Düker

GLASS LINING TECHNOLOGIES

The properties of glass lining

email850P
email800
email350

Elementary ingredients for technical enamels

The ultimate hardness. Based on fire, water, air and earth…

It takes very little to ensure that production processes in sensitive industrial areas are carried out safely: quartz, feldspar, borax, sodium carbonate, saltpetre and metal oxides are processed in several stages to become technical enamel. The special mixing proportions of the basic substances determine the final resistance of the end product to aggressive media.

Technical enamel is therefore a very special surface protection and its uses include the chemical, pharmaceutical and food industries. It meets quality and economic requirements in that components made of email800 reduce the usual amount of care and maintenance required. Düker pipelines, fittings, valves, bottom outlet valves and columns can be combined to form durable complex units. The many options for users include the standard range, the design of special parts or a customised combination of both.

The characteristics of our glass lining

Chemical resistance

New products and new process techniques are creating larger areas of use and more exacting requirements for surface protection in plant engineering. We catered for these requirements when developing our "Glass Lining Technologies" particularly durable email800 and glass lining which are different with regard to technical specifications like email350 and email850P.

email800 is highly resistant against attack, wear and corrosion and against diffusion during long holding times. These characteristics have been confirmed by independent tests and major chemical laboratories in Germany and Switzerland. Here are some datas:

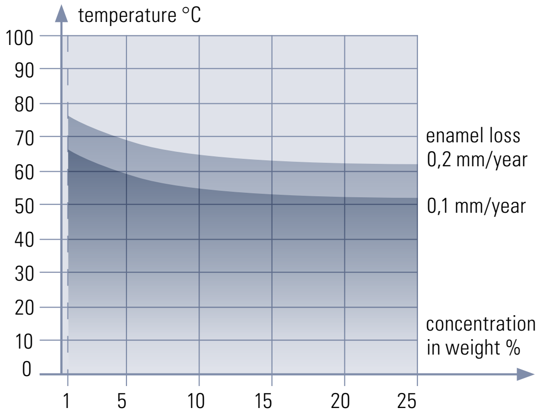
Acid Resistance:

- will be checked according to chapter 12 of DIN EN 14483-2 - boiling hydrochloric acid

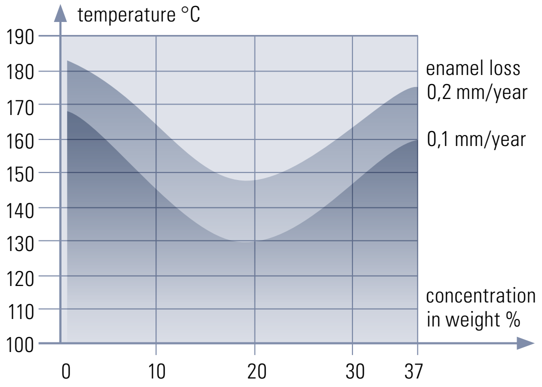
Alkali Resistance:

