Steel

perdur®

Notes on use and processing

thyssenkrupp

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Introduction

With perdur® 400 and perdur® 450, we offer you a versatile range of strip plates that combine wear resistance with excellent workability. The special feature is the guaranteed toughness combined with all the advantages of thyssenkrupp cut-to-length sheets. Our perdur® cut-to-length sheets are available in thicknesses ranging from 4.00 mm to 8.00 mm and, thanks to their very narrow thickness tolerances, offer both weight savings and advantages in terms of cold forming.

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Cold forming

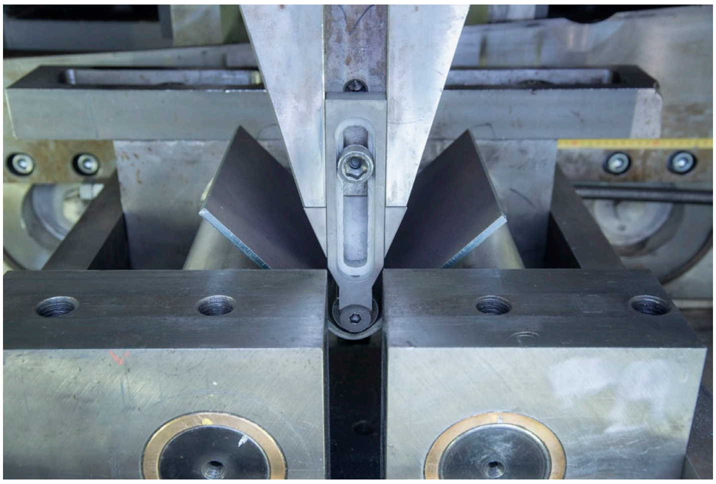


Figure 1: Bending device with support rollers.

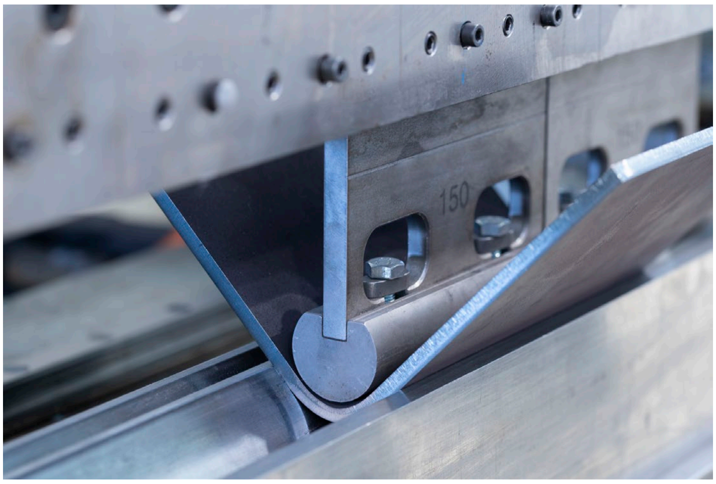
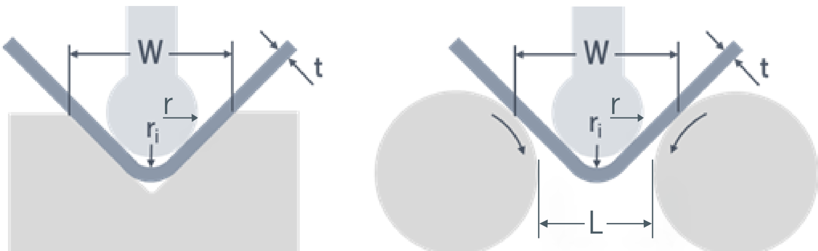


Figure 2: Press brake with 90° V-shaped die.

Cold forming, e.g. by folding or bending on presses and rolls, is a widely used process, and is also employed for wear-resistant special structural steels. The predominant forming process is free bending or folding in a 90° V-shaped die on press brakes. Compared to steels with a low yield point, however, two additional factors must be taken into account when forming wear-resistant steels: the increased force required and the greater springback. Higher forces are required due to the higher deformation resistance. However, the bending force can be significantly reduced by good lubrication of the die edges of the V-shaped die or the use of movable support rollers.

