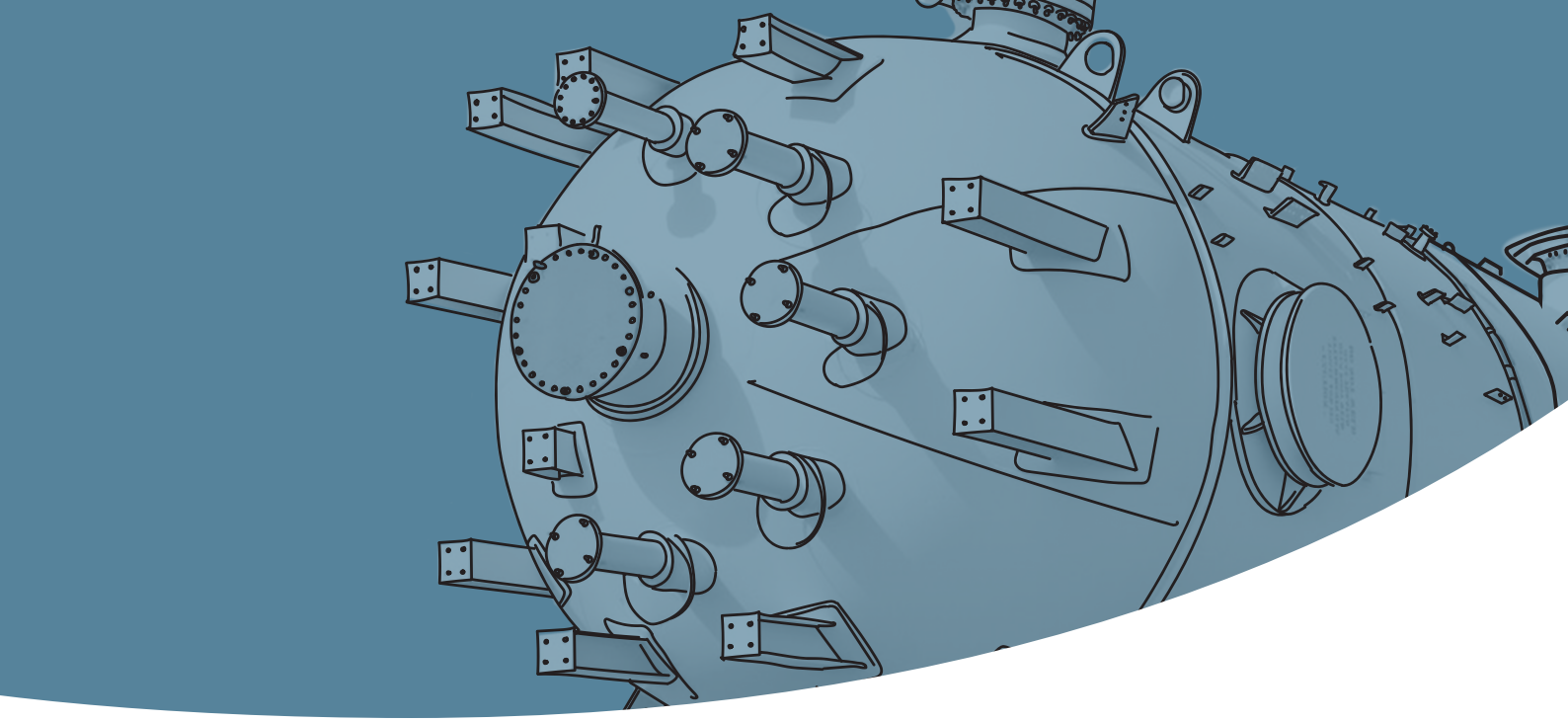


DICREST

THE RIGHT CHOICE FOR SOUR-GAS SYSTEMS

DILLINGER

DILLINGER – A PASSION FOR STEEL

We have a passion for steel. For more than 330 years, we have put our trust in a wealth of ideas and innovations coupled with a love of detail and perfection.

The better the steel, the greater our customers' success

Steel is a unique and fascinating material, and those who understand and master it are rewarded with outstanding properties. At Dillinger, the entire production process – starting with research, and proceeding via steelmaking, up to and including the rolling mill – is focussed exclusively on our heavy plate product.

This specialisation has given rise to unparalleled know-how, exploited for the benefit of our customers. Knowledge, experience and the systematic use of ultra-modern AI applications enable Dillinger to produce even highly critical grades with certainty and to advance the development of challenging products. Whenever top quality, reliability and enhanced productivity are needed, Dillinger is there for you – and that's a promise!

Dillinger can supply an incomparable range of products, featuring more than 2,000 different grades of steel and an impressive spectrum of dimensions and formats. Carefully tailored advice for customers and, increasingly, a digital range of services provide an optimum conclusion to our products and activities.

Acclaimed throughout the world

The Øresund Bridge connecting Denmark and Sweden, Shanghai's World Financial Center, one of the world's tallest buildings, gigantic offshore wind-power facilities and drilling platforms, and the Louis Vuitton Museum in Paris, with its breathtaking architecture, are imposing examples of the diversity of the applications for Dillinger's high-tech steels, assuring the meeting of maximum standards and safety requirements.

