OVERLOAD AND RATING OPERATIONS OF HBC LOW VOLTAGE FUSES AT REDUCED HEAT TRANSFER

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Abstract: The compact mounting of fuse-links in more and more space-saving HBC fuse-rails and -switches leads to reduced heat transfer conditions for the fuse-links. While the time-current characteristic is not influenced, the rating operation is influenced due to the forced interdiffusion of solder and melting element materials. Especially, the temperature of the melting elements made of copper should not exceed 160°C in order to guarantee a life time higher than 48 hours in narrow boxes and at rating currents. Moreover, i) tests made with industrial fuses from different producers have shown that the usual 8-hour-test is not able to reflect completely the melting element behaviour, and that ii) the temperature of the upper blade contact can be used as a criterion for operating conditions of fuse-links within any chamber.

I. INTRODUCTION

Low voltage HBC fuses operated in the past in open fuse bases, as well as in single-pole and as in three pole design. Due to the open construction, the temperature of the ambient air near the fuse-link is kept low by free convection. In accordance with these fuse-link operation conditions the time-current characteristic is related to an ambient temperature of 20°C ± 5°C according with DIN VDE 0636.

More recently, fuses are mounted in breaking fuse bases, fuse-rails or switch-disconnectors, and possibly in cable distribution cabinets, with reduced convection because of their slimline constructions. Therefore, the ambient temperature is increasing when the fuse-links are built in chambers with restricted convection .

In accordance with the statement in EN 60269-1 or IEC 269-1 the fuse should carry its rated current up to an ambient temperature of 55°C. However, there is no measurement procedure for this temperature. Moreover, the voltage drop over the entire fuse-link is not sensitive enough to reflect the changed conditions at the soldering points. It was the aim of this investigations to find out a measurement parameter which i) reflects sufficiently the thermal limit for diffusion processes of solders on the melting elements, and ii) is measurable very easily.

II. TIME-CURRENT CHARACTERISTIC

This characteristic can be calculated with a simplified 2D-model using the Finite Element Method (FEM) and the ANSYS – Code. The results for a NH1-160 A fuse is shown in Figure 1. As is seen, the convection heat transfer has to been taken into account only for current intensities of 1.25 x I_{rating} and smaller.

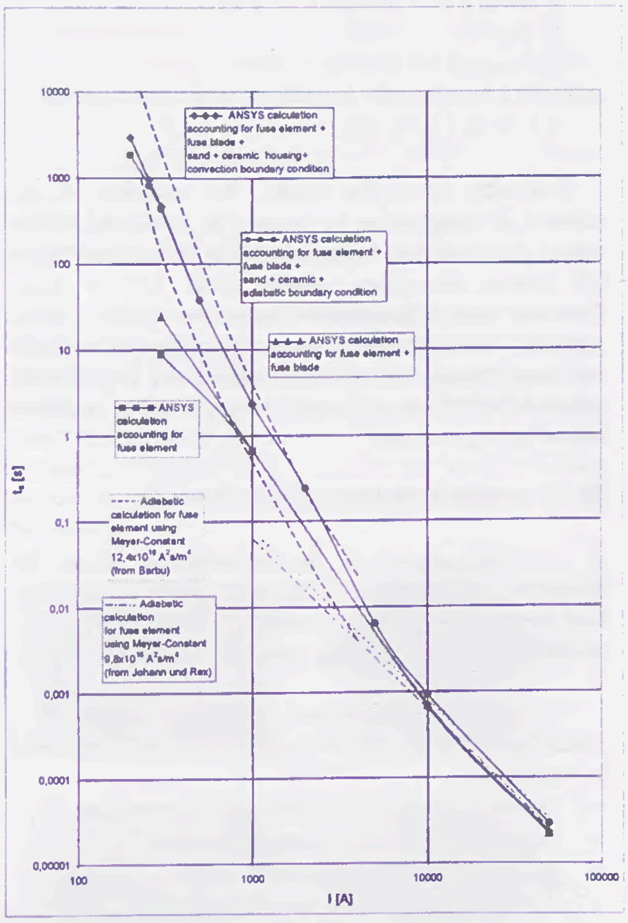


Fig.1: Time-Current-Characteristic of NH1-160A-Fuse with time-current zones (dashed lines) acc. with IEC 269-1-2

