Measurement of Temperature Dependence of Electrical Insulation Resistance of Epoxy Grout and Two Industrial Laminates for Busbar Insulation

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Abstract

Insulation materials are an important element in pot and potline design and safety. They must provide high insulation resistance between different potentials in a cell or between cells and ground as well as sufficient mechanical strength at elevated temperatures. In EGA, epoxy grout has been used extensively for busbar, potshell and potroom floor supports for insulation from ground. The manufacturer specifications usually do not include electrical properties because they depend on particular mixture of ingredients which could change with time and most epoxy grout applications are not intended for electrical environment. Consequently, it is up to the users to measure electrical resistance otherwise they may risk unwanted failures, particularly if high temperatures are involved. At EGA, a laboratory workbench for the measurements of insulation resistance has been set up according to the ASTM D257 Standard. Electrically conductive paint was chosen for contact surfaces, configured for volume resistivity measurements. Two types of epoxy grouts were measured at room and elevated temperatures up to 240 °C. The measured insulation resistance of epoxy grouts decreases exponentially with temperature which agrees with theory. The exponential coefficients were determined from the measurements. Similar measurements were also made for two rigid industrial laminates used for busbar insulation and similar behavior with temperature was observed.

The measurements of epoxy grouts were made at EGA, whereas the measurements of the industrial laminates were made at ISOVOLTA laboratory as this laboratory has a convection heating furnace according to IEC 60216-4-1 Standard for measurement of thermal endurance of insulation materials. Insulation resistance of measured epoxy grouts was sufficient for busbar supports up to approximately 200 °C and of rigid busbar laminates up to 240 °C.

Keywords: Electrical insulation resistance of epoxy grout, electrical insulation resistance of industrial laminates, ASTM D257 Standard, electrically conductive paint, thermal endurance of insulation materials.

1. Introduction

1.1. General

Aluminium electrolysis potlines and individual pots are characterized by areas of different electrical potential, which can be as high as potline voltage between potline busbars and ground [1]. In a pot the anodes and anode superstructure are typically on 4 – 4.5 V higher potential than the cathodes. However, when the pot is on anode effect, this difference could be as high as 100 V depending on plant design. To separate these electrical potentials and to separate pots from ground various insulation materials are used. Figure 1 shows a pot with the insulation locations indicated.

This work investigates and reports the results for the electrical insulation resistance of two epoxy grouts used at EGA for the insulation of the potlines to ground and two industrial laminates which are used for insulation between busbars of two adjacent pots.

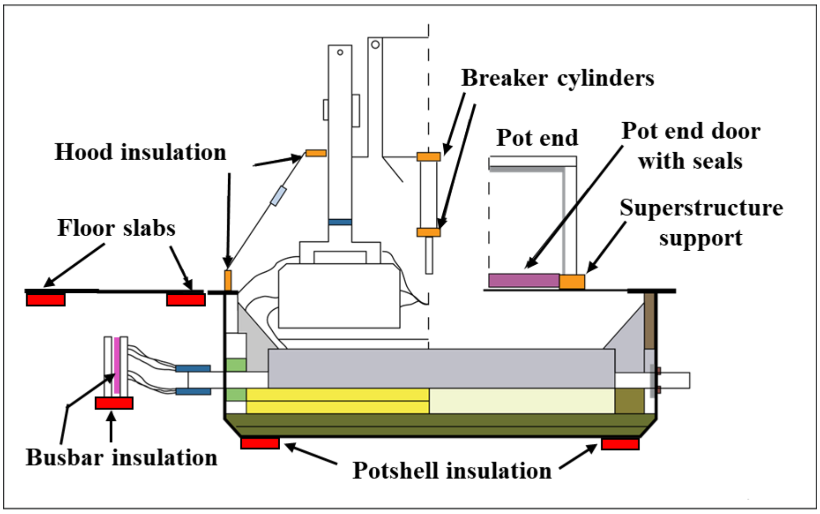

Figure 1. Location of insulators between pot superstructure and cathode as well as between the potline and ground. Investigated in this paper are epoxy grout (red) and industrial laminates (pink) – see more detail in Figure 3.

1.2. Insulation Resistance

Electrical insulation resistance is the important parameter, which is only quoted at room temperature (industrial laminates) or not at all (epoxy grout). Busbars and potshells are at high temperature, typically below 200 °C, but sometimes higher. Over time, these insulation materials can fail due to high temperatures and this aggregates because of ever increasing potline amperage. The failure can be mechanical and/or electrical. Figure 2 shows such a case [2]. Busbar insulation materials may start to degrade at 200 °C but at 250 °C many of them would have catastrophic failure [2].

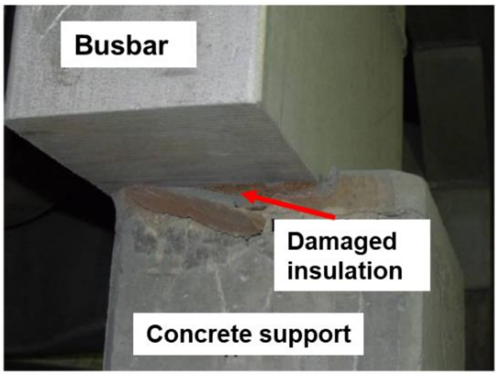

Figure 2. Busbar insulation on concrete supports crushed due to amperage increase [2].

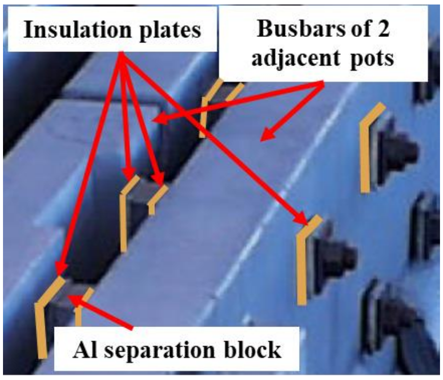

Figure 3. Industrial laminates: insulation plates between adjacent pot busbars, typically 5 – 6 mm thick.