Under favorable conditions, the minimum bending radii presented in Table 1 have proven to be effective. This assumes that the sheet edges hardened by shearing or thermal cutting have been trimmed and deburred so they are notch-free. In general, the forming behavior transverse to the rolling direction is somewhat more favorable than lengthways, since unavoidable sulfidic and oxidic inclusions in the material exert less of an effect. When press braking in the V-shaped die, care must be taken that the plates slide well, i.e. the die edges are lubricated and the dies are regularly cleaned to remove loose, flaking scale.



V-shaped die

Support rollers

t = Sheet thickness
r = Punch tip radius
r_i = Inside radius on the workpiece
W = Die width ≥ 2r + 5t
L = Clear width ≥ 2r + 3t

Figure 3: Press braking by means of V-shaped die and support rollers.

Table 1: Minimum bending radii and die widths for cold forming

Steel grade designation	Nominal thickness [mm]	r/t ⊥	r/t II	W/t ⊥	W/t II
perdur® 400	4.0 – 8.0	3.5	5.0	11	13
perdur® 450	4.0 – 8.0	3.5	5.0	13	14

⊥ Bending line perpendicular to rolling direction | II = Bending line in rolling direction | W = Die width | r/t = Radius/nominal thickness

The die width recommended here refers to a favorable combination of forming force and springback. Increasing the die width reduces the bending force, but this must be taken into account with regard to the increased springback angle after the part is released.

The degree of formability and the cracking tendency in the bending zone, on the other hand, are chiefly influenced by the punch tip radius. As the bending angle increases, it is to be expected that the sheet will no longer lie completely against the punch when free bending or press braking high-strength steels. In this case, the punch tip radius must be increased to ensure that the inside radius on the part does not drop below the minimum bending radius listed in Table 1. In addition, cut-outs in the area of the bending zone should be avoided because, depending on the internal contour and position, they can partially increase the degree of formability and thus make it more likely that cracks will form.

Heat treatment

Hot forming of perdur® steels is generally not recommended, since the original heat treatment condition of the material will be lost. This leads to losses of hardness and wear resistance in the component. To avoid hardness losses, the steel must not be heated above 250 °C.

The Brinell hardness is measured as described in DIN EN ISO 6506. The hardness is measured approx. 1 mm below the surface of the sheet.

Machining

Wear-resistant special structural steels have a martensitic or martensitic-bainitic microstructure, making them more challenging to machine than ferritic-pearlitic steels.

Drilling

Use of solid carbide drill bits, interchangeable head drill bit with PVD coating or indexable inserttipped milling heads for circular milling is recommended for machining perdur® 400 and perdur® 450 grades.

The appropriate tool must be selected according to the bore diameter. The following must be observed when drilling wear-resistant special structural steels:

- The drill bit used should be kept as short as possible to avoid deflection of the tool.
- Shortly before the drilling process is completed, the cutting edges of the drill penetrate through the bottom layer of the workpiece, and the build-up of cutting pressure is released at this moment. This greatly reduces the tool life and the cutting edges or indexable inserts can be damaged.
- It is advisable to place a plate made of wood, plastic or the like under the workpiece to be drilled, in order to absorb the cutting pressure and thus increase the service life of the tools. Additionally or alternatively, the feed rate and spindle speed can be reduced before the drill exits the hole at the end of the drilling process.
- With thin wall thicknesses, a wide underlayment also prevents the workpiece from bending.

Drilling is carried out in partial steps, i.e. the bit must actually be pulled back after an empirically determined length of bore; this serves to break up the chips and flush them out of the bore, which improves the cooling of the tool. The number of pull-backs must be increased for these grades, because the temperature builds up more in the area of the cutting edges; in addition, a holding time can be defined to counteract excessive temperatures.

General information on drilling

- Tools with internal cooling should preferably be used.
- The cooling lubricant recommended by the tool manufacturer must be used.
- Tools with indexable inserts should preferably be used for countersinking.
- Climb milling, as the chip thickness is minimal when the cutting edge exits the workpiece.
- For cutting data recommendations, refer to the tool manufacturer.

Thermal cutting

perdur® in the available thickness range up to 8 mm can be cut with all normally employed thermal cutting processes. Preheating is not necessary in general, but the user should check this in individual cases when processing steels at temperatures below 15 °C.

