THOUGHTS ON TESTING RESISTANCE TO ABRASION ACCORDING TO DIN-ISO 6370

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Summary

We studied the abrasion resistance test method according to DIN - ISO 6370 from the point of view of comparability. The comparison according to the standard can only be applied in the case of coatings with the same density. In order to make a correct comparison in the case of coatings with different density the loss in volume resulting from the abrasion should also be taken into account. We studied the possibility for this.

Introduction

The hardness of the glass-enamels vary usually between the values of 6 to 7 Mohs. This feature gives a favourable character of resistance to abrasion to the coatings.

Abrasion means wearing out of the surfaces by mechanical stress simultaneous with removal of material. The abrasion resistance of the enamel-coating to different particles depends mainly on the hardness, shape, size-distribution and concentration of the abrading particles as well as the characteristics of the liquid medium. Resistance to abrasion is aimed at defining the resistance of the enamel to the mechanical stress. One can draw conclusions about mechanical stress in practice from data obtained from the examinations only by using examinations reproducing the practice. Examinations should be carried out in real conditions in order to get applicable results. So it requires such test procedures, which make possible to reproduce the abrasion in practice exactly. Of course it is difficult to comply with this requirement, though it should be supposed the standard procedure to supply slightly tangible results and to stimulate carrying out more correct measurement.

The abrasion test makes possible to compare different enamel coatings, furthermore constitutes the basis of developing products with better resistance to abrasion.

In the following I will introduce the testing apparatus and the test procedure to be used for determination of the resistance to abrasion complying with the requirements of the standard and my thoughts connected with the way of the evaluation and comparability of the results. Finally I will demonstrate the trend of the rate of resistance to abrasion and my investigations in this field.

Definition of abrasion

According to the standard DIN 50 320 abrasion - in technical sense - means such undesirable change in surface of articles, which takes place as a result of coming off small particulate by mechanical effect.

Clear mechanical abrasion is reinforced usually by chemical or electrochemical processes.

Test of resistance to abrasion

The test of resistance to abrasion is described in the standard DIN-ISO 6370.

Short description of the procedure

Three similarly enamelled test specimens and three reference glass plates have to be mounted in the testing apparatus and simultaneous but apart to each other exposed to the abrasion attack of a mixture of fused aluminium-oxide grains, steel-ball and water for three periods of 30 minutes. The relative amount of wear W_r serve as the extent of the abrasion which can be calculated from the mean arithmetic value of the loss in mass for the three test specimens and the three reference glass plates.

Testing apparatus

Testing apparatus is composed of the following parts.

- Oscillating table with drive (Figure 1.)
  An oscillating table of about 10 mm in thickness, made of light metal, is placed horizontally on an eccentric drive in such a way that during the test every point of the oscillating table describes a horizontal circle of 22 mm ± 1 mm in diameter. The oscillating table is large enough for testing at least six specimens. The eccentric drive shall operate at a rotation frequency of 300 min^{-1} ± 3 min^{-1}.

- Specimen-holder (Figure 2.)
  At least six specimen-holders are required for the testing apparatus. The specimen holders are constructed of light metal lined with rubber. The opening is used for introducing the abrading charge and is able to be closed by rubber stopper.

- Steel balls
  The balls are made of stainless-steel in accordance to the standard DIN 17 440, for instance: X 40 Cr 13 (Material No.:1.4034) and they are hardened.

  The following are required: 500 g of balls of 4 mm in diameter
  400 g of balls of 3 mm in diameter
  250 g of balls of 2 mm in diameter

- Abrading material
  Abrading material is the grains of fused aluminium-oxide, of grain size P80.

- Others
  - Balance, at least of 200 g capacity, accurate to 0,2 mg
  - Desiccator, for treating specimens before weighing
  - Drying oven, capable of maintaining temperatures of at least 130 ^{o}C

- Test specimens
  The specimens for testing have to be prepared in accordance with the standard specified in DIN-ISO 2723 and 2724 for the appropriate basis metal. The material of the specimens is enamelling steel plate with 2 mm thickness.

Carrying out the test

The test has to be carried out with at least three test specimens and three reference glass plates at the same time. Each specimen holder has to be filled with an abrading charge and closed it with the stopper.
The abrading charge consists of 80 g steel balls of 4 mm in diameter, 60 g steel balls of 3 mm in diameter, 35 g steel balls of 2 mm in diameter, 20 ml ± 2 ml of water and 3 g ± 0,01g of abrasive material.