1.3. Thermal Properties

Thermal characteristics of insulation materials may be different for each property, such as mechanical strength, insulation resistance and dielectric strength. Compressive strength and insulation resistance are of particular interest for applications in the potlines. For high temperature applications, such as busbar insulation, the characteristics have to be determined on short term as functions of temperature to determine the maximum temperature at which the material will still have acceptable properties, such as compressive strength and insulation resistance. Long term properties are equally important and are functions of the continuous temperature load. At high temperature, insulation materials can slowly change physical and chemical properties, and will ultimately fail. The main author of this paper has seen the insulation between the busbars disintegrate physically after 20 years in service, where the binder of the industrial laminate used to insulate the busbars between the two adjacent pots, such as shown in Figure 3, was falling out in powder and only the web was left. A contributing factor was certainly increasing busbar temperature because of increasing amperage much beyond the original design. As result, the busbar insulation had to be changed at that position in the whole smelter at great cost and effort.

1.4. Definition of Materials Investigated in this Paper

Epoxy grout is made from epoxy resins and a filler powder and is cast and cured in situ at room temperatures. The electrical properties at room or high temperatures are not in manufacturers specifications.

Industrial laminates generally refer to a class of electrical insulating materials produced by impregnating fibrous webs of material with thermosetting resins, then fusing multiple layers together under high temperature and pressure. The result is an infusible laminate structure having a versatile combination of electrical, mechanical and chemical properties. Electrical insulation resistance at room temperature is usually in manufacturer specifications, but not temperature dependence.

ISOVAL® R-AL. From ISOVOLTA specifications. *“This epoxy laminate is made of glass roving impregnated with the temperature-resistant version of the ISOVAL® epoxy system. Laminates exhibit excellent thermal and chemical resistance as well as high mechanical strength at elevated temperatures. ISOVAL® R-AL can be used as a high-quality construction material as well as electric or thermal insulation material for large parts of various machines and equipment, especially for those areas where high operating temperatures are coupled with mechanical strength requirements. Compressive strength perpendicular to laminations at 23 ºC (ISO 604): 180 MPa. Insulation resistance after immersion in water (IEC 60167) (24 h/23 ºC):* 10^{10} Ω*. Thermal endurance (IEC 60216) (T.I.): 180. Short time temperature resistance: 330 ºC.”*

ISOVAL® AL 220. From ISOVOLTA specifications. *“This is an epoxy resin laminate based on glass roving impregnated with a high functional epoxy resin system. Application: Due to good electrical and mechanical and properties it is used as insulation for aluminum smelters. Compressive strength perpendicular to laminations at 23 ºC (ISO 604): 600 MPa. Insulation resistance after immersion in water (IEC 60167) (24 h/23 ºC):* 5×10^{10} Ω*. Thermal endurance (IEC 60216) (T.I.): 180. Short time temperature resistance: 220 ºC.”*

2. Standards for Measurements of Insulation Resistance and Volume Resistivity

2.1. Definitions

2.1.1. Electrical

Insulation resistance is the ratio of the DC voltage between two electrodes divided by the total current between the electrodes, consisting of surface current and volume current through the material. Insulation resistance consists of surface and volume resistance. Surface resistance is measured between two electrodes on the surface of the specimen. Volume resistance is measured between two electrodes across the specimen on opposite surface of the specimen. To measure volume resistance, surface resistance has to be excluded and the electrical standards specify how that shall be done as seen below. Volume resistivity is a physical property of materials determined from the measured resistance by Equation (1)

$$\rho_v = \frac{A}{t} R_v \qquad A = (a+g)(b+g) \tag{1}$$

where: R_v Volume resistance, Ω
ρ_v Volume resistivity, Ωm
A Effective area of electrodes, m^2. For the measurement system chosen in this work, using guard electrodes shown in Figure 4.
t Thickness of the specimen, m
a Length of central electrode (No. 1), m
b Width of central electrode ((No. 1), m
g Width of the gap between central electrode and guard electrode (Figure 4).

Volume resistivity is a very useful property for insulator design since it allows calculating the electrical insulation resistance with any size (area and thickness) of the insulator. Whereas, insulation resistance is most often specified in material specifications as measured according to IEC Standard 62631-3-3 between two tapered electrodes after immersion in water, and consequently, is useful for comparison of different insulation materials, but it cannot be used in practice for design applications!

In practice surface resistance is also very important as it may be one order of magnitude lower than the volume resistance. It depends on the type of material, but much more on surface condition such as dust, oil and humidity or water. It is important that exposed insulator surfaces are maintained clean and dry. In this work we did not measure the surface resistance, but made some tests to measure total resistance on the samples without using guard electrodes. We found of course that the total resistance was always lower than the volume resistance, since the surface resistance contributes to current leakage between the electrodes in parallel to volume resistance.

2.1.2. Thermal Endurance Testing

According to Underwriters Lab Standard UL746B [6]:

“8. The properties of a polymeric material degrade with time when exposed to various environments. A prime cause of degradation is exposure to heat.”

“8.3 The thermal-aging characteristics of a material can be determined by measuring the changes in its properties to a predetermined level by aging test specimens at each of several elevated temperatures; plotting log of time-to the specified end point at each temperature against the reciprocal of absolute temperature; and plotting the best-fit straight line by regression analysis. The plotted line is often referred to as the life-line of a material.”

“12.1 At least four oven temperatures are to be selected. The lowest oven temperature (T4) selected is to produce an anticipated end point of the material’s property at this temperature in not less than 5 000 hours. The highest oven temperature (T1) selected is to produce an anticipated end point of the material’s property at this temperature in not less than 500 hours.”

It is obvious that such a long and elaborate procedure to determine the thermal endurance cannot be undertaken by a user, even though it is exactly this information that would be welcome for a pot designer and a technology supplier. In this work, the decision was made to evaluate only short term temperature dependence of one property - insulation resistance of four materials. Even this turned out to be a complicated and elaborate task.

