Classification of Industrial Enamel rsp. glasslined technical equipment:

“… enamelling used in processes in which physical and chemical stress are in a main consideration…“

Basic features of glasslined technical equipment

Enamel optimized design and different illustrative examples based on industrial enamelling

Applications aside from the general known ones in plant construction of chemical industry

ELC2 – first steps, open questions

Glasslined technical equipment as all-round 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 the 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.

Enamelling itself, from the material technology point of view, is a clearly describable and controllable process. The physical and chemical relationships are known and generally offer a broad range of possibilities to optimally adjust the interrelationship between basic material and the surface determining enamel to the given load conditions. The mechanical limits of the material system are known and can be certainly calculated and any possible fear of "spontaneous flaking" results as a general rule through the lack of knowledge of these interrelationships.

Typical material properties

The term glasslined technical equipment 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 glasslined technical equipment is concerned the technological demands put on the surface finish are in the foreground. As a consequence, this
The 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 glasslined technical equipment:

- High resistance to corrosion attack, more especially in the case of acidic media even at higher processing temperatures.
- Color permanence, stable in presence of rain, snow, dust, heat, sunlight, oxidizing agents and corrosive fumes, unaffected by ultraviolet and infrared radiation
- Gloss, specular reflectance in a span of 50 up to 60°, extremely in a range of 10 to 85°
- Light reflectance, white enamels have a reflectance of ca. 75% to 80%
- Higher resistance to 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.

**Electrical and High Temperature properties**

- Dielectric strength, ranges from 200 to 500 V/mil (total thickness 4 – 6 mils), 16 – 20 kV/mm (Biscardi et al., J. Vac. Sci. Tech. A, 2000), increases with dense, decreases with bubble structure
- Dielectric constant, 6 to 12, sharp increase in the temperature range 120 to 150 °C, volume resistivity (at 400 cycl/s), 1013 to 1016 Ω/cm at rt, function of temperature
- Dissipation factor (at 400 cycl/s), 1 to 2 %, increases above 93 °C, decreases with increasing frequency
- Resistance to oxidation and corrosion, barrier to diffusion of oxygen, protective ability depends on temperature at which it starts to soften (ca. 200 °C below firing temp.)
- Thermal shock resistance, typical steel enamelling over 200 °C

**Physicochemical 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.

**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 the firing at 850 °C**

During the firing operation 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 takes 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 absorbability 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). 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**

Glasslined technical equipmentling 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, glasslined technical equipmentling is gaining increasing significance in general plant and machine construction. Glasslined technical equipmentling 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.

**First step in the field of UHV-application at CERN, definition of requirements and open questions**

As a first step to check the applicability of enamel coating in the field of UHV a steel pipe (diameter 100 mm, 500 in length) has been coated with a 20 mm broad enamel-layer inside (see also Fig. 4). It will be tested in the next time at CERN. To get a better feeling of the needed properties a number of requirements of the enamel layer has to be discussed and screened:

- Geometry, thickness, wideness
- Surface, smoothness, cleanliness of the enamel-free area
- Electrical and UHV-features
- Design of connection, flanges
- Production.
Figures, legend:

Figure 1:
Glasslined technical equipment with extremely smooth surface finish in conjunction with high wear resistance to abrasive acting media and high resistance to corrosion.

Figure 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.
Figure 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.

Figure 4:
Prototype of a steel pipe (diameter 100 mm) coated with a 20 mm broad enamel-layer inside.