The characteristics are calculated by assuming the following material properties inside the temperature region of 0 □ T □ 1084 °C :

- copper melting elements [MOR]
  λ [W/m·K] = 401 – 0.0675·T (linear fit[CRC])
  □ [kg/m^3] = $8890/(1+16.5x10^{-6}\cdot T+4x10^{-9}\cdot T^2)$
  c [Ws/kg·K] = $380(1+3.55x10^{-3}\cdot T+3x10^{-8}\cdot T^2)$
  ρ [□·m] = $1{,}59x10^{-8}(1+4{,}3x10^{-3}\cdot T+5x10^{-7}\cdot T^2)$
- brass blades [WIE]
  λ [W/m·K] = 123
  □ [kg/m^3] = 8440
  c [Ws/kg·K] = 376
  ρ [□·m] = $6.17 \cdot 10^{-8}$
- sand [FRE]
  λ [W/m·K] = 0,44
  □ [kg/m^3] = 1757
  c [Ws/kg·K] = 810
- ceramic body (cordierite)
  λ [W/m·K] = 0,0125·T + 1.25
  □ [kg/m^3] = 2100
  c [Ws/kg·K] = 5.0 · T + 700

and with a heat transfer coefficient to the surrounding
$\alpha = 10\ W / m^2 K$ [BEJ].

Following from the results, the variation of the ambient air temperature by heating up fuse-links within closed chambers has to be taken into the consideration for current intensities smaller than 1,25 x I_{rating}. However, for continuous operations with rating currents, the temperature increase influences strongly the interdiffusion between the solder and the element material (M-Effect) and cannot be neglected as is shown below by experiments.

III. EXPERIMENTAL SET-UP

The scheme of the experimental set-up for measuring temperatures at different points of the fuse-link under reduced heat transfer in an enclosing box made of thermally isolating material is shown in Figure 2.

Using this arrangement, the temperatures at 5 special points under different operating conditions could be measured:

- the temperature of the upper cable connection
- the temperature of the upper fuse blade
- the temperature of the ceramic body
- the temperature of the lower fuse blade
- the temperature of the lower cable connection

The temperature of the soldering point is optionally measured with especially mounted fuse-links. The temperatures are measured by thermocouples made of NiCr-Ni or Pt-100 measuring resistances. The values are stored via the data recording system ALMEMO 8990-6 to the PC. Furthermore, the voltage drops across the fuse links and the current intensities through the fuse-links were registered. The voltage is measured by an AC-to-true-RMS-transformer, the current is measured by a 600A/5A or a 5A/20mA transformer , respectively.