The way out of this difficulty in testing on long term is to follow up on the behaviour of these materials in practical installations in the potlines and record the data. For example, EGA has used epoxy grout for many years without any problems in spite of much more stringent operating conditions today because of substantial amperage increase in all potlines. On the other hand, ISOVAL® R-AL and ISOVAL® AL 220 have also proven its worthiness in many potlines in the world. This is a pragmatic approach to thermal endurance of potline insulation materials.

2.2. Standards for Measurement of Electrical Resistance

Electrical resistance of insulation materials is difficult to measure because it is difficult to make a good contact between the measuring electrode and the insulator surface. Pointed electrodes cannot be used because the measuring electrical current cannot readily spread over the surface and into the volume of the sample from a point source. Extended electrodes have to be designed so that there is a very good uniform contact between the electrode and the sample material. In order to make results comparable between different insulation materials and different manufacturers, several measurement standards have been established, specifically ASTM D257-14 [3], IEC 62631-3-1 IEC [4] and IEC 62631-3-3 [5]. In the tests reported here, ASTM 257 - 14 Standard was used. Among options given in the standard, electrically conductive paint (coating) was chosen as the contact electrode at the top and at the bottom of rectangular samples.

Figure 1 shows how the conductive surfaces have to be prepared according to the ASTM 257 - 07 Standard. In order to separate volume electrical resistance and surface electrical resistance, a guard Electrode No. 2 is attached on the top surface of the specimen, with a separation gap g from the central Electrode No. 1 (also called guarded electrode). The guard electrode No. 2 is on the same electrical potential as the central electrode No. 1 in order to reduce to zero the surface currents from Electrode No.1 to Electrode No. 3, which are used for the volume resistance measurements by applying high voltage between Electrode No. 1 and Electrode No. 3 and measuring the current through the specimen.

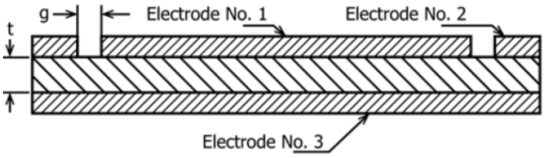

Figure 4. Electrode arrangement on the specimen of insulation material (Figure 4 of ASTM 257 - 14 Standard [1]).

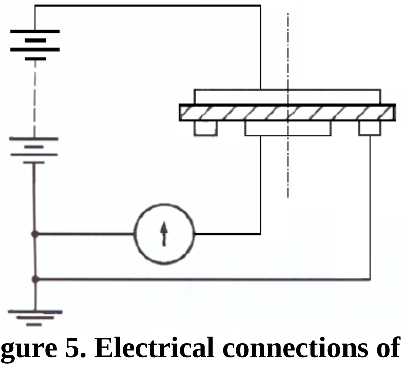

Figure 5. Electrical connections of specimen electrodes to voltage and ammeter. Electrode No 3 is positive, electrodes No 1 and 2 are negative (Figure 1 of IEC 62631-3-1 [2]).

2.3. Heating of the Samples

The ovens for heating the samples of insulation materials for thermal aging are specified in IEC 60216-4-1 standard [7]. This standard requires:

- The oven chamber shall be provided with a supply of pre-heated ventilating gas, passing the chamber at one side and being exhausted through another. Rates in the range 5 to 20 changes per hour shall be made available through the exposure
- The specimens should be mounted on a rack separated from each other and from the furnace walls. The volume of specimens should not occupy more than 10 % of the working volume of the oven.

In this work, the samples of two industrial laminates measured at ISOVOLTA laboratory were heated in an oven complying with IEC 60216-4-1 standard (Binder FD 115 furnace). However, the samples of epoxy grout measured at EGA were measured in a radiation furnace, because a convection furnace was not available, but the samples were shielded from direct radiation with an aluminium roof over the samples. This appeared to be fine for epoxy, even though the heating was slow and the pre-set temperature was not achieved, but the trials with industrial laminates showed that it was not possible to heat the samples uniformly in such an oven. In any case, for heating of all insulation materials in the future, we recommend a convective oven as specified in IEC 60216-4-1.

3. Set-up and Measurements in EGA in Workbench Shop and at ISOVOLTA Laboratory

3.1. Preparation of Samples

Epoxy grout samples were prepared by mixing up the industrial material components, according to industrial application recipe and then poured into a mold with dimensions 100 mm x 100 mm cross-section and 50 mm thickness. Four samples of each material, Masterflow 648 PC from BASF and Conrep 410 SA from Weber/Sodamco. The samples were painted with conductive copper paint (coating) Spraylat 599 B3755 from Spraylat. One painted sample is shown in Figure 6.