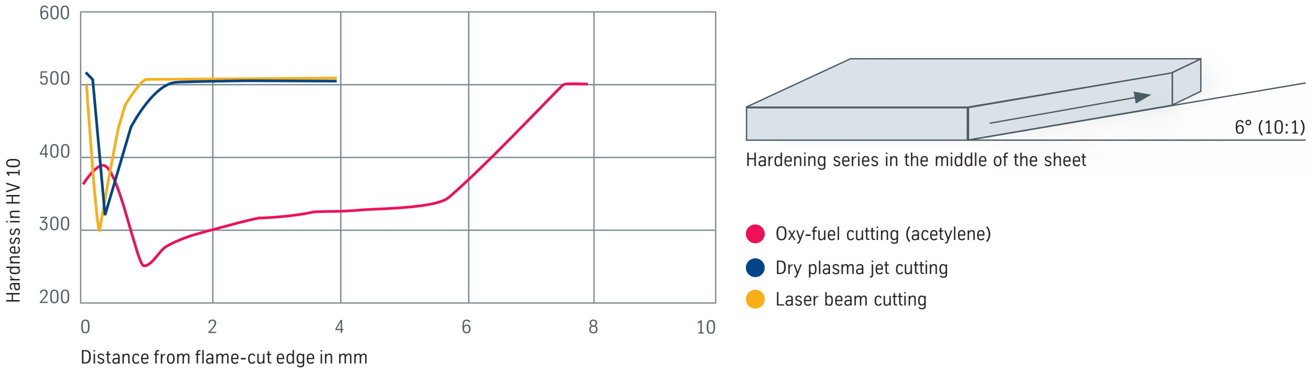
As with all materials, the surface can influence the degree to which perdur® is suitable for cutting, especially laser beam cutting. If the cut quality is insufficient, it may be advisable to clean heavily scaled or corroded surfaces. This can be done mechanically or thermally, for example by first tracing along the subsequent cutting contour at low power. During thermal cutting, a very high temperature is briefly reached in the area of the cut edge, followed by rapid cooling.

The resulting material changes often manifest themselves in a hardness increase directly at the cutting edge, and Figure 4 shows the typical hardness curve in the heat-affected zone during thermal cutting of perdur® 450.

The lowest thermal influence occurs during laser beam cutting. With plasma cutting, the degree of impairment is only slightly more severe. Alternatively, abrasive waterjet cutting is an option for completely maintaining the hardness in the edge area, even with relatively small parts or narrow cutting contours.

For oxy-fuel cutting, it is advisable to select a suitable cutting sequence to avoid excessive heating of the parts.

Figure 4: Thermal cutting of perdur® 450 (hardness profile in the heat-affected zone)



Welding

perdur® steels have been optimized for the lowest possible carbon equivalents, and are therefore outstandingly suitable for welding. They can be welded using all common processes, preferably MAG and manual metal arc welding.

The filler metal should be selected depending on the welding task. When welding wear-resistant steels, there are often no requirements on the filler metal that correspond to the yield point of the basic material.

Consequently, the filler metal should be selected depending on the requirements for strength, notch impact energy and cold cracking resistance. The ferritic filler metal G69 M21 Mn4Ni1,5CrMo in accordance with EN ISO 16834-A often represents a good compromise between the aforementioned requirements; for increased cold cracking resistance, it is recommended to use an austenitic filler metal such as G18 8 Mn in accordance with ISO 14343-A.

