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1. How to produce heatable rear windows

1.1 “Direct Deposit System”

The Direct Deposit System is the conventional method of producing heatable rear windows by direct screening of a silver paste mixture in a single layer. The required electrical resistance is controlled by the thickness of the fired silver layer. This can be varied by altering the mixing ratio of two silver pastes (of different silver contents) and by changing the screen printing process parameters.

1.2 “Electroplating System”

The Electroplating System is a multi-layer process, in which the electrical resistance is controlled by the thickness of copper and nickel layers which are electroplated onto a thin, pre-fired silver film. Although the electrical resistance can be more accurately controlled and the final nickel layer does provide good anti-corrosion properties, the Electroplating System is usual more costly than the Depot Direct System, as well as having the potential environmental problems associated with electroplating processes.

1.3 Production Steps

- a) Print black enamel colour
- b) Dry or cure the enamel ink
 - I. Infra-red (physical drying)
 - II. UV curing (chemical “drying”)
- c) Print silver paste
- d) Dry silver paste (Infra-red drying)
- e) Firing and glass bending
- f) Galvanization – for Electroplating Process only
 - I. Copper
 - II. Nickel
- g) Soldering terminal connections

2. Calculations

2.1 Calculation of electrical parameters of a heatable rear-window

Basic calculations require only simple electrical theory:

- Ohm's Law
- Kirchoff's Law

Ohm's Law

$$U = I \times R \quad \Leftrightarrow \quad R = \frac{U}{I} \quad \Leftrightarrow \quad I = \frac{U}{R}$$

U = voltage (Volts)
I = current (Amps)
R = resistance (Ohms)

$$P = U \times I \quad \text{with} \quad I = \frac{U}{R}$$

$$\Rightarrow P = \frac{U^2}{R} \quad \Leftrightarrow \quad R = \frac{U^2}{P}$$

P = power (Watts = Volts x Amps)

Kirchoff's Law

$$R = \frac{n}{R_L}$$

R = total resistance
R_L = resistance of 1 line
n = number of lines

The steps in the calculation are:

- 2.1.a What is your supply voltage (e.g. 12 - 13 V)?
- 2.1.b What is your power requirement in Watts, to produce desired heating effect?
- 2.1.c From $U = I \times R$ (Ohm's law) and $P = U \times I$, calculate total resistance required for the resistive track.
- 2.1.d Which pastes do we need?

Example I: Supply voltage 13 volts = U
Power requirements to achieve the desired heating effect
169 watts = P

$$R = \frac{U^2}{P} = \frac{13^2 \text{ volts} \times \text{volts}}{169 \text{ volts} \times \text{amps}} = 1 \frac{\text{volts}}{\text{amps}} = 1 \Omega$$

Therefore, the total resistance of the track must be 1 Ω .

For simple calculation, neglect resistance of the busbars.

In general the electrical resistance R for fired Ag-layers is given in Ohm (Ω) per square (\square) at a fixed fired layer thickness.

Example II: layout 10 lines
length per line = 1 000 mm
width per line = 0.5 mm

a) number of squares

$$\frac{\text{length of the lines}}{\text{width of all lines}} = \frac{1000 \text{ mm}}{10 \times 0.5 \text{ mm}} = 200 \square$$