Our philosophy of sustainability

Steel is especially sustainable, like no other material, not least of all due to its extreme recyclability. Environmental protection, furthermore, is assigned special importance at Dillinger. The core feature of our sustainability strategy consists of low CO_2 steel production, environmentally safe products, continuous enhancement of energy-efficiency and resources conservation, the reduction of emissions and improvement of the environmental protection of water. Dillinger identifies with the aims of the Paris Climate Agreement. Our credo is:"Top-gradeindustrial technology coupled with sustainable management" – no more, no less.

DILLINGER AT A GLANCE

More than **330** years of experience in steel

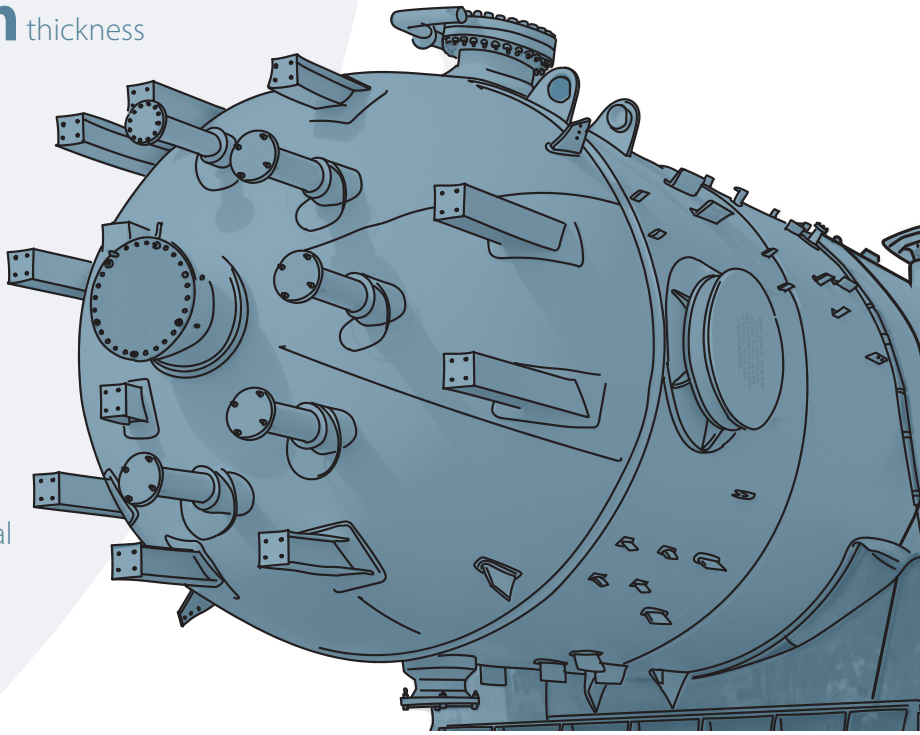
Over **2,000** different grades

Expert advice for more than **10** diverse fields of application

Heavy plates up to **28 m** length and **500 mm** thickness

Plate weight up to **52 t**

More than **200** international approvals, certificates and material qualifications



OUR EXPERIENCE MEANS YOUR SAFETY

DICREST – Dillinger Crack Resistant Steel – We have featured an established brand of sour-gas-resistant steels for more than thirty years. The high quality of our DICREST products assures maximum safety for the petrochemicals industry.

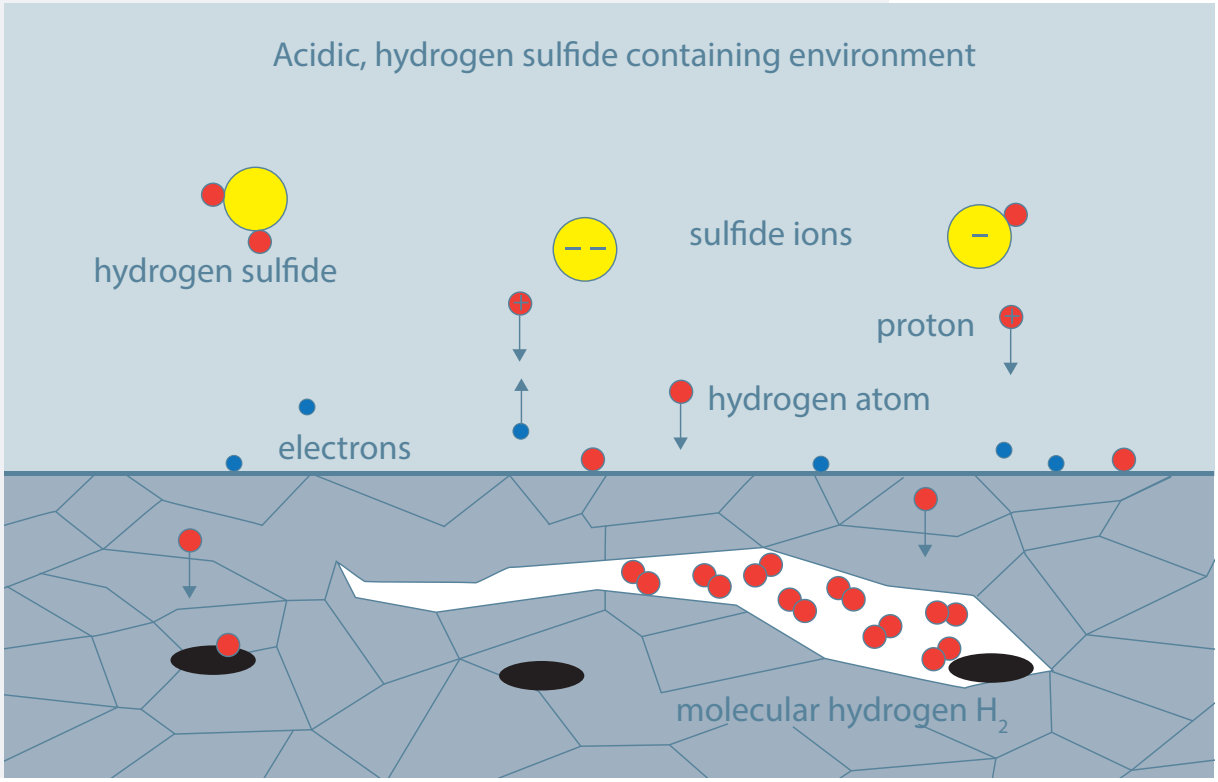
Numerous plants in the petrochemicals industry are exposed to fluids containing hydrogen sulphide or amine. These substances can cause serious damage to pressure-vessel and linepipe steels. This is the result of corrosion processes caused by the release of hydrogen. Since the damaged areas are located on the inside or within component walls, they can only be detected from the exterior by means of complex testing procedures. Component weakening resulting from this damage can therefore occur without warning and can, in extreme cases, cause catastrophic failure.