- will be checked according to chapter 9 of DIN EN 14483-4 - hot caustic soda

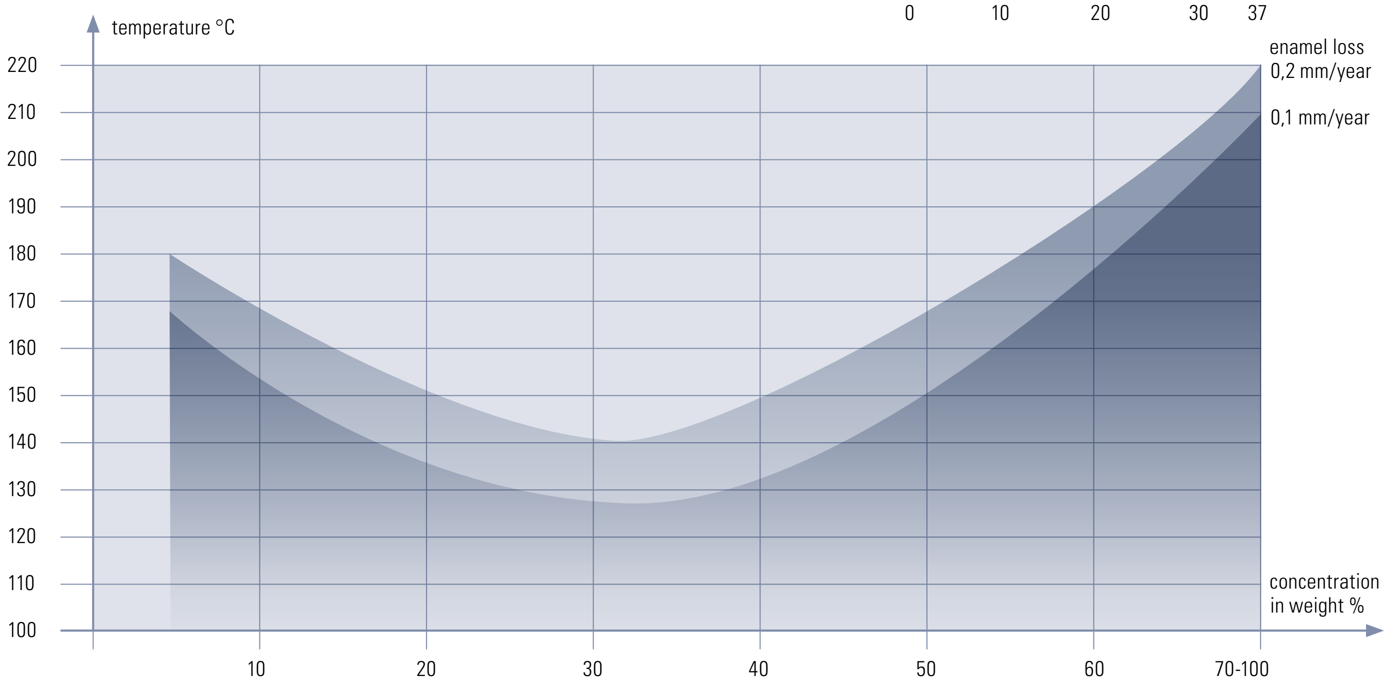
Corrosion velocity in NaOH-aqueous solutions



Corrosion velocity in HCL-aqueous solutions



Corrosion velocity in H_2SO_4-aqueous solutions



The properties of our glass lining

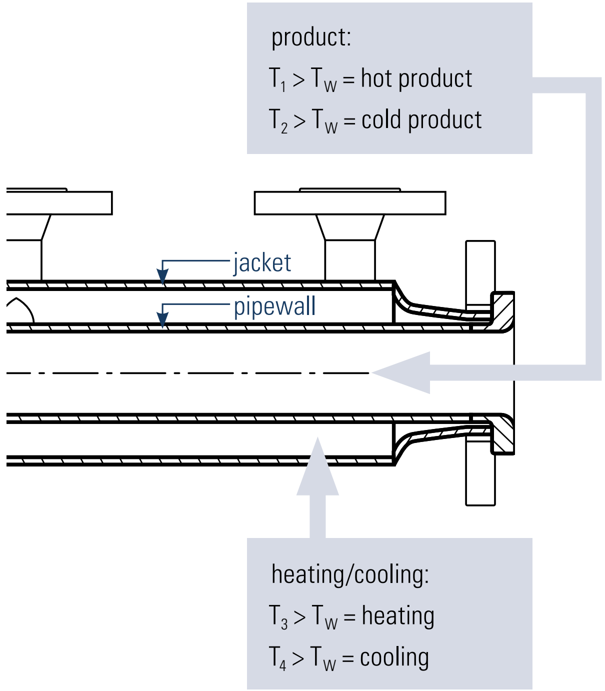
Physical properties

Thermal shock resistance

The thermal shock resistance of glass lining is mainly determined by the prestress of the glass.