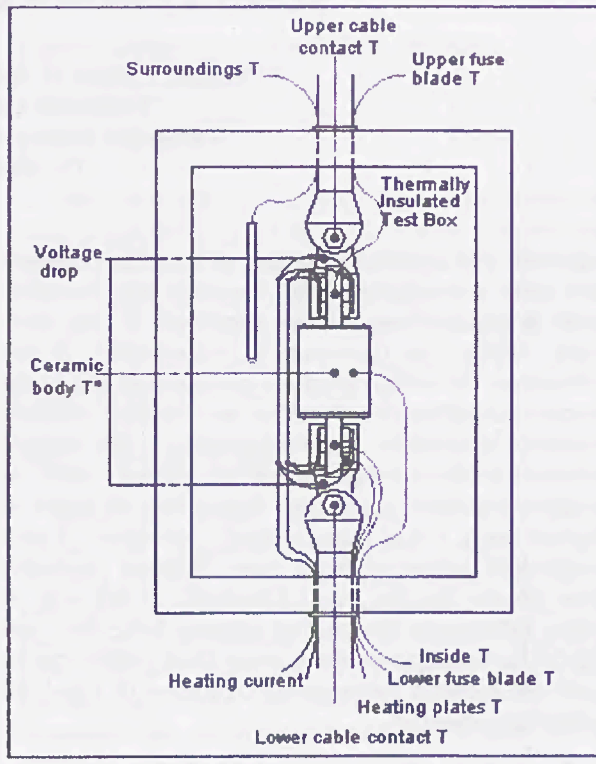


Fig. 2: Experimental set-up for temperature measurements

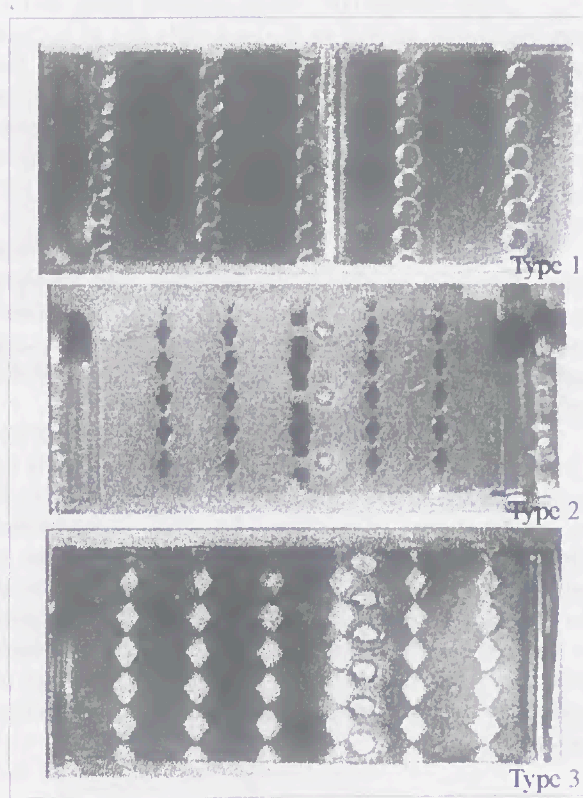


Fig.3: Types of melting elements investigated

The measurements are carried out for the NH3-315A-fuses with three different types of melting element design (Figure 3).

Moreover, to estimate the temperature limits for the upper fuse blade, both , the upper and the lower blade are heated by means of ceramic coated micro-heaters made of platinum which are fastened on each side of the blades. By means of this arrangement the temperatures at the blades can be controlled exactly.

The tests are carried out in the test field at the TU Ilmenau. The test current intensity is controlled by a motor-driven transformer in series with a high-current transformer. The current fluctuation is about 3%.

IV. CHARACTERISATION OF FUSE-LINK CONDITIONS

IV.1 The upper fuse blade temperature

At standard ambient temperatures of $T_A = 20°C$ the temperature of the upper blade is about 65 °C as shown in the Figure 4. This temperature increases up to 85°C when the ambient temperature rises to 55°C , and up to 140°C at an ambient temperature of 130°C, as measured at the points given in Fig.2.

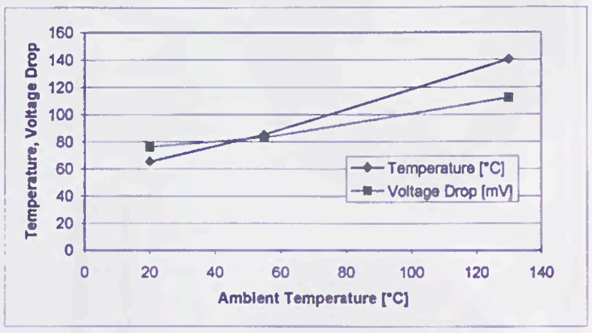


Fig.4: Temperature of the upper blade versus the ambient temperature at rated current for NH3-315A

Only the two lowest values of the ambient temperature, 20 and 55 °C, are allowed according with the standards.

In contrast to temperature of the upper blade, the voltage drop is not so sensitive to varying ambient conditions: A temperature rise of 1 K leads only to an increasing in the voltage drop of about 0,3 mV. Thus, for voltage measurements voltage meters with a high accuracy are required.

Therefore, the temperature of the upper blade will be used in the following as the governing parameter for the operating behaviour of fuse-links or melting elements, respectively.

