

Characterization of Silicon Fiber Sheet for Making the Read out Strips Panel

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ABSTRACT: The India Based Neutrino Observatory (INO) is going to use about 30, 000 Resistive Plate Chambers (RPC) which will require 60, 000 read out panels. Since it is an underground laboratory (near about 1.3 Kilo meter), it is required that almost all materials going to be used in it must be fire and water proof. We have observed that Silicon Fiber Sheet dielectric material is more suitable in comparison to the other materials such as plastic honeycomb which is in use currently, for making the read out panels of underground laboratory. In the present paper we have performed experiments which indicate that we should use it in making read out strips panels. We have also made up 1 m × 1 m (meter) read out panel and study about the signal's quality (such as reflection, termination, distortion etc.) through it produced in RPC gas chamber.

KEYWORDS: Silicon Fiber Sheet, Resistive plate chamber detector, Effect of temperature, X-ray fluorescence, Plastic honeycomb.

I. INTRODUCTION

Resistive Plate Chamber (RPC) Detectors are parallel plate fast gaseous detectors built using electrodes of high resistivity ($\sim 10^{12}$ ohm-cm) such as glass or Bakelite [1]. Both electrodes are connected to the positive and negative polarities of the high voltage power supply. When a charged particle such as muon passes through the chamber, it ionizes the gas and charges moved towards opposite electrodes. The electrodes are transparent to the signal, which is finally picked up by external metallic strips called as read out strips, after a small but precise time delay. The pattern of hits in RPC detectors and strips give a quick measure of the muon track's direction and momentum, which is then used by the trigger to make immediate decisions about whether the data are worth keeping or not.

Currently used material world wide for pickup strip panel is a honeycomb in which polycarbonate is used as dielectric material, which has two major drawbacks such as it is not very flexible and can catch fire very easily. Since India Based Neutrino Observatory- Iron Calorimeter (INO-ICAL) experiment will take data underground (near about 1.3 Kilo meter (Km)), therefore almost all materials used for detector or/and shielding should be fire and water resistant. As well as INO will use a large number of $\sim 30,000$ RPC detectors and each RPC will use two read out panels and therefore there will be $\sim 60,000$ read out panels having dimension 2 m × 2 m (meter) used in this experiment [2]. Therefore, it is required for the purpose of environmental safety as well as safety of the experiment, that each and every material in use must be fire and water proof, especially detector and front end electronics related. This is the first and primary criteria, rest will be the secondary.

Keeping in mind the above requirements, we looked for suitable dielectric material that fulfils the following criterion.

1. Material must be fire resistant, especially flame resistant.
2. Each pickup strip of the Copper foils should be terminated on the non read out end with a 50Ω resistance to match the characteristic impedance of preamplifier. For the perspective of electrical properties, it will be ideal

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to have the characteristic impedance of the strips so formed, match with that of the front-end electronics, so that signal reflections are minimized. Another important consideration is the attenuation in the pickup strips, which should be minimized as well [3].

3. Material must be flexible, so that it could be in proper contact with gas chamber, to properly read out the signals.
4. Material should be light weight; otherwise it will put extra weight.
5. It should be very important and necessary that material must be cost effective and easily available in any size in the local market.

II. MATERIAL SELECTION

In the light of above criterion, we tested various materials such as Ceramic foam, Ceramic Fiber, PCB board, various thermal insulating materials available in local market, and found two materials which are close to the above mentioned requirements in which one of the materials is Ceramic Fiber and other is Silicon Fiber sheet. In case of Ceramic Fiber we found that it is of non sticky nature and hence it was very difficult to attach the suitable conducting materials (Aluminium foil and Copper strips) on it even by using good quality of adhesive. But we found that Silicon Fiber sheet is suitable to our requirements which will be justified by our further experiments on it.