Fix the specimen holders on the oscillating table. Start the apparatus for a period of 30 minutes. Then remove the specimens thoroughly rinse under running water and replace them on the apparatus with fresh abrading charge. Start the apparatus for a further period of 30 minutes and then repeat the whole procedure a third time. Test specimens exposed to abrasion altogether three times for 30 minutes will be evaluated.

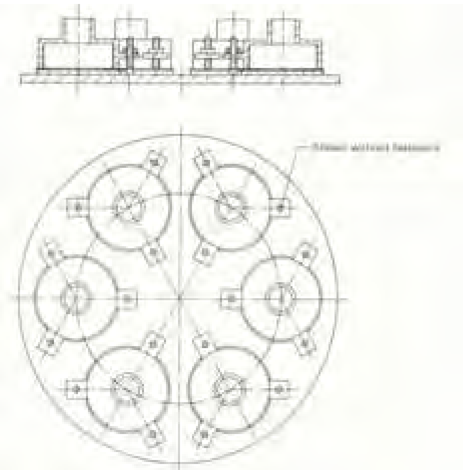


Figure 1. - Arrangement of the specimens in the abrasion testing apparatus

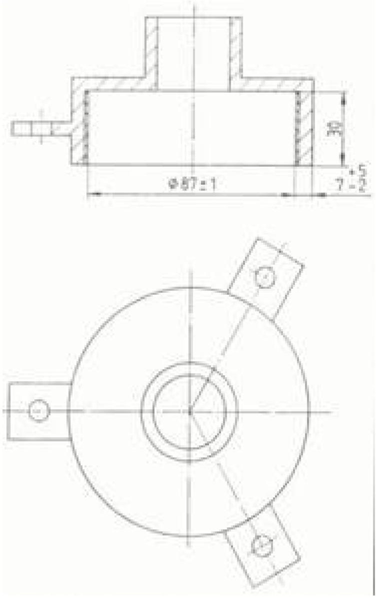


Figure 2. - Retaining ring

Expression of results

The loss in mass, Dm, is to be calculated for each test specimen and reference glass plate. The relative amount of wear W_r is to be calculated using equation (1):

$$W_r = \frac{Dm_{s1}+Dm_{s2}+Dm_{s3}}{Dm_{r1}+Dm_{r2}+Dm_{r3}} \qquad (1)$$

where
- Dm_{s1}, Dm_{s2}, Dm_{s3} are the respective losses in mass of the test specimens
- Dm_{r1}, Dm_{r2}, Dm_{r3} are the respective losses in mass of the reference glass plates

Theory of evaluation and the practice

In the foregoing we could see how the abrasion test works according to the norm, furthermore how the test results are evaluated. Unfortunately the determination close to practice can't be realised comply exactly with the norm. So the examination serves as comparative test. Most obviously the standard was elaborated for this purpose. The ratio W_r obtained at evaluation point to this. If one consider this test places the observed enamel at the point of a scale of number, points out that the observed enamel is better or worse than the other one. It does not present a basis for creating a numerical idea in connection with the resistance of coating to abrasion for the practical expert.

Therefore the producers of enamel coated chemical equipment do not apply the procedure of comparison to the reference glass plate, they calculate the ratio of resistance to abrasion using equation (2) as the loss in mass taking place on a unit surface during a unit time:

$$v_a = Dm / (At) \qquad (2)$$

where: - Dm - loss in mass (mg)
- A - attacked surface (cm^2)
- t - testing time (hour)

The values obtained so are tangible numerical values, however there is no conclusions compare with the reality. They give some kind of information about the effect of the abrading material on the duration of the coating. In this case as well as in the comparison according to the standard, **the comparison can be applied in the case of coatings with the same density.**

The question arises whether it is the best way to express the resistance of coatings to abrasion by loss in mass. It is sure that from the point of view of measuring technique this method is a solution that can be carried out the most safely, but the measuring does not take into account the reducing of the layer thickness resulting of abrasion.

The density of the coating is influenced by the mill additions, the composite of the fritt as well as the bubble structure of the coating. In the case of chemical resistance enamels it is true especially as this is the only one possibility to improve the mechanical properties. Consequently each enamel cannot be considered to have the same value of density.

Generally the density is about 2,5-2,6 g/cm^3 for enamel fritts, while about 2,2-2,4 g/cm^3 for the enamel coatings. If enamel contains zircon the density might be higher. Recently zircon has widely been added as mill-addition or in melted form for improving the mechanical and thermo-mechanical properties as well as the chemical resistance.