IV.2 The interdiffusion process

The interdiffusion between the solder and the fuse element material is a solid state process, and therefore it occurs already at room temperature. However, in accordance with the Arrhenius relation

$$k = A \exp(-B / T), \qquad (1)$$

where k - coefficient of the reaction velocity
A,B - process parameters

the diffusion process will be accelerated when the temperature increases. Assuming parabolic dependence for diffusion depth

$$x^2 = k \bullet t \qquad (2)$$

where x – diffusion depth ,
t – time,

the k – values for the frequently used solder materials and copper as the element material are obtained by optical microscope measurements of the diffusion zones at different temperatures and times. The resulting rates are as follows:

- Sn/Cd 80/20
  $k\,[cm^2/s] = 0{,}066 \exp(-12.190/T)$ (3)
- Sn/Ag 95/5
  $k\,[cm^2/s] = 0{,}0702 \exp(-11.698/T)$ (4)
- Sn/Cu 97/3
  $k\,[cm^2/s] = 0{,}0001 \exp(-8.317/T)$ (5)

At low temperatures the diffusion proceeds slowly. However, fuse element temperatures of about 180°C lead no more to stationary conditions. The reduction of the current carrying cross section due to the interdiffusion leads to the temperature rise due to the increasing current density which in turn leads to further increase of diffusion, and finally to the breaking-off of the circuit.

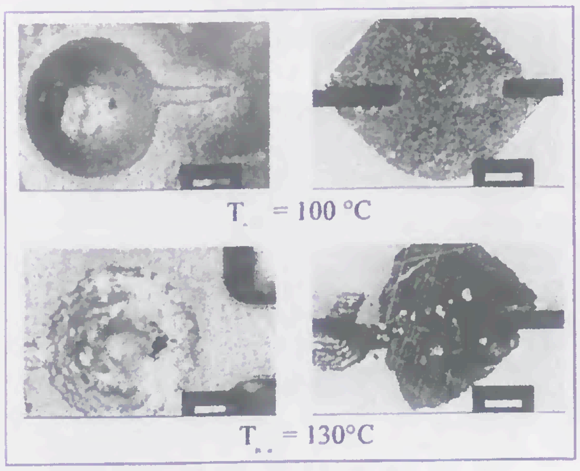


Fig.5: Top views and cross sections of solder points at two temperatures of the upper blade

Moreover, the 8-hour-test does not reflect the real solder conditions. According to the time consuming diffusion process a test time of 24 hours is chosen. During this time the solder can react with the element material and with the surrounding sand as is shown in Figure 5.

There are two possibilities for characterising the solder conditions. The top view shows if sand grains are bonded to the solder surface. Only, if the solder is sufficiently heated up, the sand grains can be pressed into the solder material. The polished cross sections show if the solder already reacted with the element material.

V. EXPERIMENTAL RESULTS

V.1 Ambient temperature of T_A = 130 °C

The ambient air inside the test chamber is heated up to about 130°C with controlled micro-heaters.

As is shown in Figure 4, the temperature of the upper blade $T_{B,u}$ reaches about 140 °C at this temperature of the ambient air. From former investigations it is known, that the overtemperature □T_{ME} in the middle of a LV HBC melting element is about 60 K.

The consequence is that, the temperature T_{ME} could reach 200 °C. This temperature is in the melting region of the solder material, and is therefore under no circumstances suited for continuous operations . That can be also confirmed by long time studies carried out with the three given fuse types of different design of melting elements. In Figure 6 is given an example for melting fuse elements at rating current and a temperature of 130°C of the ambient air.

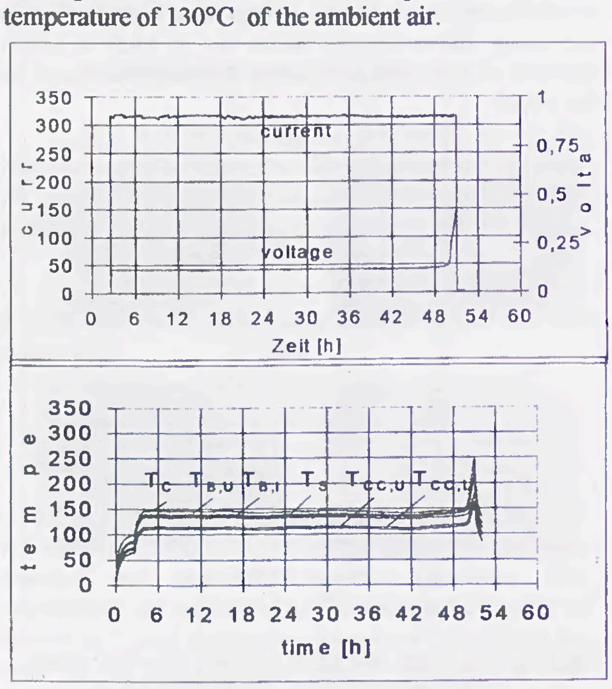


Fig 6: Current, voltage drop and temperatures T of the fuse link (Type 3) versus the loading time