Düker **email800** has a prestress on the steel of about 120 N/mm^2 at room temperature. This is achieved by adjusting the expansion coefficient. When temperature increases the prestress decreases until it disappears at about 400 °C (see stress curve).

The table of the thermal shock resistance of glass lined parts considers this reduction. Furthermore it takes into account that the most danger to the hot glass is when subjected to cold product. Exceeding the permissible temperatures will result in tearing and later on in cracking of the enamel on the pipewall.



product:
$T_1 > T_W$ = hot product
$T_2 > T_W$ = cold product

heating/cooling:
$T_3 > T_W$ = heating
$T_4 > T_W$ = cooling

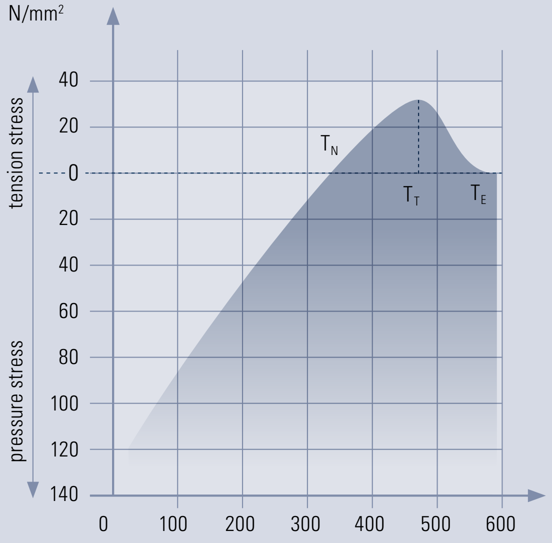
Application examples

We use the temperature of the enamelled pipewall (T_W) as the basis. At a given temperature T_W (°C) the temperature of the product should be between T_1 and T_2 and the temperature of the heating/cooling agent should be between T_3 and T_4 .

Material data:

Specific weight	2,5 g/cm^3
Coefficient of thermal conductivity	1,2 W/mK
Modulus of elasticity	80.000 N/mm^2
Compressive strength	≈ 800 N/mm^2
Tensile strength	80 N/mm^2
Dielectric strength	20-30 kV/mm
Surface finish of enamel	0,05 µm

Stress curve in the enamel of steel



T_N = Neutral temerature
T_T = Transformation temperature
T_E = Solidification temperature

pipewall T_W °C	hot product T_W °C	cold product T_W °C	heating agent T_W °C	cooling agent T_W °C
230	250	150	250	100
220	250	140	250	90
210	250	125	250	80
200	250	100	250	70
190	250	90	250	60
180	250	75	250	50
170	250	60	250	40
160	250	50	250	30
150	250	35	250	20
140	250	20	250	10
130	250	10	250	0
120	250	0	250	-10
110	240	-10	240	-20
100	230	-20	230	-30
90	220	-30	220	-40
80	210	-40	210	-50
70	200	-50	200	-60
60	190	-60	190	-60
50	180	-60	180	-60
40	170	-60	170	-60
30	160	-60	160	-60
20	150	-60	150	-60
10	140	-60	140	-60
0	130	-60	130	-60
-10	120	-60	120	-60
-20	110	-60	110	-60
-30	100	-60	100	-60
-40	90	-60	90	-60
-50	80	-60	80	-60
-60	70	-60	70	-60

1. Hot product

The temperature of the pipewall is 50 °C.
Which temperature must be exceeded?

From T_W = 50 °C horizontal in the table to T_1 = 180 °C

2. Cold product

The temperature of the pipewall is 200 °C.
Which temperature must the product have at least?

From T_W = 200 °C horizontal to T_2 = 100 °C

3. Heating

The temperature of the pipewall is 20 °C.
Which temperature of the heating agent must not be exceeded?

From T_W = 20 °C horizontal to T_3 = 150 °C

4. Cooling

The temperature of the pipewall is 180 °C.
Which temperature of the cooling agent must not be fallen below?