We examined changing of the density of Enamel"A" as a function of zircon content. We added zircon as mill addition. We made a coating from the enamel slip and measured the bulk density and the specific weight of the coating. The results can be seen in Table 1.:

Table 1.

	ZIRCON CONTENT (%)		
	0	**15**	**30**
Bulk Density (g/cm^3)	2,4	2,7	3,0
Specific Weight (g/cm^3)	2,6	2,8	3,2

We can see, that the bulk density and the specific weight increase with the increasing the zircon content. The bulk density is smaller than the specific weight.

As the density of the coatings may be different from one another, so when comparing them according to the standard it may happen that the enamels qualified of the same value on the basis of loss in mass have a different value of loss in coating thickness. It may happened, that the enamel qualified of better on the basis of loss in mass has larger value of loss in coating thickness than one enamel qualified of worse.

But it is not indifferent for the users how long the enamel wear off the base metal. Important for them is that the change in the coating thickness should be the least possible.

In order to make a correct comparison in the case of coatings with different density the loss in volume resulting from the abrasion should also be taken into account.

Technically this can be carried out by weighing the density and taking into account in evaluation or measuring the change of coating thickness directly.

The experiments was taken in this direction.

Examinations

In my examinations I have investigated the dependence of the abrasion resistance on testing time expressed in loss in mass and in loss in coating thickness too, the change of the ratio of resistance to abrasion in time and in the different testing period. I made the investigations by freshening the abrading material in each period and without freshening too. I have investigated the density and the abrasion resistance of different enamels.

Density measurement

There are two types of density. Partly the density of the compact enamel, which can be determined by using pycnometer and depends on the enamel composition, partly the bulk density of the coating which beyond the above mentioned depends on the bubble structure of the coating. It can be determined by density measurement of the base-enamel-free coating with pycnometer or using hydrostatic balance.

Coating thickness measurement

The change in volume resulting of the abrasion can be easily determined by coating thickness measurement. The resistance to abrasion can be expressed in change of coating thickness without weighing by numerous measurement taken in test plates and statistical evaluation of the data. We used FISCHER Deltascope MP3C coating thickness gauge for measurements and FCC100 software for data-processing.

Resistance to abrasion as a function of time

I investigated resistance to abrasion in testing time without freshening the abrading material and with freshening it as well. By *freshening the abrading material* I mean measuring in each 30 minute period as described in the standard with in each period washed out and refilled sample holders. By *measuring without freshening* the abrading material I mean a continuous measuring with once filled-up sample holders. I took measurements with increased testing time too. The results are given in Diagram 1. and Diagram 2.:

Diagram 1.
Dependence of abrasion resistance on testing time expressed in loss in mass

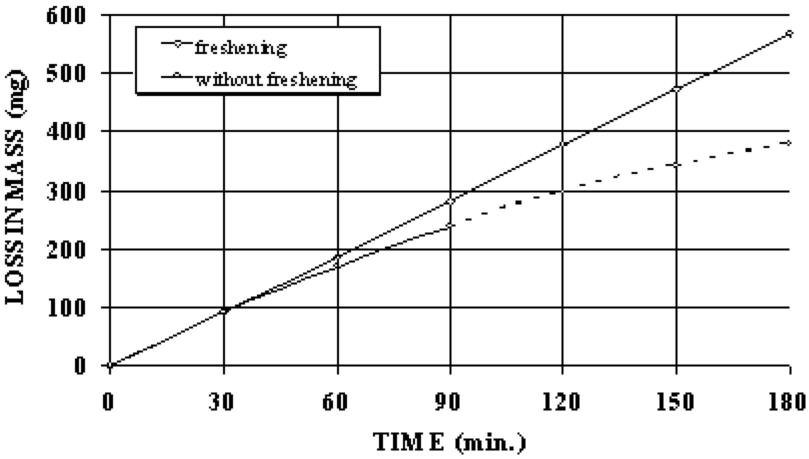
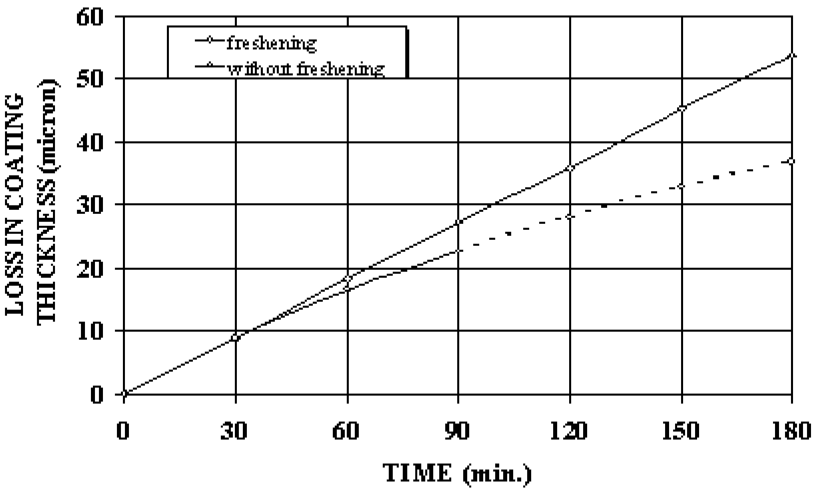