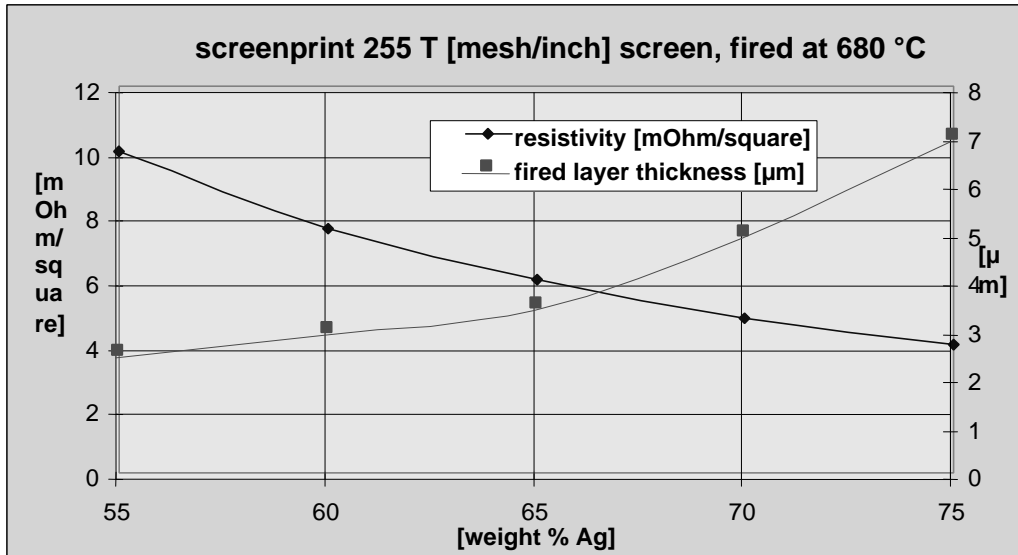
b) Ohm per square

The total resistivity should be 1 Ω (see example I)

$$\begin{aligned} \Rightarrow \frac{\text{Ohm}}{\text{square}} &= \frac{1 \Omega}{200 \square} = 0.005 \frac{\Omega}{\square} \\ &= 5 \frac{\text{m}\Omega}{\square} \end{aligned}$$

To get a heatable rear-window, having P = 169 watts from 13 volts with the layout described a silver paste giving 5 m Ω /? after screen printing and firing the glass must be used (simple calculation, neglected busbars). The resistance of 1 line can be calculated by using Kirchhoff's law.

2.2 Mixing curve for two silver pastes



The values for the electrical resistivity of silver paste mixtures depend on the detailed working conditions (for example, drying-firing profile).

Therefore, actual values must be determined for each individual production-line. The mixing curve shown above is for example only based on results achieved from two specific pastes tested under our laboratory conditions.

3. How to use Ferro Silver pastes

3.1 Storing

It is recommended that Ferro silver pastes are stored in a dry environment at between 4 °C and 25 °C.

The unopened cans of paste should always be allowed to stabilise to the temperature of the printing room before use, as this avoids any atmospheric condensation problems.

3.2 Stirring and mixing

The quantities required for the intermixing of pastes or for additions of thinning and other special oils to standard pastes, should be weighed using a balance, or dispensed via graduated vessels.

It is recommended that mixing and stirring of pastes be carried out using an electrical stirrer with power rating of at least 700 watts.

Pastes should be stirred thoroughly before printing – this reduces the inherent thixotropic character in the paste and ensures good printing from the outset.

3.3 Measurement of viscosity

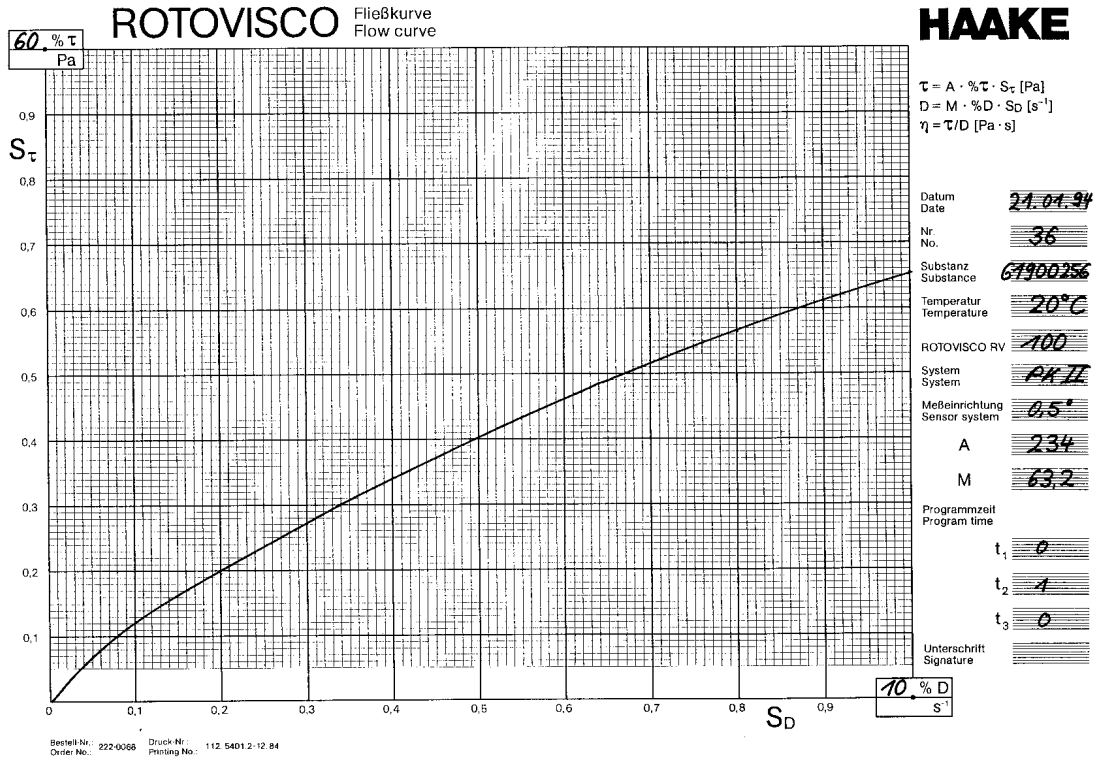
Most silver pastes have thixotropic, as well as pseudoplastic properties and as a result, their viscosity decreases with increasing shear rate.