From T_W = 180 °C horizontal to T_4 = 50 °C

Industrial enamel

Industrial enamel as allround material is firmly established between surface finishing materials fulfilling rather inferior demands and the special materials with to some extent very specific performance data particularly in the chemical and pharmaceutical industry but also for water supply systems and in special niches in general machine construction.

Depending upon the area of application enamel with its generally broad function profile can be adjusted to meet special demands. Whether for supplying potable water, textile chemicals or in the treatment of waste water, in soldering plant construction and in the pharmaceutical industry under GMP conditions or to comply with hygienic design stipulations, enamel fulfils many and varied demands with different focal points by linking the structure material with the surface finish determining grades of enamel.

Fig. 1: Industrial enamel with extremely smooth surface finish in conjunction with high wear resistance to abrasive acting media and high resistance to corrosion. Visual counter light inspection of surface.

Typical material properties

The term industrial enamel can be seen to be analogue with industrial ceramic. It would appear sensible to differentiate between commercial enamel for every day use in the home or for jewellery, etc., because as far as industrial enamel is concerned the technological demands put on the surface finish are in the foreground. As a consequence, this term is applied for enamelling in processes in which physical and chemical stress conditions can be defined and the thus derived demands on the surface system are the main consideration.

The main typical material features of industrial enamel:

- High resistance against corrosion attack, more especially in the case of acidic media even at higher processing temperatures
- Higher resistance against wear by abrasive media
- Surface smoothness (Fig. 1)
- Easy to clean with no tendency towards adhesion
- Biological and catalytic inert behaviour

The properties of the enamel are supported by appropriate sophisticated constructive designs which strengthen the positive properties and overcome existing limitations as far as possible.

Physiochemical compound material

Enamel as such is outstanding when compared with other popular surface coatings and finishes such as wet paint, powder coating, lining with plastic, etc., inter alia by the given intensive physical and chemical connection with the basic material. This is marked by diffusion processes from the basic material towards the enamel and vice versa. Over and above this forms a real compounding layer of but a few but also to some tens of micrometers thick depending on the material system (Fig. 2).

Optimal morphology by releasing elements close to the surface and linking the substrate material in the enamel matrix is initially generated to develop the mechanical and physical connection.

The increased roughness by releasing the substrate surface in connection with the development of backcuts offers a large number of anchor points for micromechanical positive connection.

This mechanism is supplemented by generating integral pressure tension in the enamel in cooled state which contributes in the further stabilisation of the mechanical compound.

