measurement and tracking housing
MWD/LWD technology
– Magnadur® 509 / Magnadur® 601

4. Rotor / Stator
Downhole motor of the drill head
– Hard chromium coated AISI 630 / engineering steel tube with rubber inlet

5. Drive Subs
Coupling between the drill bit and drive motor
– Engineering and stainless steel grades

6. Drill bit
– Tungsten carbide coated engineering steels

Magnadur® 501

	Chemical composition in %								
	C	Si	Mn	P	S	Cr	Ni	Mo	N
Min	-	0.30	18.5	-	-	13.0	0.25	0.35	0.32
Max	0.04	0.60	22.0	0.03	0.005	15.0	0.50	0.50	0.40

Customer specific limitations of standard analysis are possible after consultation with Deutsche Edelstahlwerke.

Standards and designations

Magnadur® 501 is a non-standard special steel developed by Deutsche Edelstahlwerke.

Special Properties

Non-magnetic alloy $\mu_r < 1.01$ in combination with high strength and high corrosion resistance.

Corrosion Resistance (PREN[1] = 19 - 23)

Magnadur® 501 has a high resistance against intergranular corrosion (IGC) according to ASTM A 262 practice A and E and possesses a good resistance against stress corrosion cracking (SCC) especially when a suitable surface treatment like shot or hammer peening is applied. The pitting corrosion resistance is suitable for standard drill collar applications.

[1]PREN: Pitting resistance equivalent number %Cr + 3.3x %Mo + 16x %N

Physical properties

Density in kg/dm³ at 20 °C *(in lb/in³ at 68 °F)*	7.8 *(0.282)*
Young's modulus in GPa at 20 °C *(in ksi at 68 °F)*	195 *(28.3 x 10³)*
Thermal conductivity in W/(m K) at 20 °C *(in BTU in/(h ft² °F) at 68 °F)*	14.0 *(97.16)*
Thermal expansion coefficient in 10^{-6} K^{-1} *(in 10^{-6} F^{-1})*	
20 °C – 100 °C *(68 °F - 212 °F)*	16.5 *(9.17)*
20 °C – 200 °C *(68 °F - 392 °F)*	17.6 *(9.78)*
20 °C – 300 °C *(68 °F - 572 °F)*	18.5 *(10.28)*
Specific heat capacity in kJ/(kg K) at 20 °C *(in BTU/(lb °F) at 68 °F)*	0.50 *(0.119)*

Mechanical properties in forged and strain-hardened condition at room temperature[1]

Ø in mm *(in)*	50 - 175 *(2 - 6 7/8)*	176 - 279.4 *(7 - 11)*
Hardness in BHN	≥ 275	≥ 275
$R_{p0.2}$ in MPa *(ksi)*	≥ 825 *(120)*	≥ 770 *(112)*
R_m in MPa *(ksi)*	≥ 930 *(135)*	≥ 900 *(130)*
$A_{2"}$ in %	≥ 25	≥ 25
Z in %	≥ 50	≥ 50
AV in J *(ft-lbs)*	≥ 135 *(100)*	≥ 135 *(100)*
Fatigue strength[2] in MPa *(ksi)*	≥ 350 *(50)*	≥ 350 *(50)*

[1] All specimens are taken one inch below surface in longitudinal direction according to API standard.
[2] Rotating bending @ 10^7 cycles

Magnadur® 509

	Chemical composition in %								
	C	Si	Mn	P	S	Cr	Ni	Mo	N
Min	-	-	18.0	-	-	17.0	2.50	0.90	0.50
Max	0.05	0.30	20.0	0.03	0.005	19.0	3.50	1.20	0.60

Customer specific limitations of standard analysis are possible after consultation with Deutsche Edelstahlwerke.

Standards and designations

Magnadur® 509 is a non-standard special steel developed by Deutsche Edelstahlwerke.

Special Properties

Non-magnetic steel grade $\mu_r < 1.01$ in combination with high strength and high corrosion resistance.

Corrosion Resistance (PREN[1] = 28 - 33)

Magnadur® 509 has an excellent resistance against IGC according to ASTM A 262 practice A and E and withstands SCC to a certain extent. A surface treatment also improves SCC resistance. With regard to pitting corrosion Magnadur® 509 shows excellent behaviour. The critical pitting corrosion potential is higher than the potential of Magnadur® 501 and close to that of Magnadur® 601.