In response to the needs of plant operators, Dillinger has developed a range of steels with high resistance to hydrogen-induced cracking (HIC) for the construction of all types of pressure equipment. Building on the experience gained with sour-gas-resistant linepipe steels, pressure-vessel steels that assure the highest safety have been developed. Among them is: DICREST - Dillinger Crack Resistant Steel. Its special feature: the product design is such that homogeneous HIC resistance is achieved across the entire plate. Since the early 1990s, DICREST steels have proven themselves in a large range of petrochemicals plants throughout the world and are constantly being further improved by Dillinger for even more specialised applications. So-called "sour-gas steels" are also specified for the construction of tank containers, to which the same quality standards apply. Dillinger has long been well established on the market for sour-gas steels and advises both direct customers and major end customers. Its also incorporates its expertise into the committee work for the development of standards such as NACE TM0284, NACE TM0177, NACE MR0175 / ISO 15156, Part 2. This means that our customers always receive valuable and well-founded feedback on their enquiry - Tailor Made! Our product range includes HIC-resistant steels like DICREST that meet your specific requirement profile. If you have demanding specifications for HIC testing and need an especially reliable steel, take a look, for example, at our DICREST-PLUS. If your aim is to design a thin-walled vessel that meets HIC standards, our DI-TANK series is the answer. If, on the other hand, you are designing a pressure vessel using A / SA-516 Grade 60 / 65 / 70 or A / SA-537 Class 1 as per ASTM/ ASME or even in conformity to EN requirements and fabricated in P275 / P355, our range of products has the right solution every time! Just contact our Sales or Marketing department and enquire about HIC-resistant steels - they'll be pleased to provide a carefully tailored solution in steel.

THE CHALLENGE

Atomic hydrogen - the element that repeatedly challenges plant operators. At Dillinger, we use our DICREST steels to counteract hydrogen-induced cracking (HIC).