Flow characteristics of the paste on the screen, as well as the levelling properties of printed lines, are associated with the paste rheology at low shear rates. These conditions can be achieved using a rotational visco-meter fitted with spindles and performing the measurement at low rotational speeds.

While printing, the material passes the screen meshes with respective high shear rates and forces applied. Rotation viscometers with plate-cone systems can give comparable conditions for such viscosity reading.

All measurements should be carried out at a constant temperature, since viscosity is highly temperature dependent.

Flow curve measured with a plate & cone system



Viscosity η can be calculated from shear rate D and shear force τ (using the equations shown above).

3.4 Influence of viscosity

The optimum operating viscosity of the paste is, to some extent, dependent on the parameters associated with the screen printing process. Changes, such as variations in ambient temperature, squeegee speed, squeegee to screen angle, squeegee pressure and screen to substrate snap off distances, will all affect the quality of the printed film. Adjustment in the paste viscosity for any particular screen printing set up can only be fully optimised by experiment.

If, for instance, printed lines have a tendency to spread on standing, it is likely that the viscosity of the paste is too low. Alternatively, where the printed films display mesh marking, pinholes or very thin areas, it is likely that the paste viscosity is too high.

3.5 Printing

To achieve acceptable soldering, the layer thickness after firing should be at least 3 µm.

The most commonly used screens are:

- ◆ 230 - 280 mesh/inch for the Electroplating System
- ◆ 175 - 240 mesh/inch for the Depot Direct System.

Typical screen printing conditions are:

- ◆ hardness of squeegee 70 - 80 shores
- ◆ squeegee speed 20 - 40 m/min
- ◆ snap-off distance glass to screen 2 - 4 mm

Users should however, consult the manufacturers of both screens and printing machines to ensure optimum set up of their equipment. It is particularly important to ensure that the screen and substrate are parallel in order to achieve an even film thickness. Furthermore, the screen printing station should be sited in an area that is not only clean and dry, but also preferably temperature controlled.

3.6 Drying and storing before firing

Ferro also offers products which do not have to be dried before firing. Special pastes with slow evaporating solvents, should be used in combination with an infra-red drying system. If storage between printing and firing is necessary, products containing plasticisers might be advised. These pastes should be dried as well.

Best results are obtained, anyhow, with an infra-red drying equipment (before firing) in order to achieve constant resistance and maximum adhesion.

Suitable products should be selected together with our technical service group.