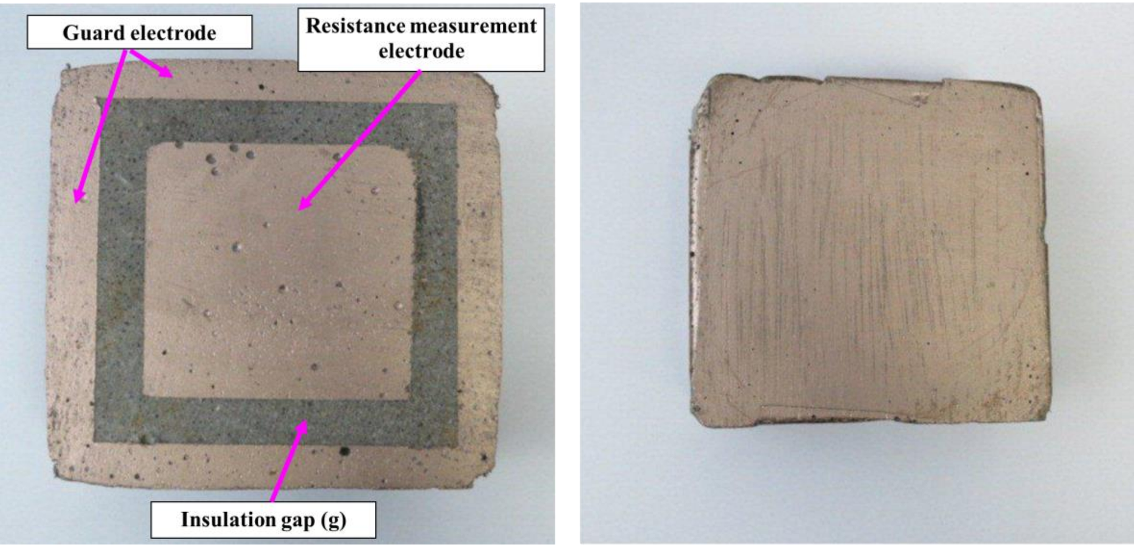

Figure 6. Top (left) and bottom (right) view of the specimen with painted electrodes.

ISOVAL® R-AL and ISOVAL® AL 220 were prepared the same way in EGA workshop for the measurements at EGA and ISOVOLTA. The samples had industrial thickness and were prepared by cutting in two the plates received. The dimensions when painted were on the top: central electrode cross-section: - 148 mm x 87 mm and the thickness of specimens 7.1 mm of R-AL and 8.7 mm of AL 220. The gap and the guard electrode width were 10 mm each, the same as in epoxy grout samples. The bottom painted face had the dimension 168 mm x 107 mm, covering the same size as the guard electrode on the top as required by the standard.

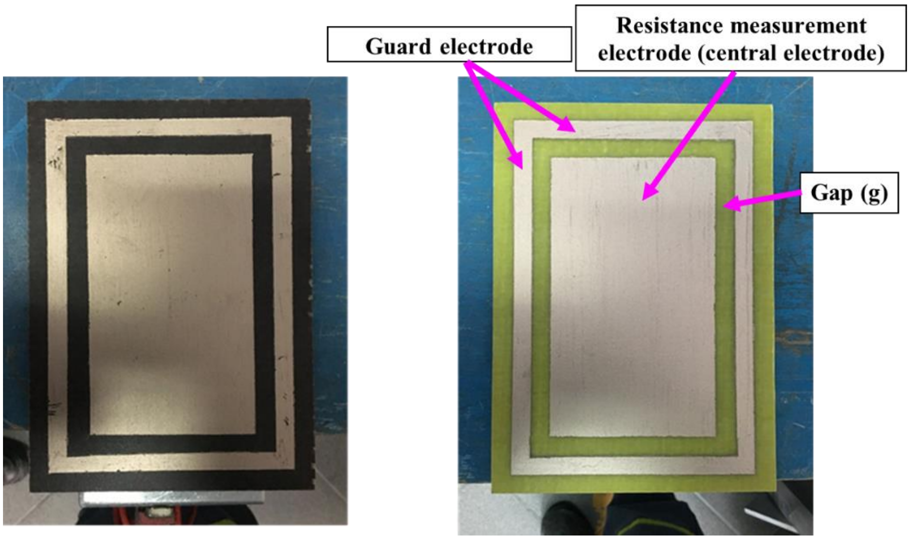

Figure 7. Top of the painted electrodes on ISOVAL® R-AL (left) and ISOVAL® AL 220 (right).

3.2. Measurements

At EGA, the electrical resistance was measured by a high resistance ohmmeter of Megger, Model Megger S1-1052-2 (10 kV) Digital Insulation Tester or MIT 1020/2 Digital Insulation Tester (10 kV). The instrument has a Guard Electrode terminal (G, blue), shown in Figure 8, which was connected to the guard electrode painted on the samples. The role of the guard electrode for volume resistance measurement has been already explained. In all measurements the setting of 2500 V (top left number on display is the real voltage during measurement) was used as this is higher than the potline voltage, and it is according to the requirement of an electrical standard, which specifies that all equipment for potrooms should be tested at a DC voltage higher than the potline voltage. It is also known and test were made to confirm that the measured resistance is lower at lower settings.

At ISOVOLTA the apparatus was Fetronic High Resistance Ohmmeter HM 307-D, which had the maximum voltage setting of 500 V and this was also the measurement voltage. The electrode connections in this apparatus are at the back.

The measurement setup at EGA is shown in Figure 9. The top for the contact with the middle painted electrode was a standard weight electrode for epoxy grout measurements and steel plate for ISOVAL®. The bottom was an aluminium plate. The contact with guard electrode was made via a steel frame. The same electrode contacts were used at ISOVOLTA as shown in Figure 9, right.

As usual for insulation resistance measurements the charge on the electrodes must be exactly one minute (the Megger apparatus stops automatically when 1 min is set – top right display in Figure 8 left is at 58 seconds, 2 seconds before stopping). The theory behind this is well explained in [8]