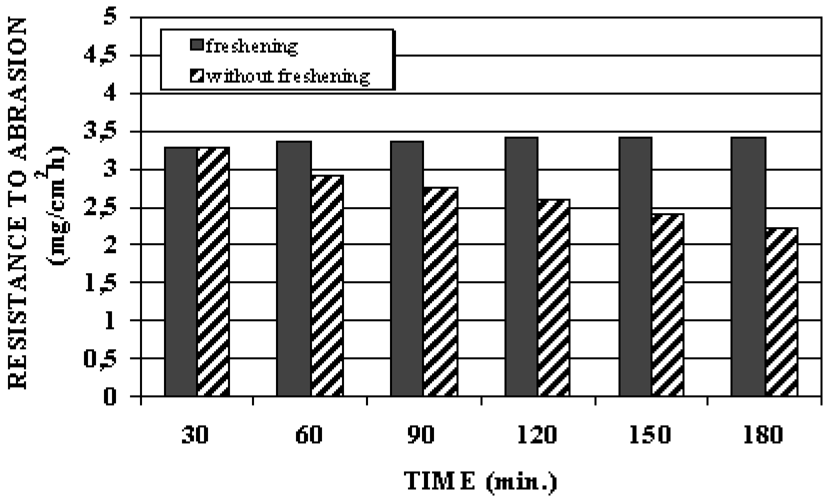
Diagram 2.
Dependence of abrasion resistance on testing time expressed in loss in coating thickness



It can be seen, that the loss in mass and the reducing of coating thickness during the abrasion with freshening arises practically linearly in abrading time. The dependence without freshening is not linear. It can be established, that the extent of abrasion is more intensive in the case of freshening of the abrading material than without it. Standard tries to approach to the practice by freshening the abrading material.

The influence of testing time on the ratio of resistance to abrasion expressed on the base of loss in mass is given in Diagram 3.:

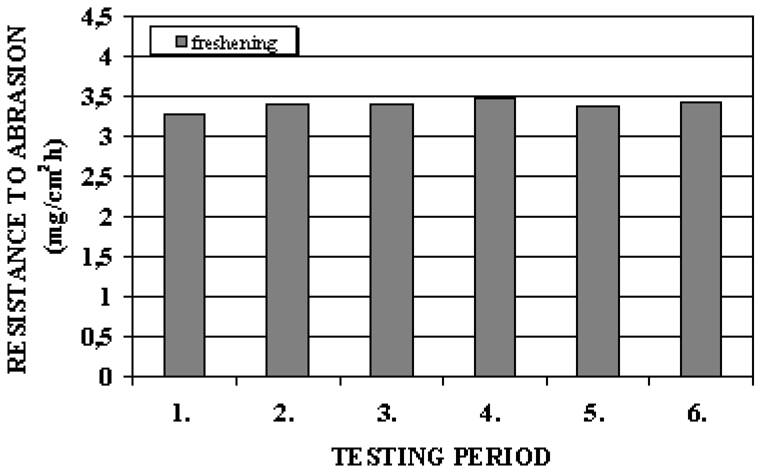
Diagram 3.
Influence of testing time
on the ratio of resistance to abrasion