The investigated fuse types (Fig.3) switched off always the rating current, however at different times:

- type 1 : $t_{melting}$ > 35 h
- type 2 : $t_{melting}$ > 40 h
- type 3 : $t_{melting}$ > 45 h

Viewing the transient voltage drop of the example in Figure 6, an interdiffusion process of the solder and the melting element material needs at least to about 48 hours. During that time, there is no significant increase in the electric resistance. However, the alloying of fuse element already occurred to such an extend that the temperature of the melting element is about 10% higher than in the beginning.

V.2 Temperature of the upper blade

As is written before, the solder condition is studied by means of photographs and cross cuttings of solder points after careful dismantling the fuse links. Some results of one series are demonstrated in Figure 7

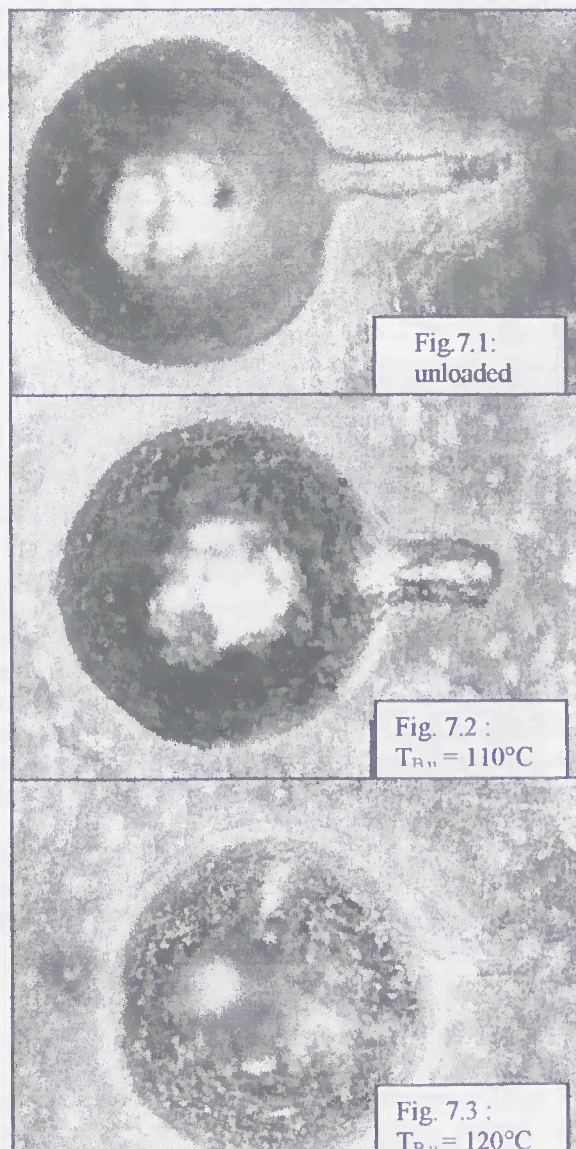


Fig.7.1: unloaded

Fig. 7.2 : $T_{B,u}$ = 110°C

Fig. 7.3 : $T_{B,u}$ = 120°C

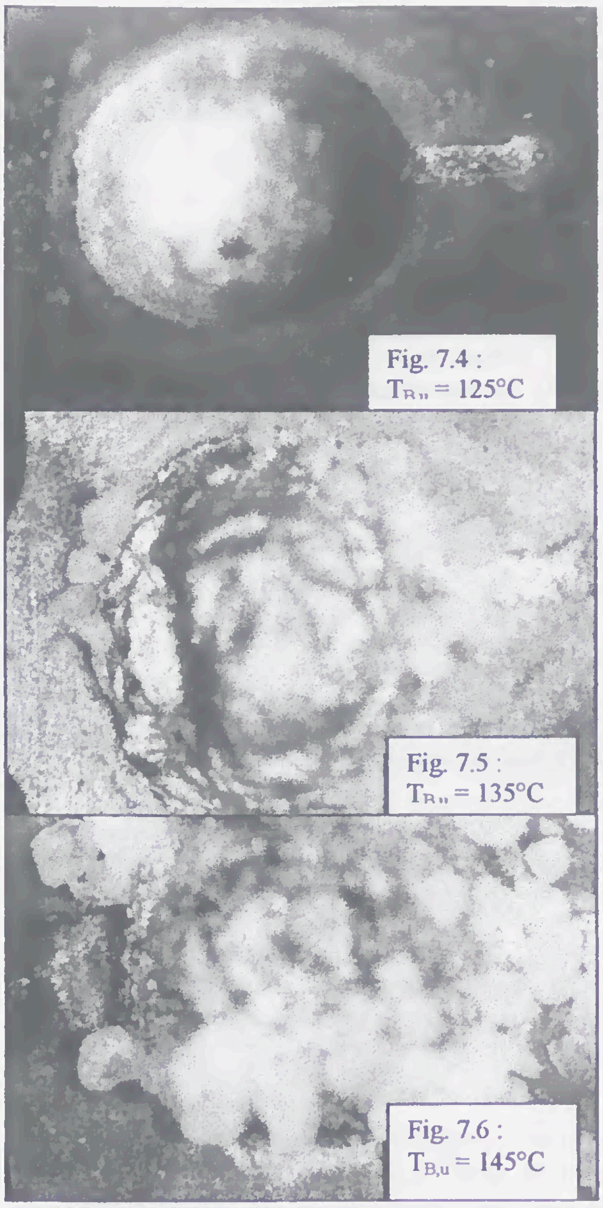
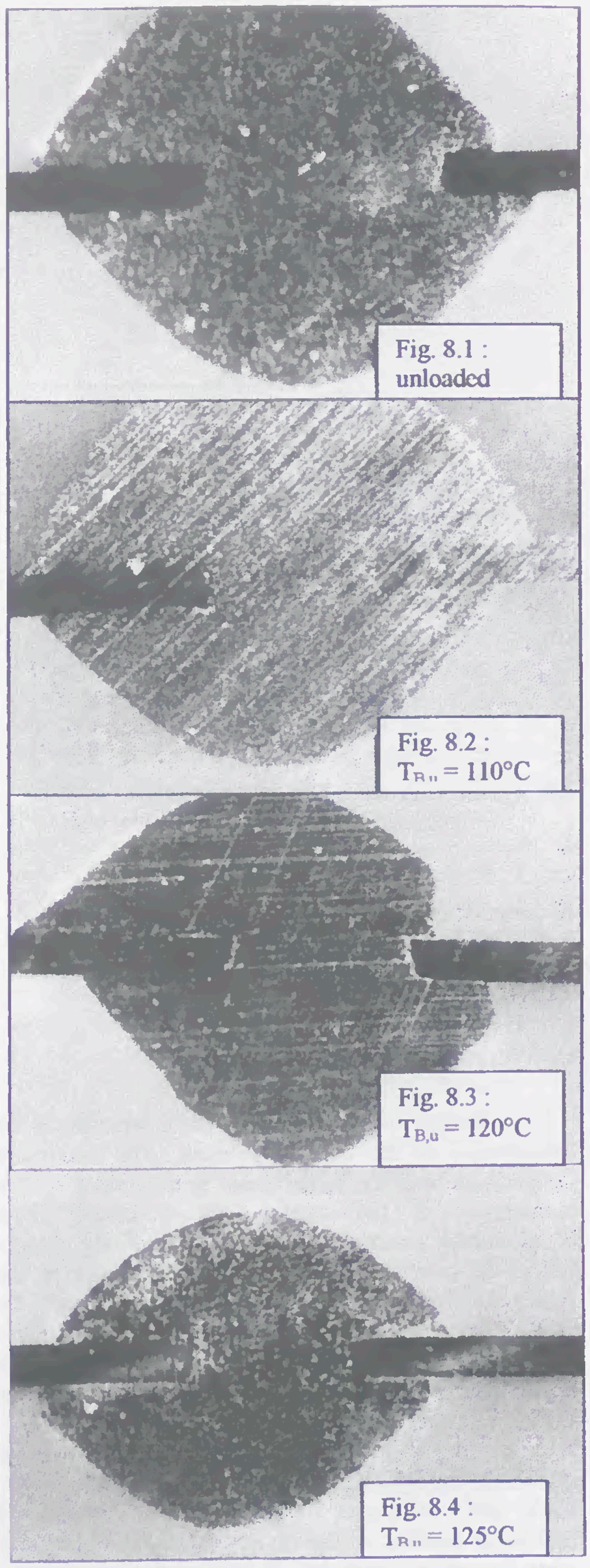