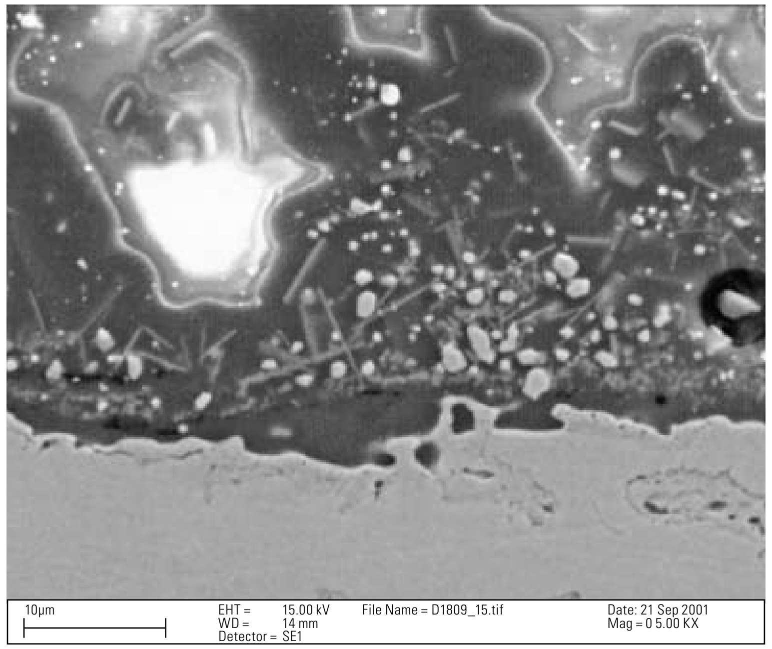


Fig. 2: Detail photograph of a compound layer enamel (in this case with grey cast iron (GGG) electron raster microscope photograph Fraunhofer-Institut ISC, Würzburg) in approx. 5000-fold magnification. Clearly visible is the (micro) roughness of the surface (bright to the bottom) with back cuts. Following to the top is a thinner homogeneous appearing seam about 2µm thick and the actual bonding layer afterwards clearly over 10 µm thick with different precipitations (ferrotitanium crystal in needle and pellet form) and inclusions.

However, if the stress in the enamel layer is too high, this can also lead to increased sensitivity towards impact where convex surface elements are concerned.

Enlargement of the specific surface supports the development of intermolecular bonding apart from this mechanical and physical bonding mechanism. Considerable effects are achieved through Valenz and Van-der-Waals bonding but nevertheless, metallic bonding in the bonding layer likewise plays a role in the iron-silicium-oxygen system.

Construction and corrosion resistance

The durability of high acid resistant enamel as used in chemical plant construction, for example, is marked to some extent by extremely high SiO_2-content in compound with titanium, zirconium, lithium and boroxide. Special modifications are possible if the resistance to lye has to be increased.

Although in theory enamel is considered not to be stable in the case of watery solutions the wear is usually so low that it can be assumed that the technical stability of the system is given but this is not the case with phosphoric and fluoride acid.

For example, the wear rate for 20% HCl at 110 °C is 50 µm per year (equivalent to 9000 working hours). This is to be compared with the typical coat thickness of surface enamel of about 1000 µm. As a rule the respective wear down in the fluid phase is in a t-2 relationship (t = time).

Basic conditions for high quality

The quality of any enamel depends on a large number of pertinent parameters and periphery conditions. Of decisive significance is the metallurgical quality of the basic material, its microstructure the mechanical pre-treatment it has been subject to and its surface finish.

Only steels with restricted analysis can be given a high quality enamel finish. Carbon, sulphur and almost all metal accompanying elements must be limited. Clean ferritic microstructure in the periphery layer facilitates enamelling. Carbon inclusions make enamelling more difficult in the same way as micro faults which can act like hydrogen traps. This applies generally for enamelling iron foundry materials.

Thermal and mechanical preparation is subject to two main conditions. Clean, abrasive acting blasting material cleans, activates and enlarges the surface (Fig. 3). However, any contamination of the surface must be avoided after blasting. From this one can see the demand for a very quick production sequence, i.e. pre-treatment, application of the enamel slick, drying and firing the enamel.

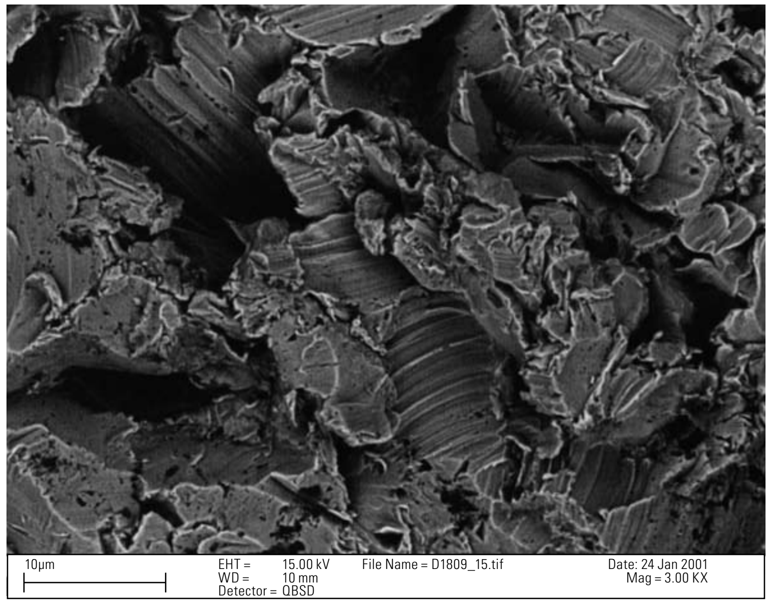


Fig. 3: Detail photograph of a corundum-blasted steel surface, approx. 3000-fold magnification (raster electron microscope photograph Fraunhofer-Institut ISC, Würzburg). The surface as a result of the blasting operation is clearly split and eroded. This finish offers an ideal surface for building up the material compound in the subsequent enamelling process.