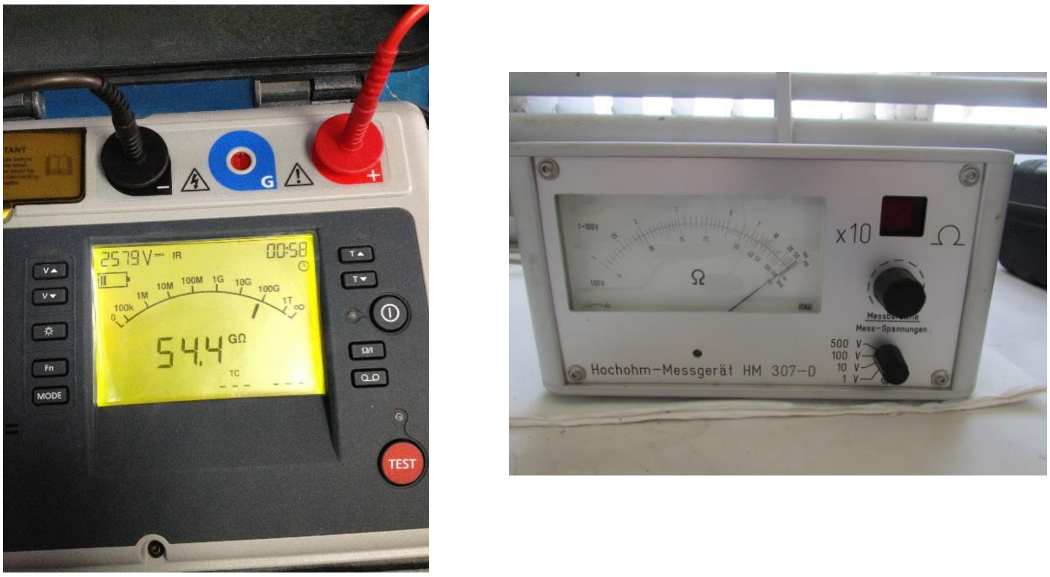

Figure 8. Megger Digital Insulation Tester (left) and Fetronic High Resistance Ohmmeter (right).

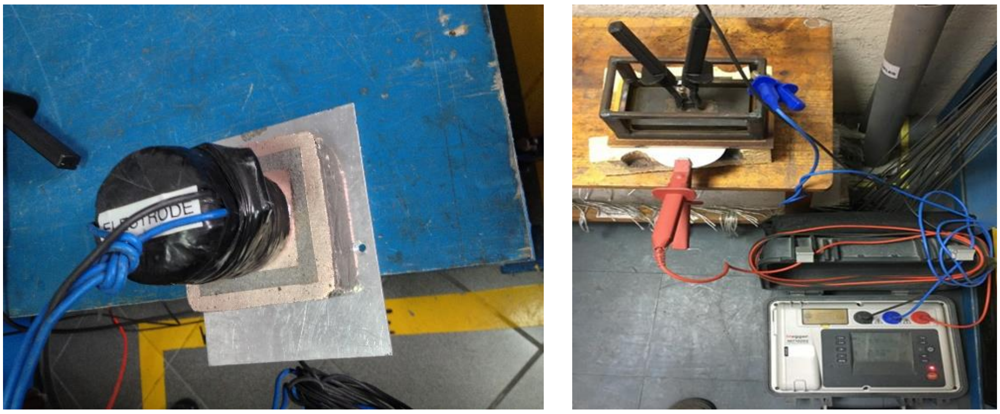

Figure 9. Electrode contacts and connections to the meter at EGA: for epoxy grout (left) and for ISOVAL® (right).

The samples were first measured at room temperature and then, set up on a rack, they were put in the oven for about 2 hours at temperature settings: 50 °C, 100 °C, 150 °C, 200 °C and 220 °C and 250 °C. After 2 hours in the furnace at each temperature setting, samples were taken out one by one and quickly the following steps were followed:

- The sample was put on the aluminium electrode, which was taken out of the furnace and put on a thermally insulating surface to prevent fast cooling.
- The temperature of the sample was be measured with a contact thermocouple.
- The steel electrodes, which had been also heated in the furnace were grabbed and put quickly on the sample in their right position.
- The megger electrodes were quickly connected and measurement made. Note that the sample cannot be measured twice in a row (if you fail to record the reading at 1 minute), because it has been charged during the first minute. According to the standard [7], at least one hour must be between the two successive measurements.
- After the measurement, take off the top electrodes and measure the temperature with a contact thermocouple in the middle of the sample again.
- After the measurement, each sample will immediately be put back in to the furnace so that it will not cool of much before the next heating stage.
- Repeat the process for each sample and at each temperature setting.

4. Results and Analysis

4.1. Epoxy Grout

The measurements are shown in Figures 10 - 12 in function of temperature. The data fitting recommended by standards [3] as a function of temperature is the exponential function of the activation energy type (Arrhenius equation), given in Equation (2). This is the equation used in this work for the insulation resistance.

$$R = B\exp(\frac{m}{T+273}) \tag{2}$$

where: R Insulation resistance, MΩ
B Proportionality constant, MΩ
m Activation constant, 1/K
T Temperature, °C.

The measurements were fit to this function by plotting the natural logarithm of the resistance in MΩ vs 1/(T + 273), shown in Figures 10 for all data by supplier and Figure 8 for all data combined. Constants B and m are given in Table 1. With this curve fit it is possible to extrapolate the insulation resistance beyond the measured temperature, e.g., to determine at which temperature would the epoxy grout resistance of the 100 mm x 100 mm sample become 5 MΩ. However, the extrapolation of such strong exponential function should not be much outside the measured range. In these measurements, there is no extrapolation for Masterflow epoxy grout, but 34 °C of extrapolation is required to obtain 5 MΩ insulation resistance of the Conrep samples, which is acceptable.