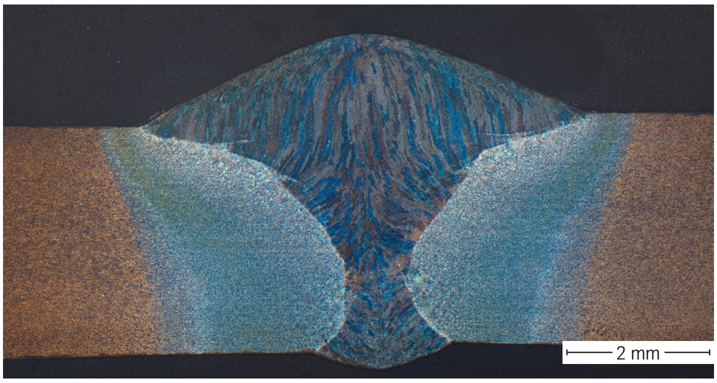


Figure 5: GMA welding on perdur® 450, sheet thickness 6 mm

In principle, special attention must be paid to the cold cracking behavior of all wear-resistant steels. Cold cracks are cracks in the heat-affected zone or in the weld metal that arise after a time delay, and can form under the influence of hydrogen and stresses. Preheating of the components is an effective way of preventing these cracks. It delays the cooling in the area of the weld, and thus promotes hydrogen effusion. Furthermore, measures must be taken to ensure the lowest possible input of hydrogen into the weld metal, e.g. cleaning and drying the welded joints, setting a stable shielding gas flow during MAG welding, and the use of back-dried basic rod electrodes during manual metal arc welding. The welding sequence should be designed to minimize residual stress.

Preheating can generally be dispensed with for an austenitic weld metal; MAG welding should be preferred when using a ferritic weld metal. It offers advantages over manual metal arc welding due to the low hydrogen content in the weld metal.

The carbon equivalent CE is often used to assess the general suitability for welding, which can be estimated using the formula $CEIIW = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15$. The cold cracking sensitivity of a steel can also be estimated on the basis of its chemical composition. The carbon equivalent CET derived from extensive cold cracking investigations is particularly suitable for this purpose, and can be calculated using the following relationship: $CET = C + (Mn + Mo)/10 + (Cr + Cu)/20 + Ni/40$.

Table 2: Typical values for CE and CET of perdur®

	CE_{IIW} [%]	CET after SEW088:2017-10 [%]
Steel grade designation		
perdur® 400	0.36	0.25
perdur® 450	0.41	0.30

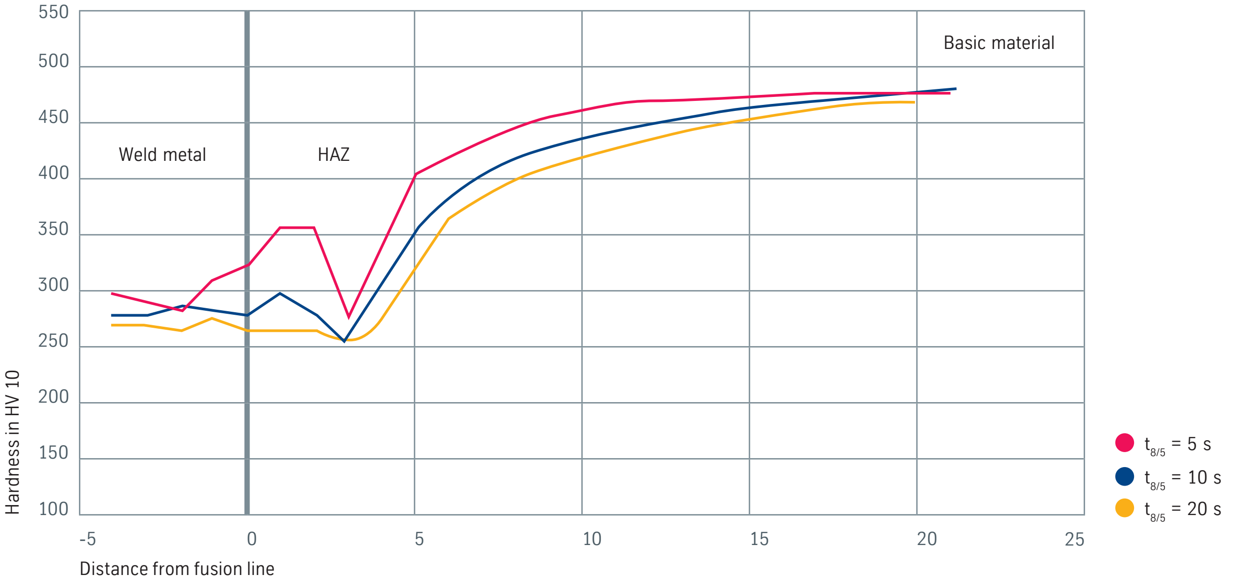
In addition to the chemical composition of the basic material and the weld metal, the cold cracking behavior is determined by the sheet thickness, the hydrogen content of the weld metal, the heat input during welding, and the residual stress condition in the area of the weld. Investigations into the prevention of cold cracking have been included in the steel-iron material sheet SEW 088 and DIN EN 1011 (Part 2, 2001) as the CET concept.