Chemical and physical sequences while firing at 850 °C

During the firing operation (see also Fig. 4) different chemical and physical processes take place dependent on temperature and time.

Initially the surface of the steel is oxidised further under the drying slick and is supported by the residual moisture of the dried slick. Water and hydrogen escape. Afterwards the oxide layer is released step by step by increasing the temperature, yet again. The chemical adhesion action take place during this step, this being responsible for the development of the bonding zone to achieve the mechanical anchor. To be also considered is that the enamel does not fuse at a defined temperature but the fusing process takes place within a fusing period because the different enamel components fuse at different temperatures.

The various components have a different effect on both the dissolving behaviour of the oxide coating and the viscosity of the melt. Iron oxide escapes in the over saturated enamel melt and leads to faults that cannot be repaired (such as copper heads, and burn through) should the absorpabilty of the enamel be over stressed as a result of too long or too hot firing. Faults can occur which are also restricted locally in the case of less uniform distribution of the enamel mass.

The described sequences and effects contribute to differences in the base enamel (initial or first and second layer on the component) and the top enamel layer (and the build up of the following layer is aimed at ensuring the overall layer thickness).

Fig. 4: Components in front of the furnace after completion of the firing operation. Homogeneous temperature distribution within the component is the basic requirement to ensure quality enamelling.

In function the softer less resistant basic enamel is responsible for optimal bonding to the basic material. The harder, highly resistant top enamel layer bonds very well with the base enamel and ensures the desired surface creating properties of the overall compound.

Mastered technology, broad field of application

Industrial enamelling from the material theory point of view, is a clearly definable and controllable process. The physical and chemical interrelationships are known and generally offer a broad range of possible optimal adjustments for the interrelationship between the basic material and the surface determining enamel within the given limits of the given load conditions.

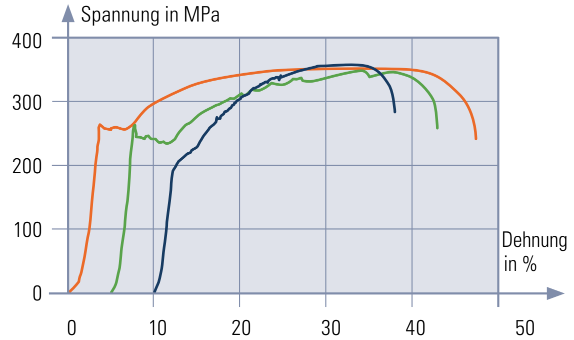
Apart from the traditional areas of application in chemical plant construction, pharmaceutical and water supply systems, industrial enamelling is gaining increasing significance in general plant and machine construction. Industrial enamelling is a first choice material system in all those applications where marked resistance towards aggressive media is to be assured in conjunction with the mechanical strength even in the case of high process temperatures.

Mechanical material behavior in composites

Seen from a material science point of view, the enameling process itself can be clearly described and controlled. The physical and chemical interrelationships are known and in general offer a wide scope of possibilities for aligning the interaction between the base material and enamel to determine the surface that provides the best solution for the load conditions present. The mechanical limits of the material system are known and reliably calculable. Any likely fears of the possibility of „spontaneous blistering" are to be attributed to a lack of knowledge of the overall context.

Mechanical material behavior

The use of enameled components has its limits in plant and engine construction where a failure of the material compound of steel or iron with enamel becomes likely. But in many cases the use of enameled components is out of the question from the beginning which is due to a lack or insufficient knowledge of the interrelationships of the materials when it comes to enameled construction elements.