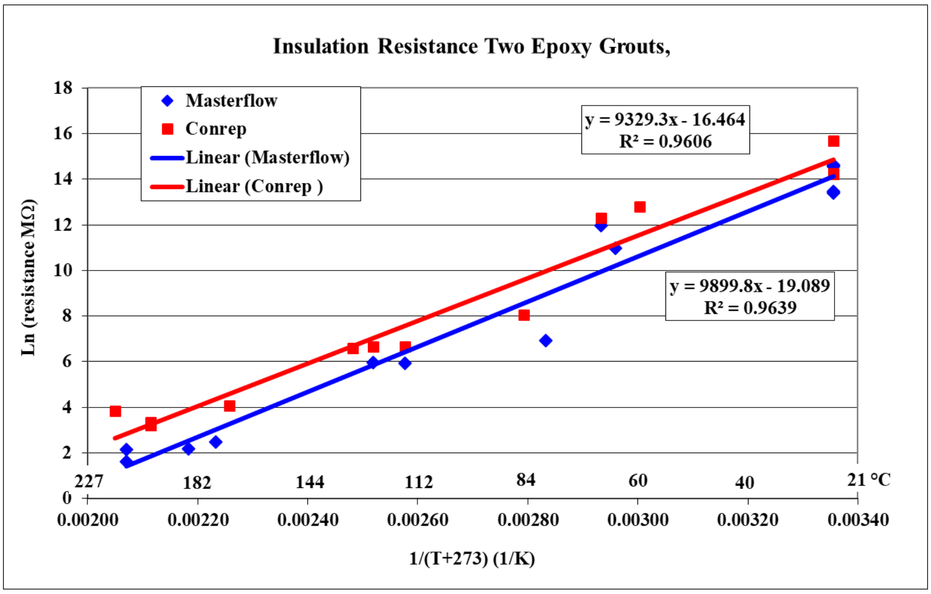

Figure 10. Natural logarithm of insulation resistance in MΩ as function of reciprocal temperature in Kelvin for two epoxy grouts. The scale in °C is also shown. The slope of the straight lines is the parameter m.

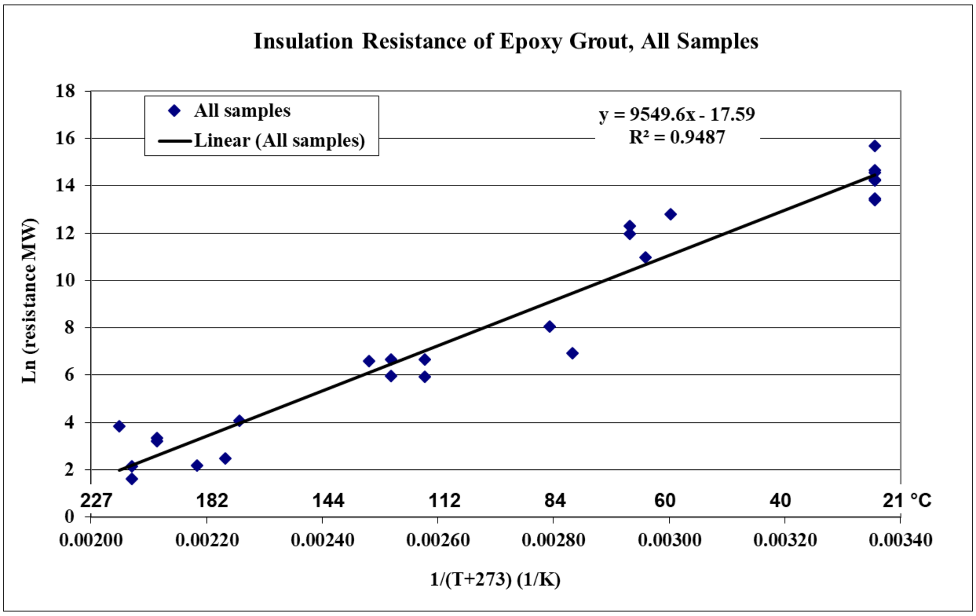

Figure 11. The same as Figure 9 but for all samples of both epoxy grouts.

Table 2. Constants B and m for Equation (2), derived from the linear fit equations in Figures 10 and 11.

Epoxy grout	B	m
Masterflow 648 PC	5.12569E-09	9899.8
Conrep 410 RSA	7.07580E-08	9329.3
Combined	2.29488E-08	9549.6

From Figures 7 and 8 it can be seen that the exponential fit is excellent. In addition it can be concluded that the insulation resistance of the epoxy grout has temperature dependence of typical insulation materials. We can also conclude that the resistances of the two materials have similar temperature behaviour, but the resistance of Conrep epoxy grout is generally higher and decreases somewhat slower with temperature. The combined resistance is given in Equations (3):

$$R_{Combined} = 2.29488\times10^{-8}\exp(\frac{9549.6}{T+273}) \qquad (3)$$

To better imagine the strong dependence on temperature, the combined epoxy grout insulation resistance from Equation (4) is shown on linear scale in Figures 12. Only the vertical scale is changed in these figures. We can see that the decrease is very rapid in each temperature range. For each 10 °C of temperature increase, the insulation resistance decreases by a factor of 1.5 (at high temperatures) to 6 (maximum variation at 60 – 80 °C).

4.1.1. Example of Usage of the Results

Using volume resistivity, calculated from the insulation resistance from Equation (1) and then reversing the equation it is possible to calculate the resistance from a pot to ground. The overall insulation resistance to ground of all the busbar supports of a pot is obtained by adding up all support column resistances in parallel. For example, for the same epoxy grout thickness of 50 mm, if the resistance of 100 x 100 mm² sample is 5 MΩ, then below a busbar with contact to the epoxy grout of 500 x 100 mm² it will be 1 MΩ. If there are 10 such supports per pot, the resistance will be 100 kΩ, for 444 pots in a potline, the overall resistance to earth will be only 225 **Ω**. This would cause a high leakage current to earth of 2.2 A at the average potline to earth voltage of 500

V. It is obvious that at temperatures above 200 °C the epoxy grout resistance by itself is not sufficient for busbar insulation from earth. In practice, other resistances are added in series to the epoxy grout resistance below the busbars, at least concrete support column resistance and in most recent EGA pot technologies also another layer of epoxy grout is built at a place where the temperatures are much lower than just below the busbars. This provides a very high resistance from busbars to ground.