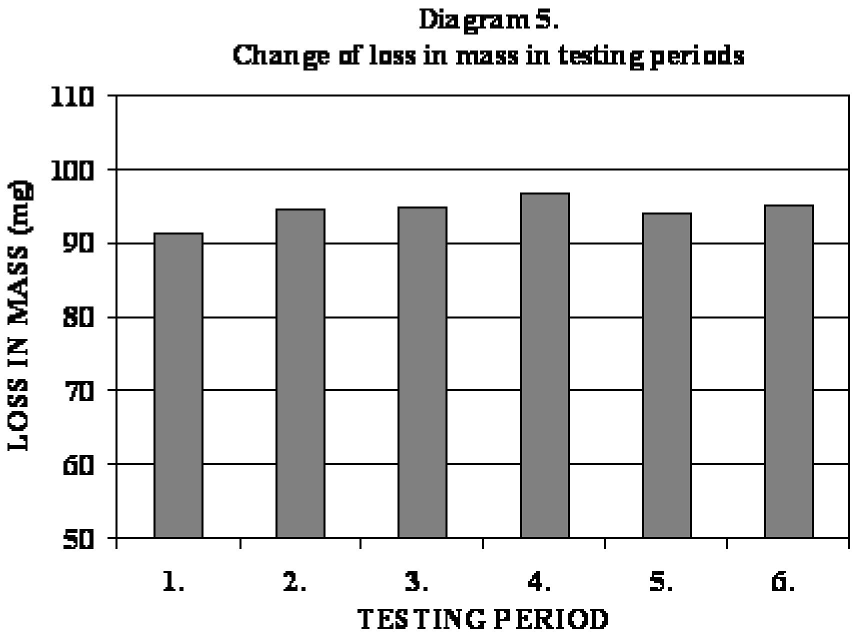
It can be established that the ratio of resistance to abrasion is practically constant in the case of freshening the abrading material, while shows decreasing without it. This means one can get comparable results in the case only if prescriptions of the standard have been perfectly kept. If the abrading material is not freshened, more favourable results can be expressed than the real one.

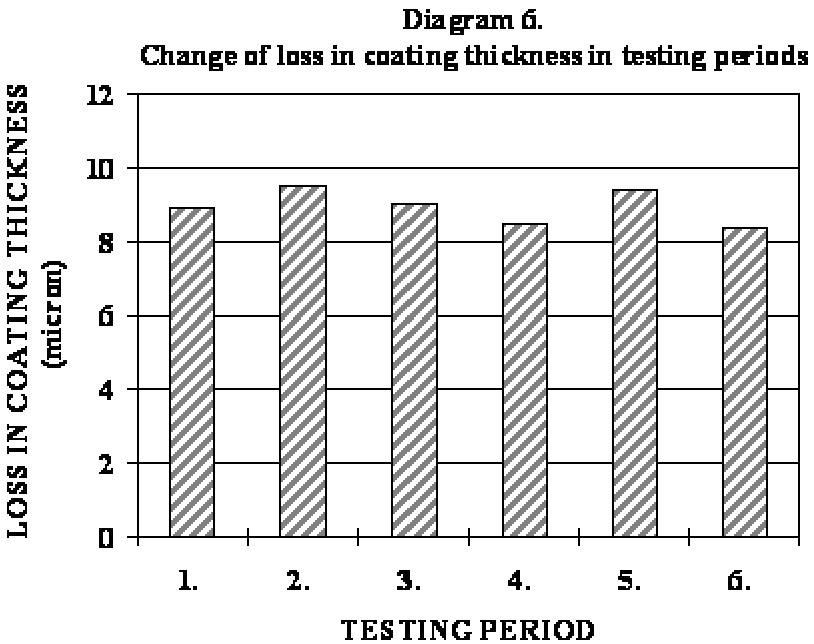
The ratio of resistance to abrasion in the testing period in the case of freshening the abrading material practically shows constant value (Diagram 4.).

Diagram 4.
Change of the ratio of resistance to abrasion
in testing periods



The change of loss in mass and loss in coating thickness in the different testing period are given in Diagram 5. and Diagram 6.:





We determined the dependence of the density and the resistance to abrasion measured by weighing the loss in mass and loss in coating thickness of the enamel added zircon. We added zircon 15% and 30 % by weight as mill addition to the investigated enamel. The results can be seen in Table 2.:

Table 2.