Strain-stress curve (tensile test), from left to right. Reference test base material RT, 100 °C (212 °F), 200 °C (392 °F), glass lined probe 200 °C (392 °F)

In addition to other test parameters, the quality of an enameled product can be described by its color coating as well as its adhesive strength and impact resistance on the substrate material. High scores signify a very good material compound and, as a consequence, a high mechanical load capacity.

The dimensions of plant components are usually laid out versus the yield point or 0.2% of yield strength of the construction material, also taking the given safety values into consideration. This method allows a reduced and localized plastic flow for typical materials with a pronounced ductility, in order to reduce local stress peaks.

The construction of enameled construction parts cannot draw on the method above. In theory, the local plastic deformation of the substrate material will lead to a local failure of the material compound or, in other words, the flaking off of the enamel. A purely elastic deformation of the substrate material, however, does have not damaging effect on the enamel layer.

Laboratory samples, results, evaluation

The above mentioned interrelationships were tested and evaluated in a series of tests in co-operation with InfraServ GmbH, Frankfurt, Germany simulating real-life situations. The tests were initially to determine the stress-strain curve of

- smooth pipe samples (DN 15) with an outer enameled surface and
- non-enameled reference samples

during a tensile test (according to test standard EN 10002). The tensile tests were carried out in a saline solution with tension applied between the base material of the sample and a point contact in electrolytes. The damaged enamel was detected visually and by way of the current flow between the sample and point contact.

In addition, tin samples with an enamel layer on one side where tested in a three-point flexural test. The test temperatures were room temperature and 200 °C respectively. The test allows the following basic conclusions to be deduced:

Tensile tests

- Failure-free deformation of the entire sample in the elastic area of the stress-strain curve
- Initial failure of the enamel upon reaching the yield point, approx. 250 n/mm^2
- Strain-induced failure at the Lüders band of the base material
- Hardening of the base material following the entire delamination of the enamel

Outer glass lined pipe probe DN15 (1/2") for the tensile test (top). Onesided glass lined flat probe for the three-point bending test (bottom)

Bend tests

- Failure-free deformation in the area of the linear course of the load-deflection curve
- Local enamel failure at the beginning of the plastic deformation in the area of the maximum bending moment and thus the maximum tensile strength (as compared to the centric application of force)
- Failure-free on both sides of the location of maximum bending stress (tension side), thus in the area of non-plastic deformation

Distension reduced failure picture of enamel in the bending test in the area of the plastic deformation (load transmission). Outside of the plastic zone, left and right, damage-free enamel.

Construction component tests, results, evaluation

Original construction components – pipe endings connected by loose flanges DN 50 as used in the construction of chemical plants – were also tested under tensile and bending load until the point of failure. Regardless of the stress type, this test has also revealed typical failure patterns which correspond to theoretical methods and the laboratory tests carried out.

- The tensile tests results in a tilting of the flange faces beginning at the outside perimeter (reverse flanges) when overload occurs. This kind of plastic deformation leads to a local failure of the enamel in the area of excess load.
- The three-point flexural test reveals localized plastic deformations in the area of the application of force and the points of support. Here, too, and only here, the enamel layer fails and the enamel flakes off.

Test arrangement three-point bending test on two flanged tube ends DN50 (2")

Conclusion

With regard to the usual engineering design of construction elements which possess a considerable reliability regarding plastic deformation, no restriction as a result of deformation can be initially ascertained with regard to the use of enameled components. Only in the case of impermissible localized plastic deformation, the enamel suffers strain-induced damage.

GLASS LINING TECHNOLOGIES

JOBBING FOUNDRY

FITTINGS AND VALVES

DRAINAGE TECHNOLOGY

ENGINEERING

Düker GmbH & Co. KGaA

Hauptstraße 39-41
D-63846 Laufach

Phone +49 6093 87-0
Fax +49 6093 87-303

Internet: www.dueker.de
E-Mail: info@dueker.de