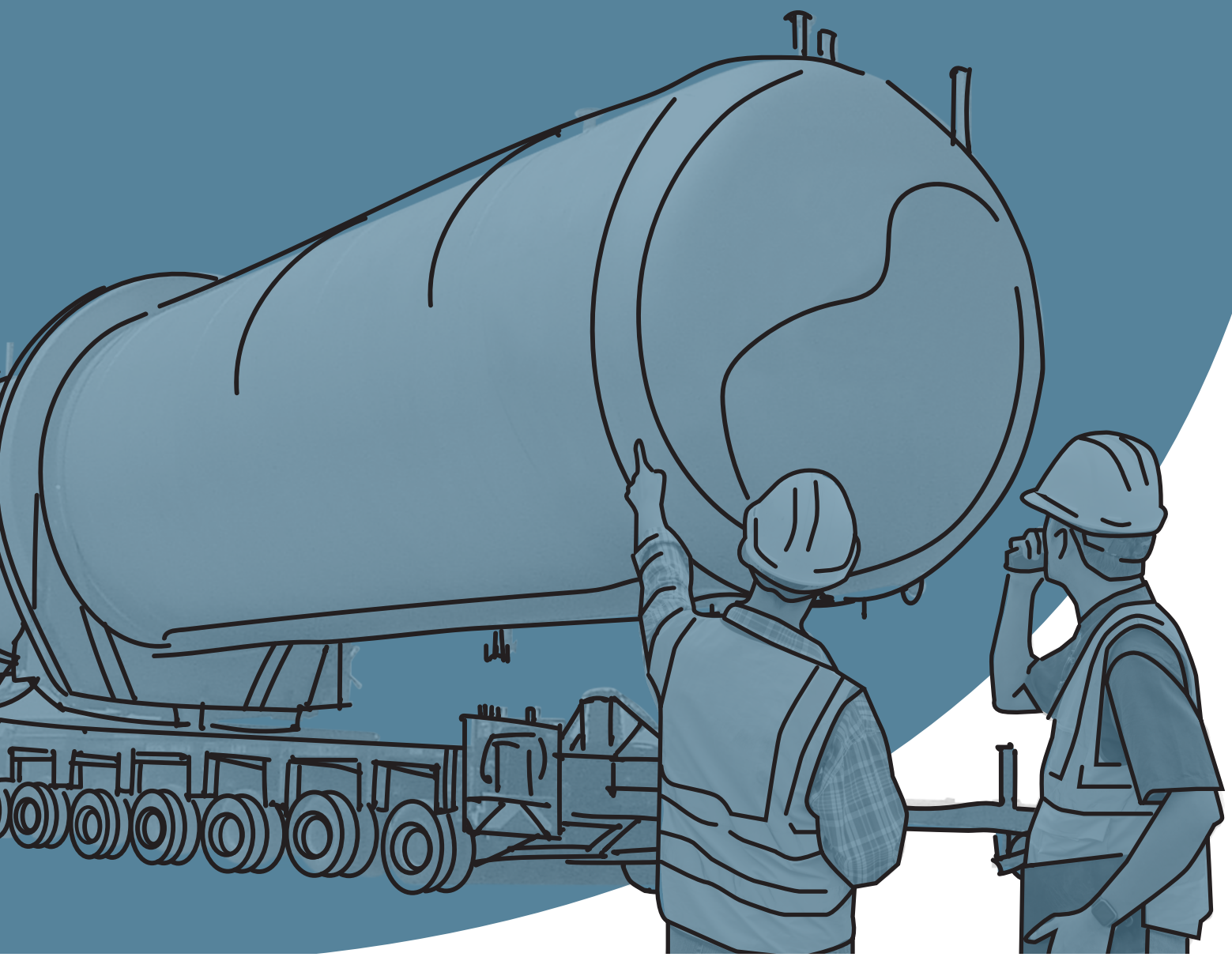
Hydrogen-induced faults are caused by electrochemical corrosion reactions between the surface of the material and the sour-gas environment. This generates atomic hydrogen, which diffuses into the material. The dissolved hydrogen reduces the bonding energy of the crystal lattice and thus cleavage-fracture stress and crack toughness. If atomic hydrogen can also accumulate on non-metallic inclusions or in micropores, it will recombine to form molecular hydrogen (H_2). As a result, the diffusivity of the hydrogen in the crystal lattice is severely diminished. Enormous pressures can then build up at the accumulation points, causing stresses that exceed the deformation limit of the steel. This can result in microcracking parallel to the surface, especially at sites of rolled sulphides and segregations. This phenomenon is known as "hydrogen-induced cracking". During system operation, such cracks can, over a prolonged period, attain a critical size.



Available HIC-resistant grades	
Thermomechanically rolled	Normalised
A/SA-841 Gr. A Cl. 1	A/SA-516 Gr. 60/65/70
A/SA-841 Gr. B Cl. 2	A/SA-537 Cl. 1
P355 ML2	P275 N/NH/NL1/NL2
P420 ML2	P355 N/NH/NL1/NL2
P460 ML2	P265 GH

Available HIC-resistant proprietary steels	
Thermomechanically rolled	Normalised
DI-TANK 355 HIC	DICREST 5
DI-TANK 420 HIC	DICREST 10
DI-TANK 460 HIC	DICREST 15
	DICREST-PLUS

Other pressure vessel steels produced according to the Dillinger HIC process route can be quoted on request.



DILLINGER'S HIC CONCEPT

To counteract this cracking mechanism, we produce DICREST using our special HIC process route. Great importance attaches here to steelmaking and to the rolling process.

Low phosphorus contents of a maximum of 0.01 % are adjusted in the steelmaking plant. The heats of HIC-resistant steels are in every case submitted to vacuum treatment: during this process, nitrogen and hydrogen are removed from the steel. During degassing, low-level desulphurisation is also performed. Subsequent cleanness bubbling then results in extremely clean steel with sulphur contents of a maximum of 0.001 %. The few globular inclusions still remaining are of no danger to the steel, thanks to their low notch effect. The risk of hydrogen-induced cracking is thus also reduced.

Continuous or ingot casting then takes place under special quality-assurance provisions for sour-gas-resistant grades of steel. Dillinger's vertical continuous-casting machines possess decisive metallurgical advantages over the customary circular-arc or oval-bow continuous-casting systems. The strand is bent only after complete solidification has occurred - in other words, any oxides still remaining in the heat can ascend and separate out on the meniscus, and cannot be trapped on the solidification front. In addition, so-called Soft Reduction of the continuous-casting machine largely reduces the macro- / centre segregation typical of continuous-cast material. Only stringent adherence to the casting parameters assures outstanding HIC properties, since even changes in casting speed, for example, can cause impairment of steel quality. Only heats which meet the highest standards are used for the production of HIC steel. Rolling takes place on high-power rolling stands, with rolling forces of up to 108 MN and drive systems of torques of up to 2 x 4,500 kNm. The heat treatment necessary for the steel is performed on every HIC steel, with the exception of thermomechanically rolled grades, in order to produce a homogeneous and fine-grained microstructure.