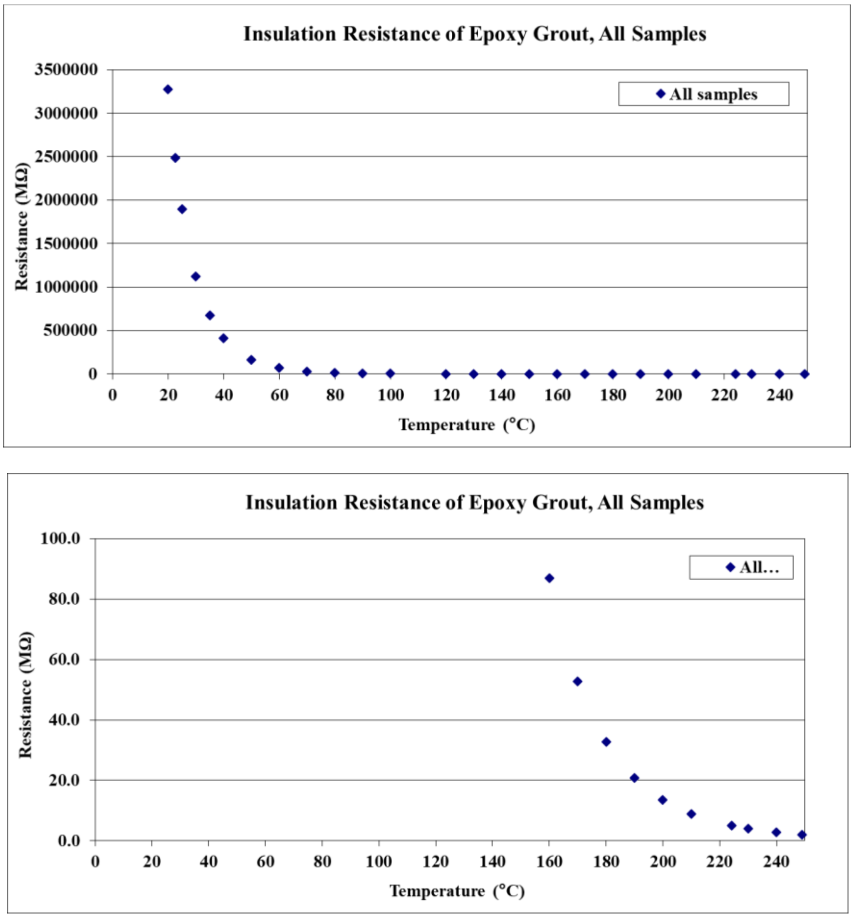

Figure 12. Insulation resistance of epoxy grout from Equation (3), all samples, linear vertical axis.

4.2. Industrial Laminates ISOVAL® R-AL and ISOVAL® AL 220

Insulation resistance of ISOVAL® materials was first converted to resistivity in order to compare the two materials, since their thickness was different. Figures 13 show the results of volume resistivity dependence on temperature. It can be seen from these two figures that a simple exponential curve with temperature fits better the results than the Arrhenius type, proportional to 1/(T + 273) (the determination coefficient R^2 is higher for the former one), however, the latter will be used for practical calculations in order to follow the theory proposed with Equation (2). It can also be seen from Figure 13 that the volume resistivity behavior with temperature of these two materials is very similar but AL 220 keeps the resistivity somewhat better at high temperatures. Figure 14 gives good Arrhenius exponential fit for both together.

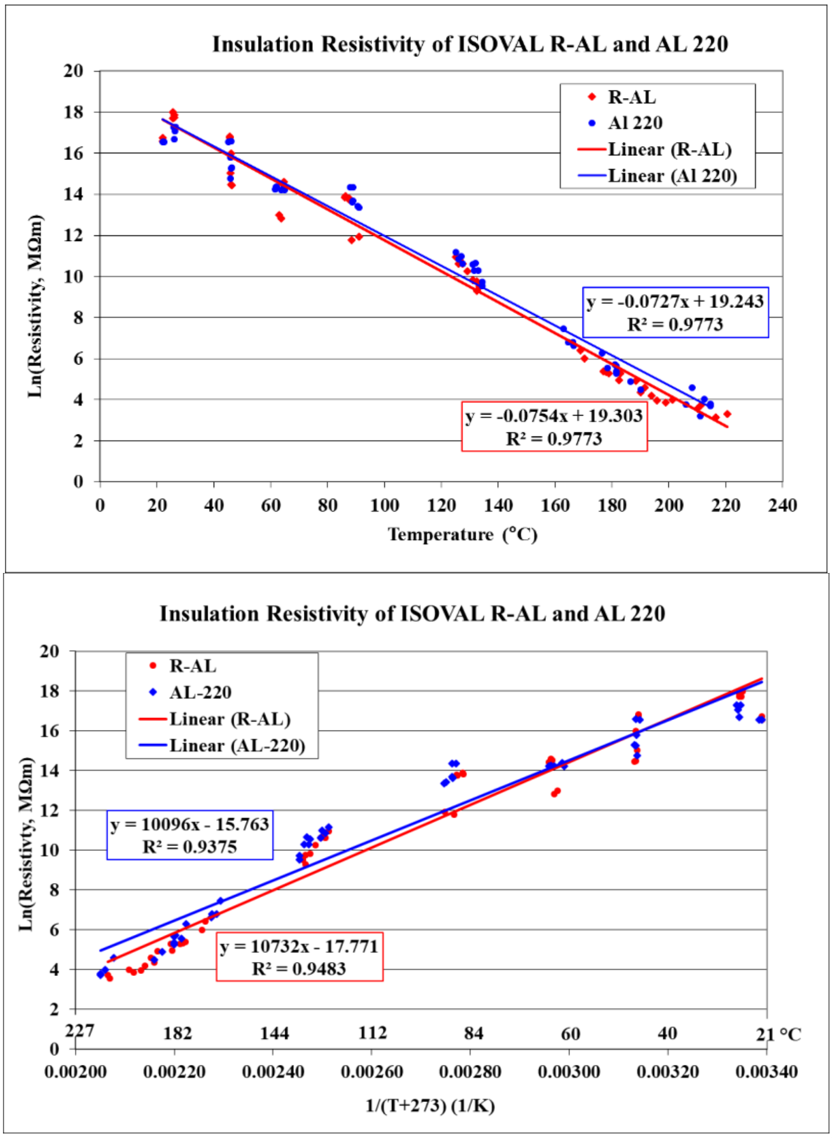

Figure 13. Two ways of representing the insulation resistance of two ISOVAL® laminates.