Fig.7: Top views of solder points of dismantled fuse elements after loading time, parameter = temperature of the upper blade $T_{B,u}$

The picture of the top at an upper blade temperature of 130°C is already shown in Figure 5. However, few sand grains are bonded at a temperature of 125°C (Fig.7) if the fuse-link is carefully dismantled.

From the cross sections (Fig.8) it is confirmed, that the interdiffusion process starts at a temperature of the upper blade of about 125°C. The ball-like shape of the solder point is already deformed and the composition of the solder material is changed (Fig.8.4)



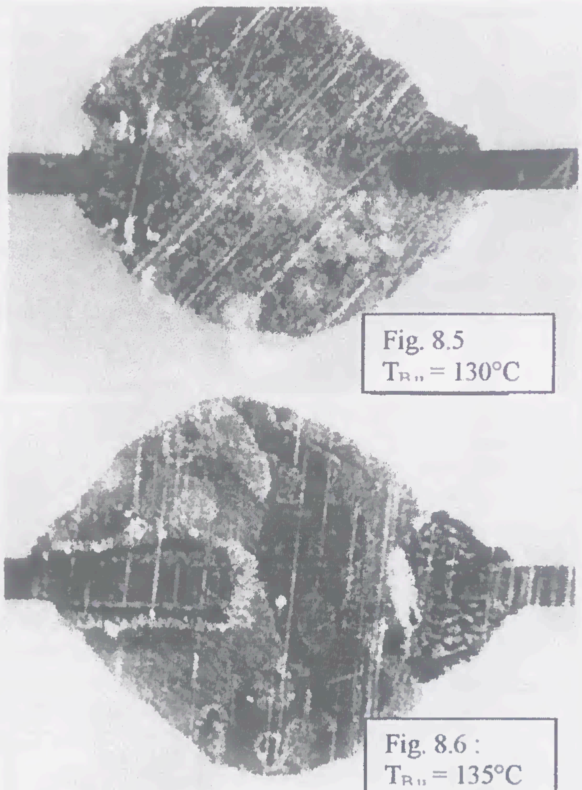


Fig. 8: Cross sections of solder points after 24h-test
Parameter: temperature of the upper blade

At temperatures of about 130°C and higher the interdiffusion makes strong progress and should be avoided.

VI. CONCLUSIONS

Rating conditions of fuse-links depends on the temperature of the melting element. The maximum temperature near the solder point is influenced by the temperature of the surroundings. Following from experimental results the temperatures of the blades reflect all conditions of the heat conduction to the cables and / or the heat transfer to the ambient air. The upper blade temperature is usually the highest temperature of the fuse-link. Due to this reason the upper blade temperature is a very good criterion of the fuse-link behaviour and the state of solder points.

The limit of the upper blade temperature for continuous operation is obtained by investigation of the solder point state after loading by rating currents and additional heating of the upper and lower blades and after dismantling the fuses.

The usual 8-h-test as a long time test cannot exactly characterise the melting element behaviour. The time consuming diffusion process requires a longer loading time in order to get measurable results. A test time of 24 hours is chosen because of this fact.

The limit of the upper blade temperature of 130°C for continuous operation is obtained from experiments. This limit should never be exceeded for all kinds of operations, independent of which heat transfer conditions apply.

VII. REFERENCES

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