[1]PREN: Pitting resistance equivalent number %Cr + 3.3x %Mo + 16x %N

Physical properties

Density in kg/dm³ *(in lb/in³)*	
at 20 °C *(68 °F)*	7.68 *(0.277)*
at 100 °C *(212 °F)*	7.65 *(0.276)*
at 200 °C *(392 °F)*	7.60 *(0.275)*
at 300 °C *(572 °F)*	7.56 *(0.273)*
Young's modulus in GPa at 20 °C *(in ksi at 68 °F)*	196.5 *(28.5 x 10³)*
Thermal conductivity in W/(m K) *(in BTU in/(h ft² °F))*	
at 20 °C *(68 °F)*	12.7 *(88.14)*
at 100 °C *(212 °F)*	14.2 *(98.55)*
at 200 °C *(392 °F)*	15.8 *(109.65)*
at 300 °C *(572 °F)*	17.0 *(117.98)*
Thermal expansion coefficient in 10^{-6} K^{-1} *(in 10^{-6} F^{-1})*	
20 °C – 100 °C *(68 °F - 212 °F)*	16.5 *(9.17)*
20 °C – 200 °C *(68 °F - 392 °F)*	17.5 *(9.72)*
20 °C – 300 °C *(68 °F - 572 °F)*	18.6 *(10.33)*
Specific heat capacity in kJ/(kg K) *(in BTU/(lb °F))*	
at 20 °C *(68 °F)*	0.48 *(0.115)*
at 100 °C *(212 °F)*	0.59 *(0.141)*
at 200 °C *(392 °F)*	0.54 *(0.129)*
at 300 °C *(572 °F)*	0.57 *(0.136)*

Mechanical properties in forged and strain-hardened condition at room temperature[1]

Ø in mm *(in)*	75 - 235 *(3 - 9 1/4)*	> 235 - 250 *(9 1/4 - 9 3/4)*
Hardness in BHN	300 - 400	300 - 400
$R_{p0.2}$ in MPa *(ksi)*	≥ 965 *(140)*	≥ 900 *(130)*
R_m in MPa *(ksi)*	≥ 1035 *(150)*	≥ 1035 *(150)*
$A_{2"}$ in %	≥ 20	≥ 20
Z in %	≥ 50	≥ 50
AV in J *(ft-lbs)*	≥ 135 *(100)*	≥ 135 *(100)*
Fatigue strength[2] in MPa *(ksi)*	≥ 445 *(65)*	≥ 445 *(65)*

[1] All specimens are taken one inch below surface in longitudinal direction according to API standard.
[2] Rotating bending @ 10^7 cycles

Magnadur® 601

	Chemical composition in %								
	C	Si	Mn	P	S	Cr	Ni	Mo	N
Min	-	-	18.0	-	-	15.5	4.20	2.00	0.40
Max	0.05	0.30	20.0	0.03	0.005	17.5	5.00	2.80	0.50

Customer specific limitations of standard analysis are possible after consultation with Deutsche Edelstahlwerke.

Standards and designations

Magnadur® 601 is a non-standard special steel developed by Deutsche Edelstahlwerke.

Special Properties

Non-magnetic steel grade $\mu_r < 1.01$ in combination with high strength and high corrosion resistance.

Corrosion Resistance (PREN[1] = 29.5 - 35)

Magnadur® 601 shows excellent resistance to SCC as long as the operational tensile stresses remain below 50% of applied yield strength. The pitting corrosion potential is far better than that of Magnadur® 501. Although the PREN values of Magnadur® 509 and 601 are in the same approximate range, Magnadur® 601 is performing better with regard to pitting corrosion due to higher molybdenum content.