Homogeneous, HIC-resistant normalised HIC-grades in components can only be achieved if the entire vessel is stress-relieving annealed. If no stress-relieving annealing of the complete component is applied after processing (if deformation or welding has not occurred, for example), stress-relieving annealing of the plates can take place after normalising. Thermomechanically rolled heavy plates are an exception to this rule.

Your product benefits at a glance

- Extreme plate formats and item weights possible
- Cost-efficient production thanks to reduced welding and inspection costs, faster completion times
- Low trace-element content increases HIC resistance
- Large range of HIC-resistant grades and proprietary steels

Your service benefits at a glance

- Experienced experts provide comprehensive advice
- On request, prefabrication of shell plates, including precisely milled welding edges

Discover our E-Service with useful tools, the personalised myE-Service area with all the information about your orders and the E-Connect app for plate identification.

NO COMPROMISES

Verification of HIC resistance is the responsibility of our laboratories, which are accredited in accordance with DIN EN ISO 17025. HIC verification is conducted in conformity to internationally acknowledged standards and customer specifications.

Dillinger also possesses a number of end-customer approvals for material production and materials testing. The employees of the Notified Bodies commissioned by the end customers are present in our plant for acceptance purposes, and are permanently seconded in some cases. Knowledge of the specifications enables us to support our customers in discussions with decision-makers and thus eliminate potential misunderstandings.

For testing in conformity to NACE TM0284, specimens of a defined position and defined dimensions are taken from a plate which is representative for all plates of the same heat of a particular order. These specimens must be in stress-relieving annealed condition, which is a basic necessity in the case of normalised plates for the attainment of the specified HIC resistance. As already mentioned, thermomechanically rolled plates are an exception to this rule. For plates of a thickness of up to 88 mm, three specimens of a maximum thickness of 30 mm are taken, staggered across plate thickness. In the case of plate thicknesses of > 88 mm five, > 144 mm seven and > 200 mm nine staggered specimens are taken and tested. It is thus assured that the entire plate cross-section is submitted to the HIC test.

The specimens are then exposed to a hydrogen-sulphide-saturated test solution for a period of 96 hours. Two different test solutions in accordance with NACE TM0284 are available for this purpose: Solution A, with a pH of 3, and Solution B, with pH 5.

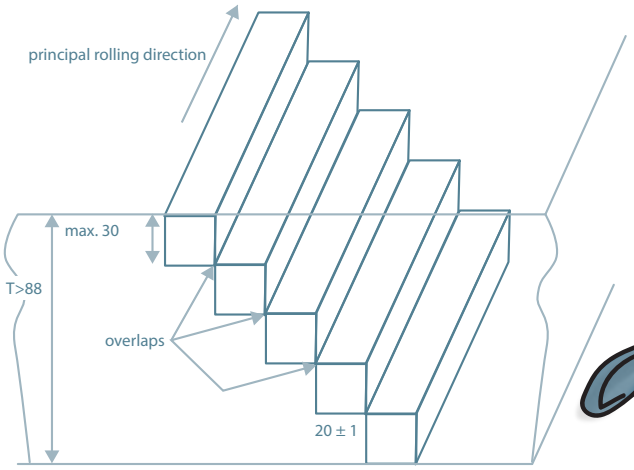
In the next stage of the test, the specimens are cut open, ground, polished and metallographically examined at three defined places. The magnitude of the cracks which have occurred is assessed on the basis of the evaluation criteria of crack-length ratio (CLR), crack-thickness ratio (CTR) and crack-sensitivity ratio (CSR). Since the entire production of HIC-resistant steels is orientated around homogeneous HIC resistance, this HIC test is representative for the entire test batch. The HIC test results are certified for your order.

As far as is technically possible, the customer's wishes can, of course, be taken into account in the test and acceptance criteria.

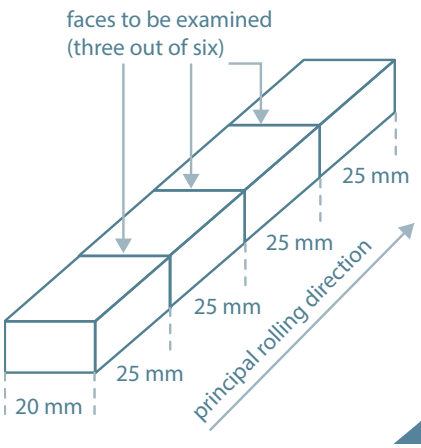
An example of the procedure for determination of HIC resistance can be found on the following pages.