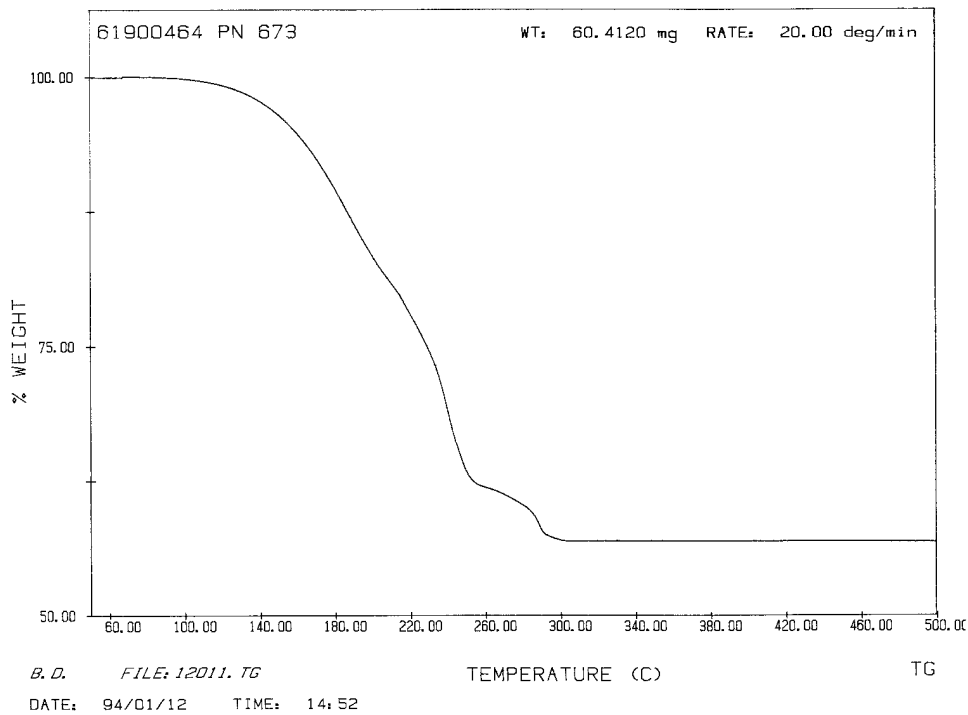
3.7 Firing

In general, Ferro silver pastes can be fired in all common glass bending and tempering furnaces. In some furnaces the fast firing of approximate 2 Minutes can cause a difference of temperature between glass surface and silver layer. We recommend drying before firing, firing time as long as possible (within the limits of the bending process). The optimum firing cycle should be determined by experiment.

Processes during a firing cycle:

- a) 200 °C - 300 °C solvents and resins will evaporate or burn off
- b) 450 °C - 500 °C Silver particles will start sintering
- c) 600 °C - 700 °C frit system in black enamel becomes fluid

Thermogravimetric Analysis



Above figure shows the thermogravimetric analysis of a typical silver paste. The paste is heated at a rate of 20 °C/min and weight loss (evaporation and burn out of organic material) is measured.

3.8 Overprinting Silver onto black enamel

Difficulties can occur when printing and firing silver paste on top or between ceramic colour layers (sandwich). The organic systems of silver and colour pastes must be compatible to avoid cracks and pinholes.

Solderability can be effected by the migration of ceramic particles into the silver-layer. Chemical reactions or different heat absorption can cause a discoloration of the printed layers. The most suited product combination of silver and black must be selected by tests under production conditions. Ferro offers compatible systems of ceramic colours and silver pastes.

3.9 Electroplating

Fired silver films obtained from Ferro silver pastes for heatable rear windows can, in most cases, be electroplated. Potential problems can occur, when the silver or copper layers are too thin or the plating current is too high.

3.10 Soldering

The terminals can be soldered onto the busbars using solder irons, direct electric current heating, high frequency heating or hot gas/air methods.

For soldering on the electroplated Ni surface, we recommend solder compositions e.g.: Sn/Pb 60/40, 50/50 or 40/60.

When soldering direct onto the silver surface, a soft solder alloy, containing a flux and 2% to 4% silver is recommended, e.g. Sn/Pb/Ag (62/36/2); 50/46/4). This will reduce solder leaching effects.

B. Process and Quality Control

To fulfil our customers' requirements to their entire satisfaction has always been Ferro's view and aim. Quality is the key principle for our every day business approach.

This means that:

- We consistently meet our customers' requirements.
- We continuously strive to improve on all aspects of quality.

Key components are the involvement and training of all employees as well as co-operation with our customers, suppliers and the community.

Our Quality Management System, certified according to DIN EN ISO 9001 is the tool to achieve these aims.

Ongoing improvements to our Quality Management System Standards will guarantee that we remain an innovative and reliable partner to our customers not only today, but also in future.

If further details are required do not hesitate to call our customer service group.