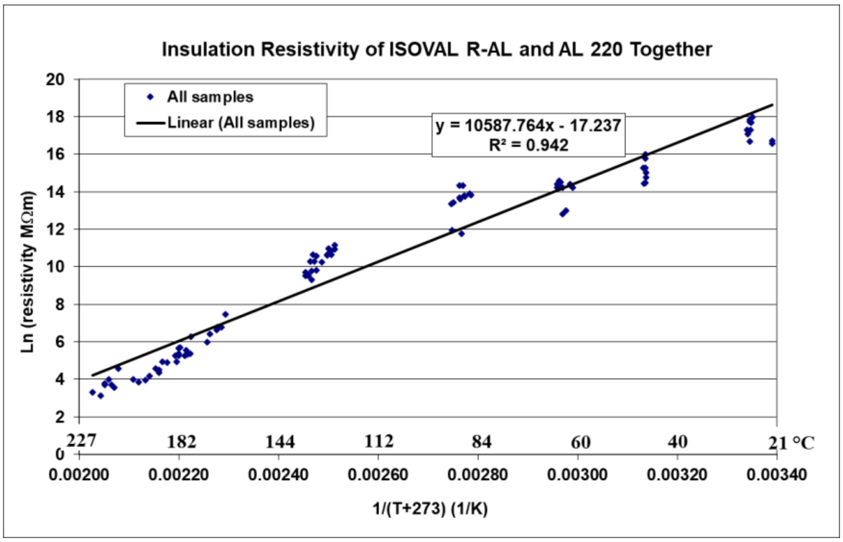

Figure 14. The same as Figure 13 but for all samples of both ISOVAL® laminates.

It can also be seen that the resistivity of ISOVAL® R-AL and ISOVAL® 220 is very high at room temperature and in spite of exponential decrease it is still very high at 220 °C. The insulation volume resistivity of the samples measured was in the range of 23 - 43 TΩm at room temperature and was still 38 - 51 MΩm at 210 °C. The example below shows that this is more than adequate for busbar insulation.

The exponential function for ISOVAL® R-AL used as an example in Table 3 is:

$$R_{R-AL} = 1.91493 \times 10^{-8} \exp\left(\frac{10732}{T+273}\right) \tag{4}$$

4.2.1. Example of Usage of the Results

The insulation between two adjacent busbars belonging to two different cells at wedge pockets, shown in Figure 3, has two insulation plates in series at each post on a bolt which is tying the busbars on each side of the wedge. There are 10 wedges, which give 20 insulation posts. The insulation plate is 10 mm thick and has the area of 0.0293 m^2. The resistances are given in Table 3.

Table 3. Insulation resistance between two adjacent busbars with ISOVAL® R-AL.

	Units	220 °C	240 °C
Resistivity	MΩm	54.5	23.3
Resistance of 1 insulation plate	MΩ	18.6	7.96
Resistance of 1 post (2 plates in series)	MΩ	37.3	15.9
Resistance between busbars (20 posts in parallel)	MΩ	1.9	0.8

In this scenario, using Equation (4), the resistance is still very high at 240 °C, considering that it has to separate at most 100 V between the cells during an unusually strong anode effect. It turns out that the simple exponential curve in Figure 13 (top), decreases faster at high temperatures than the Arrhenius one. Using this representation as the worst scenario, the resistance between the busbars in Table 3 would be 0.5 MΩ at 220 °C and 0.1 MΩ at 240 °C, which is still adequate.

5. Conclusions

The measurements of insulation resistance of insulation materials shows that the insulation resistance decreases exponentially very rapidly with increasing temperature. The service temperature in terms of insulation resistance has been established up to 220 °C with no particular damage to the samples and conserved mechanical integrity. However, further increase in temperature could deteriorate the materials rapidly as this is typical for insulation materials. No attempt was made to push the samples to destruction to determine where this limit is.

The two epoxy grouts tested have very similar behavior to each other and so do on their own basis the two industrial laminates. Even though both epoxy grouts keep mechanical integrity at 200 °C and above, they provide insufficient insulation resistance by themselves at these temperatures to properly insulate pot busbars from earth. Other insulation elements have to be built in series with epoxy grout if it is at temperatures above 200 °C.

The resistivity of ISOVAL® R-AL and ISOVAL® 220 is very high at room temperature and in spite of exponential decrease it is still quite high at 220 °C. The insulation volume resistivity of the samples measured was in the range of 23 - 43 TΩm at room temperature and was still 38 - 51 MΩm at 210 °C

In this work long term thermal endurance of the measured materials was not determined. However, long term usage of these materials in smelters has proven that they have not failed during service for many years and thus are appropriate for busbar insulation.

At EGA, we developed a workbench and a technique for testing insulation resistance of insulation materials at elevated temperatures according to international standards. Any material that has no insulation resistance specification should be tested before use in potrooms. For temperature measurements we recommend that convective ovens should be used for heating the samples according to IEC 60216-4-1.

6. Acknowledgement

We thank Dr. Bogdan Rares Enache from ISOVOLTA Bucarest Laboratory for the measurements of the two industrial laminates ISOVAL® R-AL and ISOVAL® 220.

7. Disclaimer

Electrical insulation is not the primary purpose and application of epoxy grouts. Insulation resistance of epoxy grouts is not a material specification parameter. Therefore, there is no guarantee that the values measured in the present samples will be kept the same in the future or that the chemical composition of these epoxy grouts will not be changed in such a way to affect the insulation resistance negatively. On the other hand, industrial laminates are better defined materials and are certainly more consistent. Nevertheless, the results reported here should be taken only as typical behaviour with temperature and should not be transferred to other materials or manufacturers. Therefore, the measurements in this paper are not a guarantee for any of the materials measured that the insulation resistance will remain the same in the future. This paper is also not a formal approval for any of the materials measured to be used in a specific project. It is recommended that the same measurement should be repeated before these materials are used for any major pot technology implementation.

8. References

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