III. PHYSICAL PROPERTIES OF SILICON FIBER SHEET

Figure 1 shows the physical appearance of Ceramic Fiber and Silicon Fiber Sheet (Ceramic Foam). We have observed that Polycarbonate is rigid enough, so that, sometimes it cannot make proper contact with the surface of the detector's electrodes, however in case of Silicon Fiber Sheet; it is flexible enough, so that it can be properly placed over the detector and making good contact with its electrodes surface. Due to the flexible nature of the Silicon Fiber Sheet based read out strips panel it will be very easy to pick up the signals from the detector. Therefore such pick up panel may enhance the signal detection efficiency of the detector. The Silicon Fiber Sheet is a compressive material that can be pressed under pressure and may cause change in the thickness of the material. We have observed the change in the thickness with respect to pressure in terms of weight for longer time period [4]. Due to the pressure (equivalent to the pressure exerted by the two layers of float glass applied), small change in the thickness of Silicon Fiber Sheet material is observed. This small change in thickness is not making any significant change in the value of impedance of pickup strip panel. We have dually checked this observation directly by using impedance matching circuit as well as LCR meter. In Table 1 we have tabulated the comparative physical properties of Silicon Fiber Sheet and Polycarbonate materials. From Table 1 it may be seen that Silicon Fiber Sheet based pickup strip panel will put less weight over the glass electrodes due to less density with respect to polycarbonate material. It may also be seen that laboratory humidity will not affect the performance of the Silicon Fiber Sheet based pickup strip panel because Silicon Fiber Sheet material is more prone with humidity.

Detail measurement has been performed to check the suitability of various finer parameters. From now onwards we will compare the physical properties and performance of the pickup strip panels of honeycomb and Silicon Fiber Sheet base. From this Table 1 one can easily understand that for an experiment which is going to use huge amount of read out panels it is very much risky to use the Polycarbonate as a dielectric material for making it.



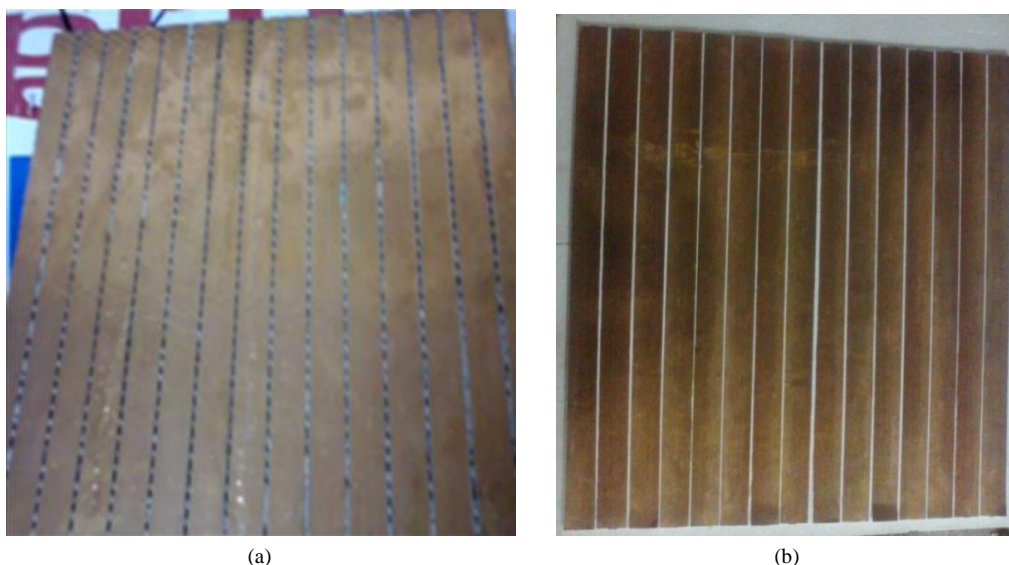
Fig.1.Ceramic Fiber and Silicon Fiber Sheet (Ceramic foam) dielectric materials respectively from left to right.

Table 1: Properties of Pickup Strip Panel's Dielectric Materials [5] [6] [7] [8] [9] [10] [11] are listed.

S. No.	Properties	Silicon Fiber Sheet (Ceramic Foam)	Polycarbonate (Plastic Honeycomb)
1.	Density (ρ)	0.3 – 0.6 g/cm ³	1.20 – 1.22 g/cm ³
2.	Flammability	Non flammable	High
3.	Water absorption over 24 hrs.	0.0%	0.1%
4.	Flexibility	Strong	Weak
5.	Radiation resistance	High	Fair
6.	Ultraviolet (1 – 380nm) Resistance	High	Fair
7.	Melting temperature	2100 °C	155 °C
8.	Linear Thermal Expansion Coefficient(α)	80×10 ⁻⁶ /K	65 - 70×10 ⁻⁶ /K
9.	Dielectric constant (ϵ_r) @ 1 MHz	3.0 - 3.4	2.9

