Quality Assurance Tests on Bakelite Produced for Station 3, Station 1 Prototype, and Station 1 RPCs of the PHENIX Forward Upgrade

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Abstract

The PHENIX Forward Upgrade Resistive Plate Chambers (RPCs) are being designed in such a way that they will be nearly identical in construction to the Compact Muon Solenoid (CMS) endcap RPCs. In an effort to produce similar detectors, PHENIX hopes to follow a production route similar to that of CMS. We needed to determine, however, if bakelite produced by the same production facility, Panelli Plastici (PanPla), can still be produced to the same specifications. We present here the results of testing on bakelite produced for Station 1 Prototype, Station 1, and Station 3 RPCs of the PHENIX Forward Upgrade project.

Introduction

Bakelite resistivity can be measured with several methods and, while the results of different measurements should be similar, there will invariably be differences. Soon after the production of bakelite, PanPla used the wet measurement device pictured on the left of figure (1) to make two measurement on each sheet of bakelite produced. Based on the average of these measurements, a decision was then made as to whether the sheet passed CMS resistivity specifications ($1 \times 10^{10}\Omega \cdot cm < \rho_{20C} < 6 \times 10^{10}\Omega \cdot dcm$). Each sheet passing specifications was then measured in 9 positions using the dry measurement device pictured on the right in figure (1). This dry measurement was done to increase our confidence level of the resistivity of each sheet of bakelite, and to obtain a reliable standard deviation measurement.

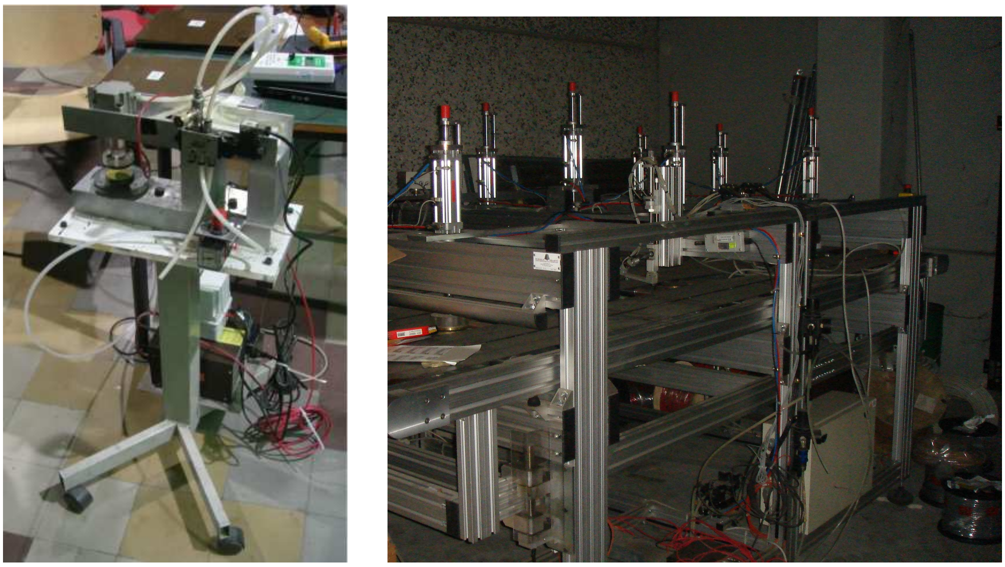

Figure 1: Two devices used for measurement. The left device was used by PanPla and uses wet cloth pads, while the device on the right was used by the authors and uses dry conductive rubber pads.