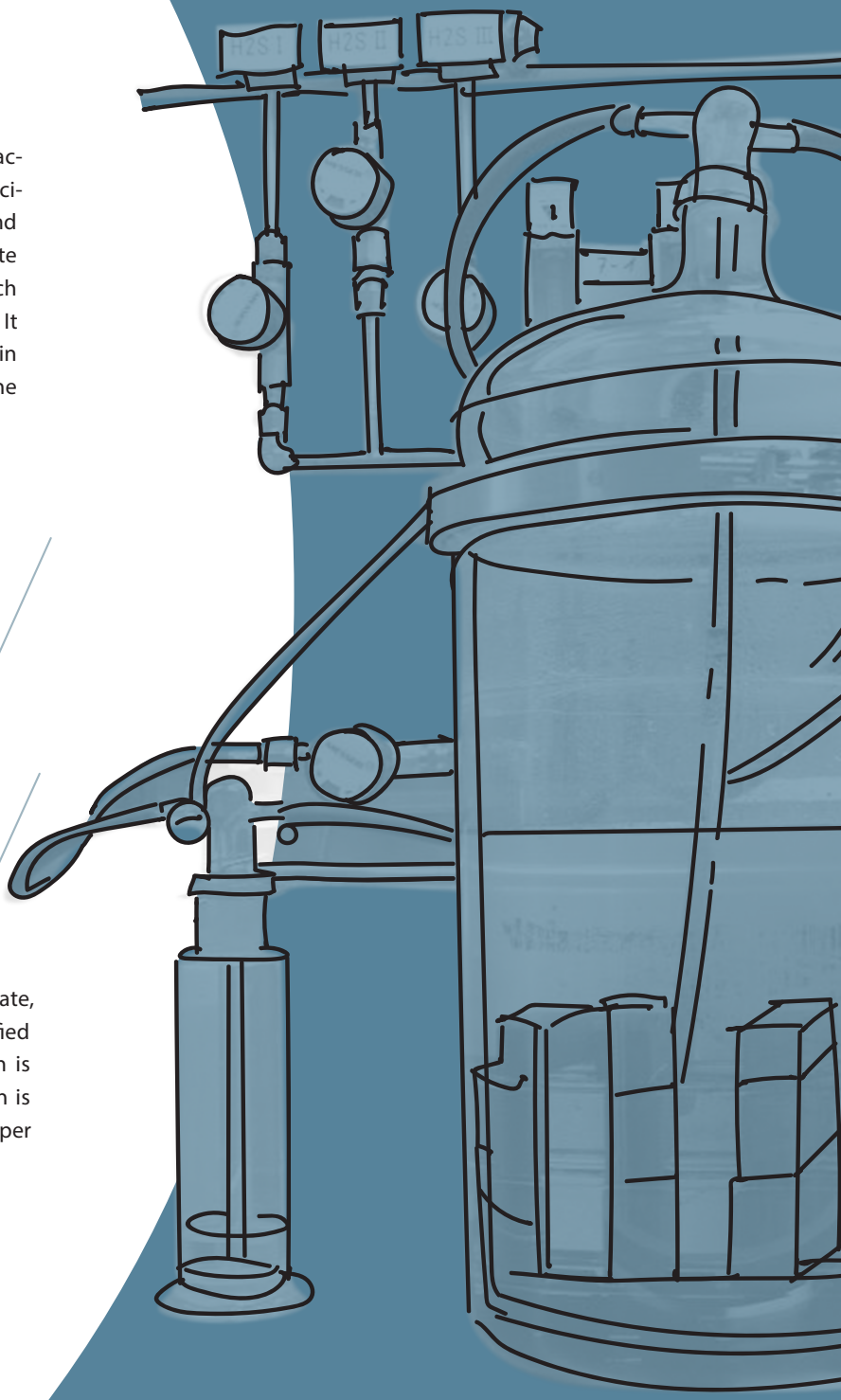
EVALUATION IN ACCORDANCE WITH NACE TM0284

The number of specimens taken from a plate varies according to the thickness of the particular plate. A specimen has a length of 100±1 mm, a width of 20±1 mm and a height of max. 30 mm. In the illustration below, a plate of between 88 mm and 144 mm in thickness, from which five specimens are taken, is shown by way of example. It should be noted that overlapping of the specimens in plate-thickness direction is mandatory in order that the entire plate thickness is submitted to the HIC test.



After the specimens have been removed from the plate, they are placed in the specified solution at the specified time interval. At the end of the test, each specimen is divided into four 25 mm long segments. One section is made per cut surface, so three sections are analysed per specimen.





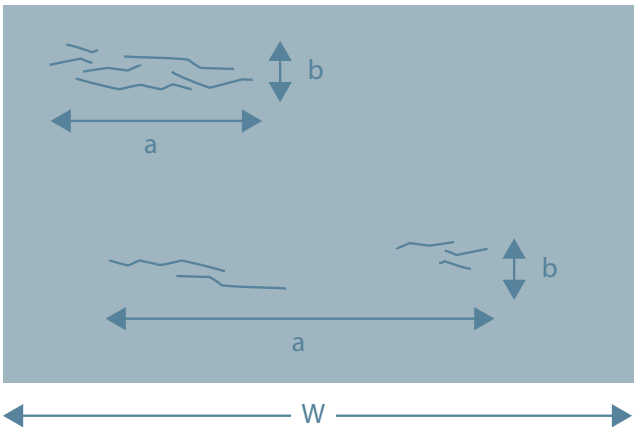
Grade	Test solution in conformity to TM0284	Acceptance criteria [%]		
		CLR	CTR	CSR
DICREST-PLUS[a)]	A (pH3)	≤ 7	≤ 2	≤ 0.7
DICREST 5[b)]	A (pH3)	≤ 5	≤ 1.5	≤ 0.5
DICREST 10[b)]	A (pH3)	≤ 10	≤ 3	≤ 1
DICREST 15[b), c)]	A (pH3) B (pH5)	≤ 15 ≤ 0.5	≤ 5 ≤ 0.1	≤ 2 ≤ 0.05
DI-TANK[d)] 355/420/460 HIC	A (pH3)	≤ 10	≤ 3	≤ 1