Choice of welding conditions

In the heat-affected zone of the weld seam, there is a change in properties as a result of the temperature-time curve during welding. The temperature-time curve depends on the welding conditions, which can be characterized by the cooling time $t_{8/5}$. This is the time required during cooling after welding a bead for the temperature to pass through the range from 800 °C to 500 °C. Excessively fast cooling of the beads leads to high hardness at the fusion line and increases the risk of cold cracking in the area of the weld seam.

Cooling too slowly, on the other hand, results in the heat-affected zone near the melting line having less toughness and strength. Due to the significant hardness of the basic material, softening cannot be avoided in the area of the heat-affected zone (HAZ), although the width of the HAZ and the minimum hardness in the HAZ and the weld metal can be influenced by heat conduction. Figure 6 shows typical hardness curves in the area of the joining zone on perdur® 450 for different cooling times $t_{8/5}$.

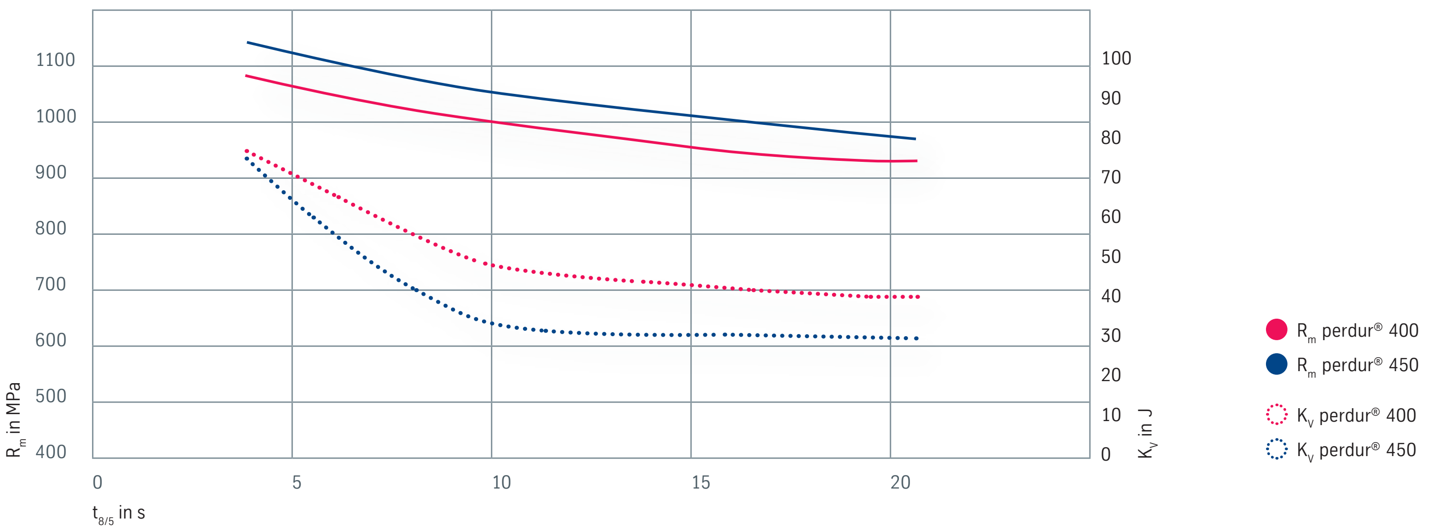
Figure 6: Typical hardness curves for different cooling times $t_{8/5}$ for perdur® 450



In principle, perdur® 400 and perdur® 450 can be processed over a wide cooling time range $t_{8/5}$ and exhibit good mechanical properties that generally exceed the usual technical requirements. Figure 7 shows the typical progression of notch impact energy and tensile strength as a function of the cooling time $t_{8/5}$ with a sheet thickness of 6 mm, and the use of the filler metal ZW G69 M21 Mn4Ni1,5CrMo; the connection was configured as a butt joint (V-shaped seam, 50° opening angle).