[1]PREN: Pitting resistance equivalent number %Cr + 3.3x %Mo + 16x %N

Physical properties

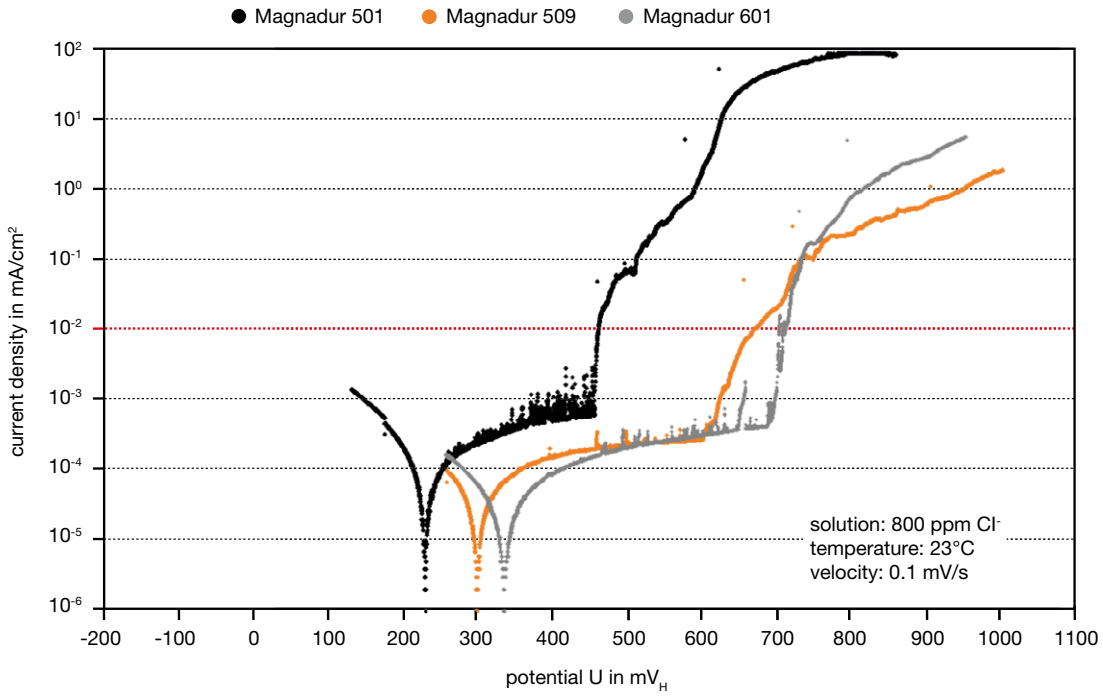
Density in kg/dm³ at 20 °C *(in lb/in³ at 68 °F)*	7.79 *(0.281)*
Young's modulus in GPa at 20 °C *(in ksi at 68 °F)*	196.5 *(28.5 x 10³)*
Thermal conductivity in W/(m K) *(in BTU in/(h ft² °F))*	
at 20 °C *(68 °F)*	12.8 *(88.83)*
at 100 °C *(212 °F)*	14.6 *(101.32)*
at 200 °C *(392 °F)*	16.3 *(113.12)*
at 300 °C *(572 °F)*	17.3 *(120.06)*
Thermal expansion coefficient in 10^{-6} K^{-1} *(in 10^{-6} F^{-1})*	
20 °C – 100 °C *(68 °F - 212 °F)*	14.6 *(8.11)*
20 °C – 200 °C *(68 °F - 392 °F)*	16.3 *(9.06)*
20 °C – 300 °C *(68 °F - 572 °F)*	17.3 *(9.61)*
Specific heat capacity in kJ/(kg K) *(in BTU/(lb °F))*	
at 20 °C *(68 °F)*	0.47 *(0.112)*
at 100 °C *(212 °F)*	0.51 *(0.122)*
at 200 °C *(392 °F)*	0.53 *(0.127)*
at 300 °C *(572 °F)*	0.55 *(0.131)*

Mechanical properties in forged and strain-hardened condition at room temperature[1]

Ø in mm *(in)*	75 - 235 *(3 - 9 1/4)*	> 235 - 250 *(9 1/4 - 9 3/4)*
Hardness in BHN	300 - 400	300 - 400
$R_{p0.2}$ in MPa *(ksi)*	≥ 965 *(140)*	≥ 900 *(130)*
R_m in MPa *(ksi)*	≥ 1035 *(150)*	≥ 1035 *(150)*
$A_{2"}$ in %	≥ 20	≥ 20
Z in %	≥ 50	≥ 50
AV in J *(ft-lbs)*	≥ 135 *(100)*	≥ 135 *(100)*
Fatigue strength[2] in MPa *(ksi)*	≥ 445 *(65)*	≥ 445 *(65)*

[1] All specimens are taken one inch below surface in longitudinal direction according to API standard.
[2] Rotating bending @ 10^7 cycles

Current density – potential curve of Magnadur® steel grades



Delivery forms and dimensions

Conditions of supply

Magnadur®	Form of delivery	Diameter in mm	Diameter in in
501	Forged bars, strain-hardened, peeled / machined, solid or bored with common API IDs	50 - 250	2 - 9 $^{3}/_{4}$
509	Forged bars, strain-hardened, peeled / machined, solid or bored with common API IDs	75 - 250	3 - 9 $^{3}/_{4}$
601	Forged bars, strain-hardened, peeled / machined, solid or bored with common API IDs	75 - 250	3 - 9 $^{3}/_{4}$

Typically Magnadur® are used in strain-hardened condition. Through a controlled forging process on a rotary forging machine a uniform strain distribution over the entire circumference is achieved. Due to a rapid quenching after the pre-forging process the Magnadur® steels are practically free of undesired precipitations. This has an extremely positive effect on different types of corrosion.

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