[a)] DICREST-PLUS: CLR, CTR and CSR per microsection

[b)] The CLR, CTR and CSR readings are calculated as the averages of all individual microsections of an HIC test.

[c)] For DICREST 15 the required test solution must be stated in the order documentation.

[d)] DI-TANK: Averages for CLR, CTR and CSR per specimen (three microsections).



$$CLR = \frac{\sum a}{W} \cdot 100\ \%$$

$$CTR = \frac{\sum b}{T} \cdot 100\ \%$$

$$CSR = \frac{\sum (a \cdot b)}{W \cdot T} \cdot 100\ \%$$

For evaluation purposes, the total of all crack lengths is now calculated (a) against specimen width (W) or the total of all crack heights (b) against specimen height (T) or the total of all crack lengths and crack heights against microsection cross-section.
The ordering customer specifies the evaluation criteria to be applied.
Specification of acceptance criteria is of central importance for evaluation of the results. The differing interpretation is described in the following example.

A total of five specimens, each with three microsections, i.e. 15 test results, are available. In one microsection, cracks with a CLR of 15 % were observed. Observation of the complete specimen (no. 2) results in a CLR of 5 %. Observation across the entire plate thickness, i.e. 15 microsections, results in a CLR of 1 %.
Averages per specimen (3 microsections) and individual readings per microsection or acceptance criteria divergent therefrom can be provided upon agreement.

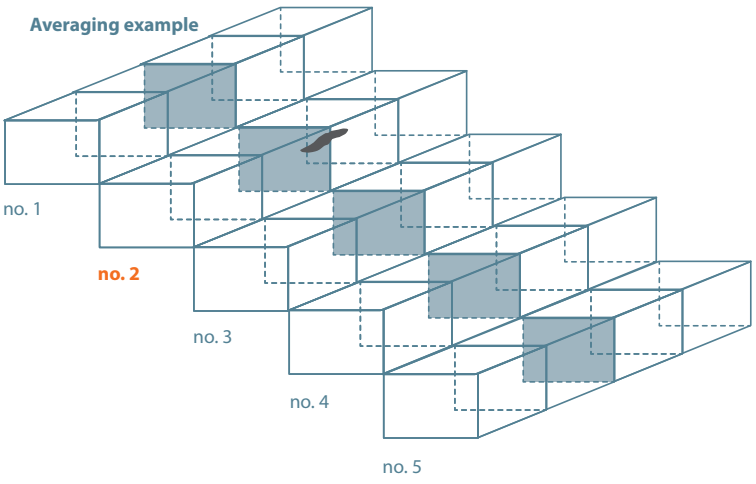


Plate thickness: > 88 ≤ 144 mm
Number of specimens: 5, staggered
Number of microsections: 15

Measurement:
Test result: CLR = 15 % in one microsection (single reading)

Averages across three microsections (per specimen)
no. 1: CLR = 0 %, **no. 2: CLR = 5 %**, no. 3: CLR = 0 %, no. 4: CLR = 0 %, no. 5: CLR = 0 %
Averages across 15 microsections (5 specimens)
CLR = 1 %