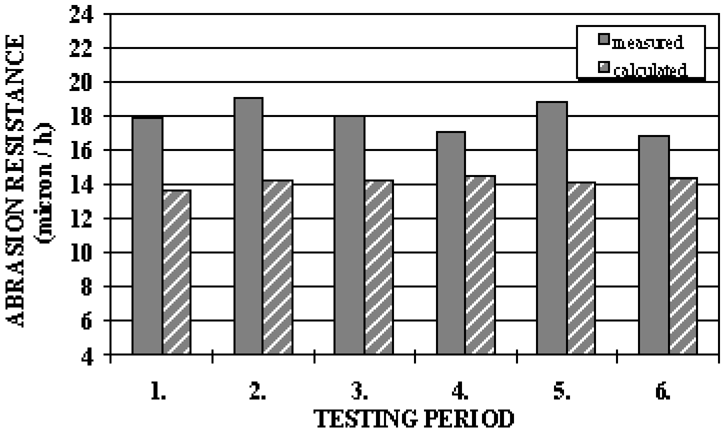
		Zircon content Enamel "A" (%)		
		0	**15**	**30**
Specific weight	**(g/cm^3)**	2,6	2,8	3,2
Bulk density	**(g/cm^3)**	2,4	2,7	3,0

Resistance to abrasion calculated in loss in mass	**(mg/cm^{2}h)**	3,3	2,6	2,3
Resistance to abrasion calculated in loss in mass and bulk density is to be taken into account	**(mm/h)**	13,6	9,6	7,6
Resistance to abrasion with direct coating thickness measurement	**(mm/h)**	17,3	12,6	10,4

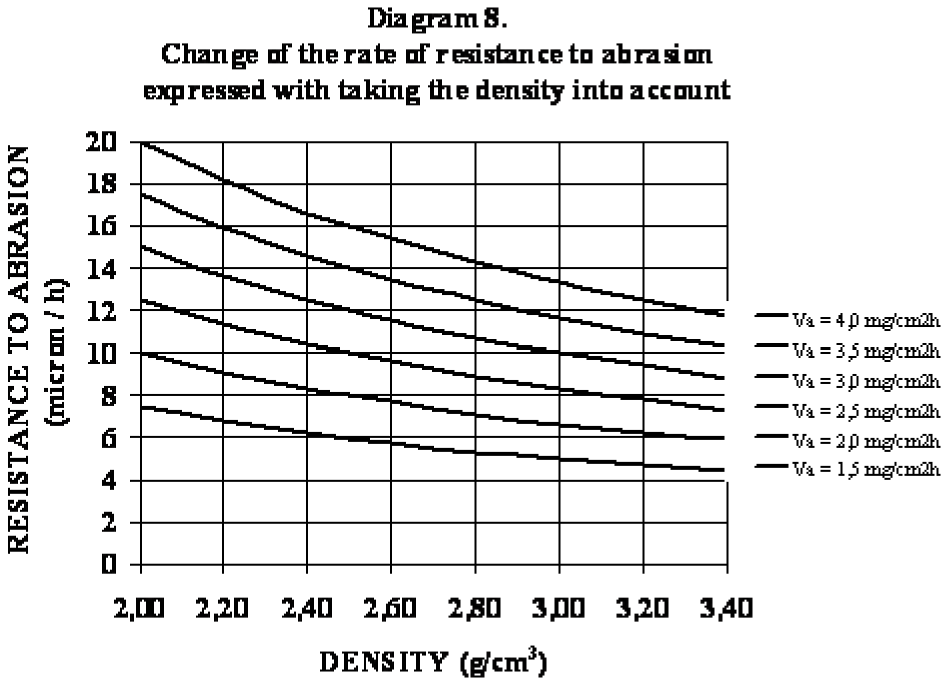
We can say, that the density and the resistance to abrasion increase with increasing the zircon content. There is a little difference between the calculated and the directly measured results.

The measured and calculated results expressed in coating thickness in testing periods are given in Diagram 7.:

Diagram 7.
Comparison of measured and calculated abraion resistance expressed in coating thickness



The change of the rate of resistance to abrasion expressed with taking the density into account are given in Diagram 8.:



It can be established that if the different enamels are qualified without taking the density into account, one can come to wrong conclusions in connection with the resistance to abrasion.

Conclusions

The results discussed above show that:

- Enamels have different density, which depends not only on the composition but the bubble structure and the mill additions too.
- We can compare the enamels from the point of view of resistance to abrasion only if the density is taken into account.
- The loss in mass and the loss in coating thickness resulting from the abrasion plotted against the testing time is linear.
- There is a little difference between the results calculated with the density taken into account and the results from directly coating thickness measurements.

There are two possibilities to determine the resistance to abrasion considering the density:

a) indirectly with determining the density
b) directly with measuring the coating thickness

So we can get comparable results in the case of enamel coatings with different density.