The V-shaped notch of the notched-bar impact-bending test specimens was 50% in the HAZ and 50% in the weld metal; the test temperature was -40 °C. The tensile test specimens were tested quasi-statically with a raised seam (not ground).

Figure 7: Typical profile of the notch impact energy and tensile strength as a function of the cooling time $t_{8/5}$, plate thickness 6 mm



The concept of cooling time $t_{8/5}$ is now used worldwide, and has been incorporated into the regulations including SEW 088 and DIN EN 1011-2 (2001). These contain numerous useful tips for applying the cooling time concept in practice. The „ProWeld“ software, which is available as a browser-based version at https://online.thyssenkrupp-steel.com/ecmlogin/proweld_register.do, makes it easy to calculate the cooling time and other important parameters for arc welding.

Wear

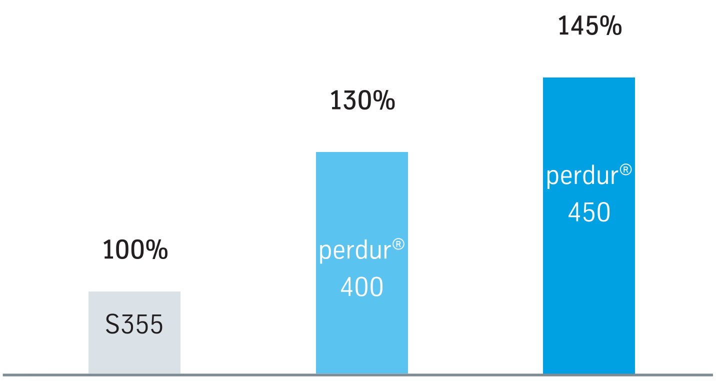
Wear is a system variable and, ideally, for a precise understanding of actual wear processes during use at the customer's premises, the overall system (tribological system) underlying the wear should always be analyzed. Various wear processes can be traced back to four basic wear mechanisms, which can occur individually or in combination. The four wear mechanisms mentioned are abrasion, adhesion, surface disintegration and tribo-oxidation, with abrasion and surface disintegration being the most relevant for wear-resistant steels in conventional applications.

Despite the complexity of real wear processes, it makes sense to characterize the wear behavior of steels in advance by means of laboratory tests, in order to be able to make an initial assessment and comparison of the wear performance of materials with limited effort.

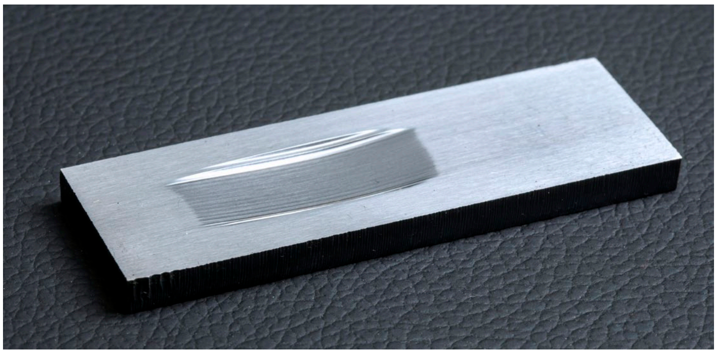
At thyssenkrupp Steel, a rubber wheel abrasion tester for tests in accordance with ASTM G65 and an abrasion vessel are available for this purpose.

The wear-resistant steels perdur® 400 and perdur® 450 offer very good toughness, i.e. high resistance to impact and abrasive wear. Internal tests on the friction wheel according to ASTM G65-16 with Ottawa sand show a high level of wear resistance comparable to the most important competing grades. At the same time, consistent wear performance was also observed with different initial sheet thicknesses.

Figure 8: Relative service life of perdur® versus S355MC



Tested with quartz sand with a hardness of approx. 1100 HV.