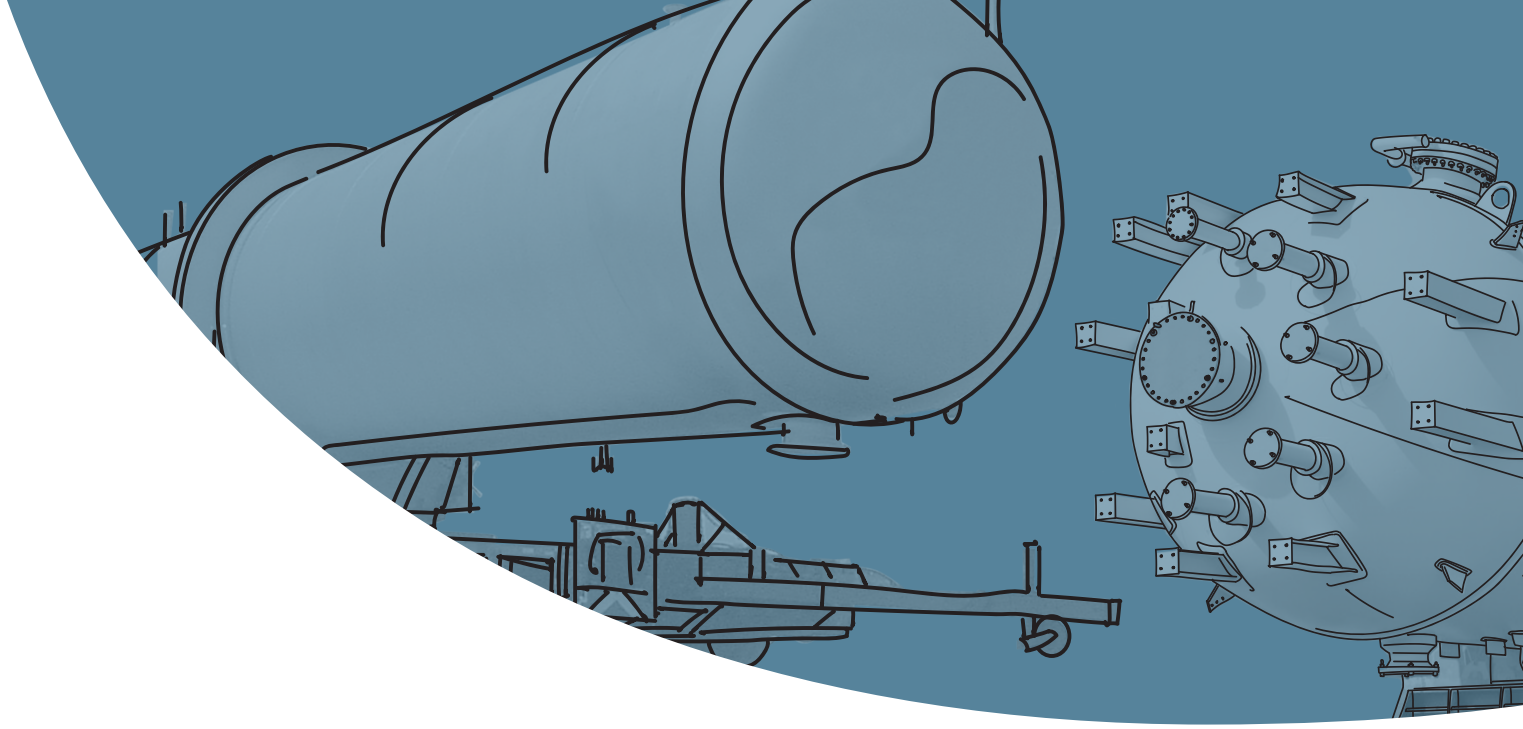
AND THAT'S NOT ALL!

We supply the most frequently selected DICREST grades, A/SA 516 Grade 60, 65 and 70 in conformity to ASTM/ASME and P275 and P355 as per EN 10028, Part 3 and the thermomechanically rolled DI-TANK grades, A/SA 841 Gr. A Cl. 1 and Gr. B Cl. 2 in conformity to ASTM/ASME and P355 M, P420 M and P460 M as per EN 10028, Part 4, as standard grades. It goes without saying that we also supply HIC-resistant steels in conformity to other standards and to your own specifications. Please take a look at our DICREST-PLUS if you have extra-high requirements on the HIC acceptance criteria for steels.

HIC-resistant steels are available in formats that exceed the normal limits on heavy plates. Our maxima are: lengths of up to 25,000 mm and widths of up to 5,200 mm. Maximum plate thicknesses and item weights depend on a large number or parameters, such as HIC test criteria and the particular grade of steel. Please see the DICREST specifications for corresponding information or submit a specific enquiry to us and we will respond in the context of a technical feasibility study.

In addition to the HIC test, Dillinger also offers for HIC-resistant steels the "SSC" test with reference to NACE TM0177, using Test Solution A, Test Duration 720 hours and a four-point bending test. SSC – sulphide stress cracking – is a form of cracking which can occur in high-strength steels and in the heat-affected zone (HAZ) of welds as a result of the simultaneous action of hydrogen and the application of external loads. Since this form of damage is primarily associated with the hardness of the material, parent material hardness is limited to < 22 HRC in conformity to NACE MR0175 / ISO 15156, Part 2. The test procedure, test solution, test duration and the magnitude of tensile stress must be agreed for performance of the SSC test.

Another hydrogen-induced cracking phenomenon, "Stress Oriented Hydrogen Induced Cracking" (SOHIC), should be mentioned for the sake of completeness. This phenomenon is of only subordinate importance in the context of steel plates. It involves cracks differently formed from the types of cracks described above, at points at which multi-dimensional stress states occur in the component. The starting points take the form of notches, crack tips or stress-loaded heat-affected zones of welded joints. A combination of cracks perpendicular to the direction of the principal stress of the most severely loaded area and horizontal cracks at a greater distance from these is typical for this type of crack. Under certain preconditions, Dillinger is able to quote this test for you. The test conditions and evaluation criteria can be unequivocally clarified on request.



Dillinger HIC-resistant steels are frequently required at short notice and / or in only smaller quantities.
Dillinger also supplies DICREST from stock.
For this, please contact our steel stockists in:

The Netherlands:

or
the United Arab Emirates:

Notes for processing of HIC-resistant steels can be found in the relevant material data sheet.

Please contact one of our partners for individual advice,
both technical or commercial.

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