Bakelite Specifications

The baseline used for determining whether or not quality bakelite had been produced was the CMS specifications as follows:

$$1 \times 10^{10}\Omega \cdot cm < \rho_{\mathrm{20C}} < 6 \times 10^{10}\Omega \cdot cm \quad (1)$$

$$\frac{\sigma}{\rho_{\mathrm{average}}} < 0.5 \quad (2)$$

where σ is the standard deviation of the measurements made on a given sheet of bakelite, and ρ_{20C} is the resistivity corrected to the resistivity of bakelite at 20°C. The conditions (1) and (2) were measured thoroughly. The equation for determining the resistivity of bakelite is

Percent Humidity	*30*	*40*	*50*	*60*	*80*
h factor	8.2	8.6	8.9	10.2	11.2

Table 1: The h factors used.

$$\frac{\rho}{\rho_{\mathrm{20C}}} = e^{\frac{T_{\mathrm{surf}}-20C}{h}} \tag{3}$$

where T_{surf} is the surface temperature of the bakelite, and h is a humitidy factor, which we approximated from fits by the CMS and ALICE collaborations of ρ vs T measurements at various humidities, which is given in figure (2) [1]. The values we used are shown in table (1). The humidity of the room was between 50-60% during testing, which led to an h factor variance of 8.9-10.2.

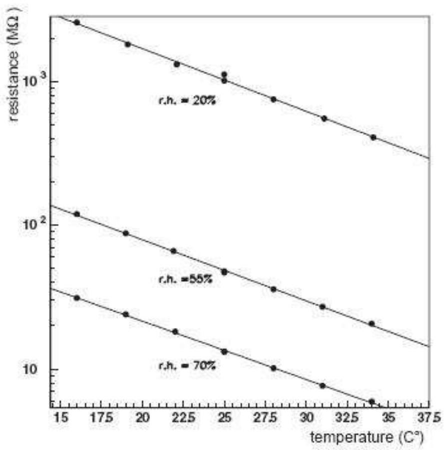

Figure 2: Resistance as a function of Temperature at three values of humidity [1].

Due to the exponential dependence of the resistivity to temperature, differences between the ambient temperature of the room and the actual surface temperature of the bakelite were needed. The LabView software written for the table only took a measurement of the ambient temperature, but equation (3) uses the surface temperature of the bakelite to calculate the resistivity. A simple correction factor is needed to correct for this difference, even if that difference is small. Equation (3) was read by the LabView software as

$$\frac{\rho}{\rho_{\mathrm{20C}}} = e^{\frac{T_{\mathrm{amb}}-\Delta T-20C}{h}} \tag{4}$$

where

$$\Delta T = T_{\text{amb}} - T_{\text{surf}} \tag{5}$$

The ambient temperature gauge, and the thermometer we used for the surface temperature are shown in figure (3). The difference in temperature was typically $1.0 - 1.5°$C. Both the humidity factor and the surface temperature were spot checked throughout testing.

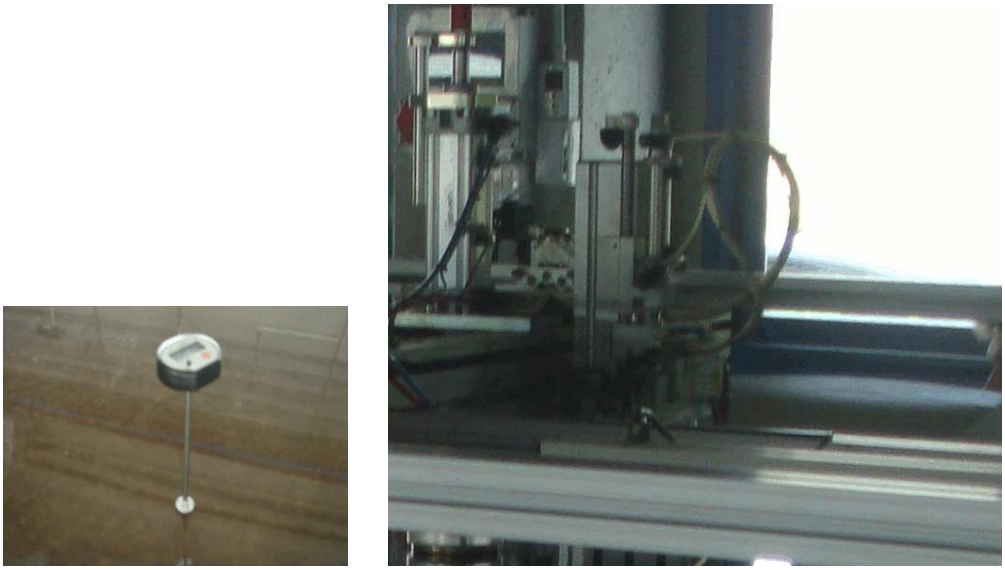

Figure 3: Two devices used for temperature measurement. The left device was used to measure the surface temperature of the bakelite, while the device on the right was attached to the apparatus and measured the ambient temperature of the room.