IV. SILICON FIBER SHEET BASED READ-OUT STRIP PANEL

For making the pickup panel we have used Copper foil for making the readout strips and Aluminium foil (which is generally used in food coverage) for making the signal reference layer. For attaching these two with the Silicon Fiber sheet we have used Araldite standard epoxy adhesive. After fixing Aluminium foil and copper strips we placed good number of Lead bricks over the entire surface and kept it for 24 hours. We have removed the lead bricks and did physical inspection of the pickup strip panel and observed that Aluminium foil and Copper strips had been attached properly or not. Recently prepared readout strip panel in our laboratory and Polycarbonate (Plastic honeycomb) based readout strip panel (from Tata Institute of Fundamental Research (TIFR) group, Mumbai) have been shown below in Fig. 2. We have kept 2 mm (millimetre) spacing between two Copper strips for enhancing the position resolution of RPC detector and avoiding the cross talk and also at the same time not increasing too much the dead space by increasing. We can't use lesser than 2 mm gap with 2.80 cm (centimetre) width of pickup strips, because it may cause the cross talks of signals between two strips. Silicon Fiber sheet is the new material for this purpose which is being used for the first time by the BHU (Banaras Hindu University) group for making pickup strip panel.



(a) (b)
Fig. 2. Pickup Strips Panel of (a) Honeycomb and (b) Silicon Fiber sheet material, respectively.

Using the above methodology we have made 10 cm × 10 cm, 30 cm × 30 cm, 50 cm × 50 cm and 1 m × 1 m read out strips panels. The physical parameters which we have used in making the readout strips panel have been shown below in Table 2. For checking these pick up panels we have terminated the one end of each strips by their characteristic impedance and another end is connected with LEMO signal connectors (The word LEMO is based on the name of company's founder, engineer Leon Mouttet). Performance of these pickup strip panels have been studied using Resistive Plate Chamber (RPC) detector. During the detector operation only a pure Freon R134a gas is flown and the applied voltages on both electrodes were 5,000 volts creating 10 kV potential difference. We observed the signals produced in the gas chamber after ionization of the gas is picked up by both strips panels, which we observed using a digital phosphor oscilloscope.

Table 2: Physical parameters related to the both Pickup strip panels.

Contents	Pickup strip panel (Silicon Fiber sheet)	Pickup strip panel (Polycarbonate)
Copper thickness	0.04 mm	0.09 mm
Aluminium thickness	0.01 mm	0.17 mm
Terminator (in Ω)	~ 50	~ 50
Dielectric material thickness	3.73 mm	4.53 mm
Relative humidity	43%	43%
Temperature	25 ⁰ C (Degree Celsius)	25 ⁰ C (Degree Celsius)
Adhesive	Araldite	We don't know

V. EFFECTS OF TEMPERATURE

To whet our curiosity as to the response of the Silicon Fiber Sheets, which are in very huge amount (~5400 tonnes), to worse case scenarios which may occur during the experiments, such as experiment catching fire due to man made mistake or electrical, we subjected the Silicon Fiber Sheet in a tubular furnace in which MDC1901 was used as temperature controller in which temperature can vary up to 1000 °C.

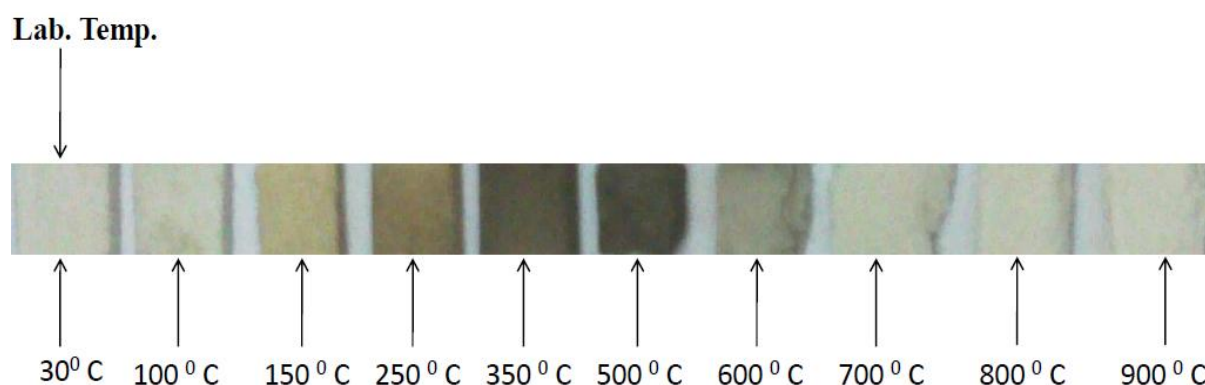


Fig. 3. Effects of temperature on Silicon Fiber Sheet material is shown at various furnace temperatures.