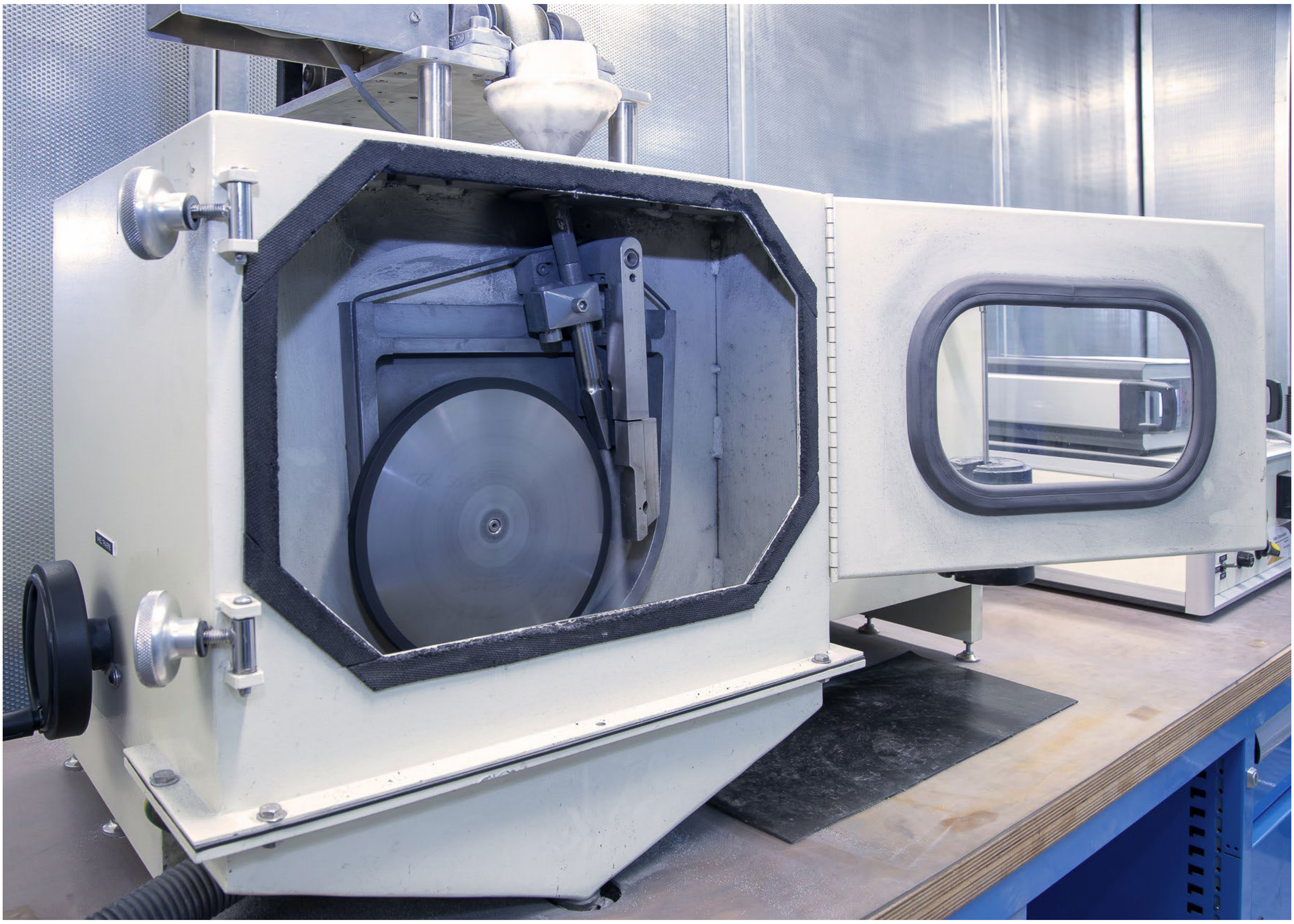


Wear test according to ASTM G65 test.

In addition to an initial test on the rubber wheel abrasion tester, tests that simulate the actual application more closely can also be carried out with customized abrasives in the abrasion vessel.

At thyssenkrupp Steel, wear tests are carried out regularly in order to establish the wear performance of perdur® grades, and to be able to compare them with the wear performance of competing grades.

perdur® under test – establishing wear behavior in the laboratory



Wear test rig used at thyssenkrupp Steel.