Calibration

Measurements made using the table of conductive rubber pads were calibrated to reproduce the measurements made by the device with a wet cloth pad on a piston by piston basis. The calibration was done so that $V_{dry} = AV_{wet} * 1.17$, where A is a simple scaling factor, and 1.17 is a geometrical ratio between the wet and dry pistons provided by CMS.

A separate A factor was calculated for each dry piston. This was done using nine small sheets of similar acceptable wet measurement resistivities. Each sheet was measured one time at each of the nine pistons. A separate A factor was calculated for each sheet at each piston. Thus each piston had

Piston	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Ave*
A	1.72	2.42	2.01	2.18	1.92	2.48	2.41	2.02	2.23	2.15

Table 2: The final scaling factors used. The method used to determine these values is described in the text.

nine A factor measurements, one from each sheet. These were averaged, and are given in table (2). This calibration was done several times, but we saw only small differences in the A factors calculated, so we decided to use the same A factors for all the bakelite sheets we tested over a three day period.

Measurements

The average of two wet resistivity measurements of each sheet made by PanPla are shown in figure (4). After the measurements were made by PanPla sheets were rejected if their resistivities fell outside of the two red lines in the figure. The six data points outside the lines in the figure were measured to have resistivity's of exactly $6.0 \times 10^{10} \Omega \cdot cm$ within the error of the device. The histogram on the right in Figure (4) contains the average resitivity of the nine measurements on each sheet made by the authors. Further rejection of bakelite sheets was made for those falling outside the CMS specifications for the dry measurement. Sheets would have also been rejected had the standard deviation over average been larger than the red line in Figure (5). Standard deviation over average was used by CMS as a measure of the uniformity of resistivity across a given bakelite sheet, which is within the CMS specifications.

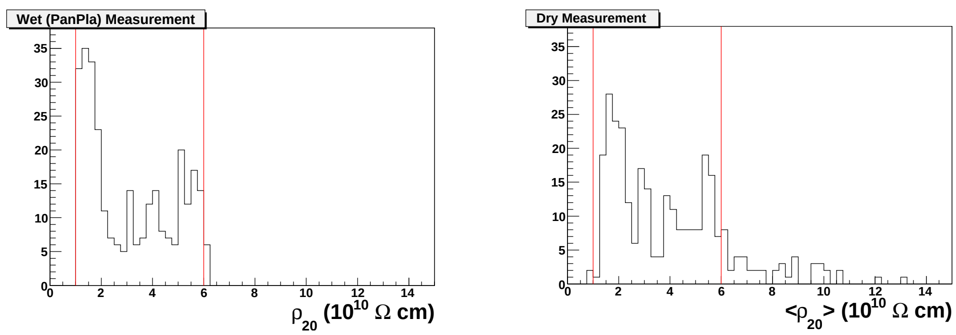

Figure 4: Measured resistivities. The histogram on the left contains measurements made by PanPla while those on the right were made by the authors.

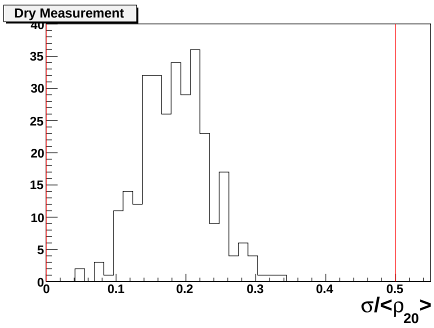

Figure 5: Sigma over average of the nine measurements made using dry conductive rubber pads.

