The properties of glass lining
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 enamel® 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 enamel® and glass lining which are different with regard to technical specifications like enamel® and enamel®P.

enamel® 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 data:

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 HCl-aqueous solutions

Corrosion velocity in NaOH-aqueous solutions

Corrosion velocity in H2SO4-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/mm² 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.

Material data:
- Specific weight: 2.5 g/cm³
- Coefficient of thermal conductivity: 1.2 W/mK
- Modulus of elasticity: 80,000 N/mm²
- Compressive strength: 800 N/mm²
- Tensile strength: 20-30 kV/mm
- Dielectric strength: 800 N/mm²
- Surface finish of enamel: 0.05 µm

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 T₁ and T₂, and the temperature of the heating/cooling agent should be between T₃ and T₄.

Stress curve in the enamel of steel

1. Hot product
   The temperature of the pipewall is 50 °C. Which temperature must be exceeded?
   From T_w = 50 °C horizontal to T₁ = 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 T₂ = 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 T₃ = 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 T₄ = 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.

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 constructiive 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.

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 SiO₂-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 1:2 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.

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).

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.

Fig. 3: Detail photograph of a corundum-blasted steel surface, approx. 3000-fold magnification (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.

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.
Mechanical material behavior in composites

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 of the base material and enamel to determine 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 of insufficient knowledge of the interrelationships of the materials when it comes to enameled construction elements.

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 enameled components.

- 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 electrolites. 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:

- 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/mm²
- Strain-induced failure at the Lüders band of the base material
- Hardening of the base material following the entire delamination of the enamel

In the case of enameled construction parts failure-free deformation, in the area of the plastic zone, left and right, damage-free enamel.

Conclusion

With regard to the usual engineering design of construction components 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.