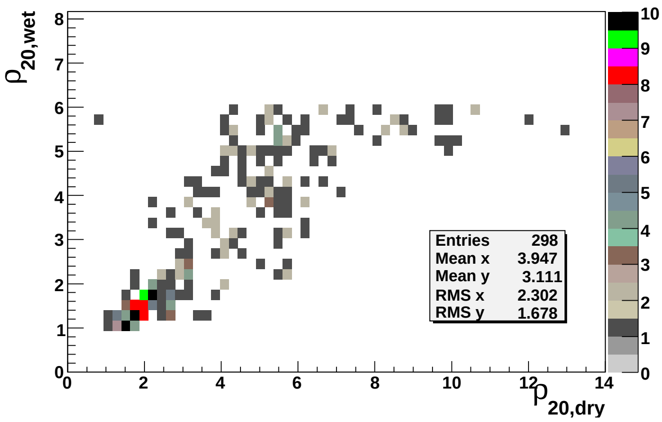

Figure 6: Plot of the wet resistivity versus the dry resistivity of each sheet. Correlations between each are explained in the text.

Also during the measurements, we noticed that it produced a nonlinear relationship between the wet and dry measurements of the bakelite sheets. The wet and dry measurements were very consistent at low to mid resistivities, but they did not necessarily agree as well towards the high $6.0\times10^{10}\Omega\cdot cm$ threshold resistivity. We decided that this was due to the fact that our nine small calibration sheets were on the lower end of the acceptable resistivity value. To be conservative, we changed our high resistivity acceptance to $5.6\times10^{10}\Omega\cdot cm$. The correlation between the wet and dry resistivity is given in figure (6)

Wet and dry resistivity measurements are compared in Figure (7). Both plots show approximate agreement between the two measurements.

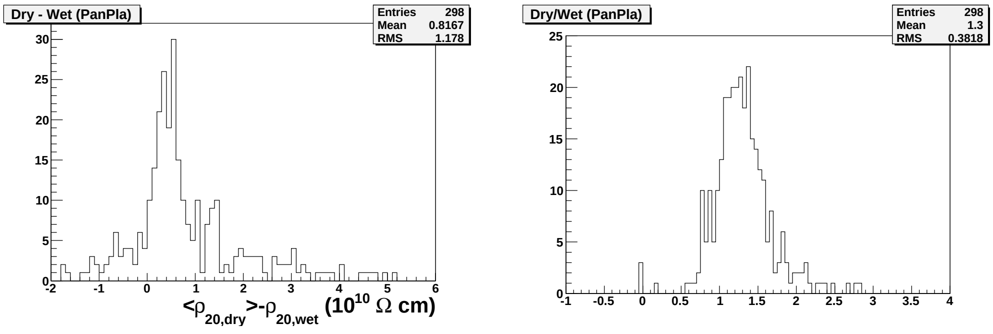

Figure 7: Measured resistivities difference and ratio. The histogram on the left is the difference between the Dry and Wet measurements, while those on the right is the ratio of the Dry to Wet measurements.

Characterization of Bakelite Sheets

A total of 314 pre-screened sheets were sent by PanPla to be tested with the dry method. 260 of these sheets had resistivities between $1.0-5.6\times10^{10}\Omega\cdot cm$, 16 sheets had resistivities between $5.6-6.0\times10^{10}\Omega\cdot cm$, and 46 sheets did not meet CMS specifications. We certified 262 of these sheets for RPC production. 240 of these sheets are assigned to be fabricated for the Station 3 RPCs, two of the sheets with resisitivities between $5.6-6.0\times10^{10}\Omega\cdot cm$ are assigned to be fabricated for the Station 1 prototype, and the University of Pavia has graciously agreed to store 20 sheets until they can be fabricated for Station 1 RPCs.

Acknowledgements

The authors would like to thank PanPla for making the initial wet measurements of the produced bakelite. Without these initial wet measurements, learning how to do the dry measurement would have been a daunting task. We would also like to thank the science staff of the University of Pavia for their assistance in moving the heavy crates of bakelite. Finally, we would like to graciously thank Paulo Vitulo and Paulo Bassao for their assistance with the dry resistivity apparatus and software, without whom we would not have had the ability to do the dry resistivity measurements.

Reference

[1] Chiavassa, Arnaldi *et al.*, Nuclear Science Symposium Conference Record **Vol. 1**, 526 (2004).