Figure 3 shows the variation in the physical parameters of Silicon Fiber Sheet with temperature. We have observed that up to 100 °C there is no physical appearance change in it due to the effect of temperature. But after that it starts fuming. During this experiment what we observed has been mentioned in tabular form in the Table 3. During experiment we kept each piece of Silicon Fiber Sheet in the oven at equal time period of 2 minutes, to avoid any other effect which may occur due to this time changing behaviour in oven.

Table 3: Effect of temperature on the physical parameters of the Silicon Fiber Sheet is tabulated.

Temperature (°C)	Effect observed
30	No effect
100	No effect
150	Starts slowly fuming and became slightly less in weight and also of light brown colour.
250	Slowly starts fuming and became little rigid (loss of flexibility) than earlier and brown in colour.
350	Starts fuming and became hard (lost flexibility) than earlier, finally became dark brown in colour.
500	Starts fuming and became like soft foam, finally became dark black.
600	Starts fuming quickly than earlier and became softer than earlier and finally became slightly white in colour.
700	Starts fuming very quickly and became completely white in colour, also very much soft in touch than earlier.
800	Fuming is over within 5 seconds and became completely white in colour; ultimately it also became very soft foamy in nature.
900	Fuming is over within 5 seconds and became completely white in colour; ultimately it also became very soft foamy in nature as earlier, and very light in weight.

From the sequential visual observations listed in Table 3, we may conclude that up to 100 °C temperatures Silicon Fiber Sheet sustains its chemical and physical properties. Although temperature of the underground labs tend to be constant; and is controlled at least in the main laboratories by air conditioning system. However the ambient rock temperature at

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6010 mwe (meter water equivalent (MWE)) underground depth is 42 °C in the case of SNO lab (Sudbury Neutrino Observatory (SNO)) [12] without any ventilation system. The 100 °C temperature is far away than the normal working temperature inside the main laboratory of any underground labs operated by human beings.

One of the main observations is that we did not observe any flame coming out from the Silicon Fiber Sheet at any time and at any applied temperatures. It shows that Silicon Fiber Sheet is a flame resistant material. Therefore, the use of Silicon Fiber Sheet in any underground laboratories will not put any threat related to fire. In addition, even up to certain temperature it will prevent other instruments from catching fire, which we must want is an important requirement for any underground laboratory for at least safety purpose. This means that the use of Silicon Fiber Sheet is very important in preventing the fire from proceeding through it to the other parts of the laboratory. We have also observed that Polycarbonate (honeycomb) catches fire very rapidly. It seems that the polycarbonate based pickup strip panels which are commonly used in various gaseous detectors now-a-days are not suitable for the underground based laboratories in case of bulk use. From the above observation and discussion we may conclude that use of Silicon Fiber Sheet based pickup strip panel is strongly recommended for the underground laboratories.

VI. ELEMENTAL COMPOSITION OF SILICON FIBER SHEET

What is the reason behind its non flaming property even at 1000 °C temperature? Are there any hazardous gases coming out during its fuming? Or while soldering strips and terminators connection are there any harmful gases which may come out due to heating. To get the answers of these questions, elemental analysis of Silicon Fiber Sheet is required to know the chemical composition. Therefore, we performed the analysis with the help of X- ray fluorescence technique (XRF) based instrument. Because X-ray fluorescence technique is the best possible technique to determine the elemental composition of metals ceramics, glass and building materials around us [13]. Table 4 shows the XRF report of Silicon Fiber Sheet.

From table 4 one can see that around 98% of Silicon Fiber Sheet is made up of mainly Si, Al and Zr, which are very common materials that form rock and sand. Due to them it is not helpful in fire catching and progressing from one place to the other place inside the laboratory. Therefore it almost fulfils our necessary criteria for the fire resistant property. Rest elements are just trace of Silicon Fiber Sheet material.

Table 4: Composition of Silicon Fiber Sheet is listed.

Compound	Wt. (%)	Std. Err.	El	Wt. (%)	Std. Err.
SiO ₂	55.47	0.25	Si	25.93	0.12
Al ₂ O ₃	39.63	0.24	Al	20.97	0.13
ZrO ₂	2.62	0.08	Zr	1.94	0.06
SO ₃	0.908	0.045	Sx	0.364	0.018
Na ₂ O	0.551	0.046	Na	0.409	0.034
Cl	0.362	0.018	Cl	0.362	0.018
P ₂ O ₅	0.155	0.017	Px	0.0677	0.0074
HfO ₂	0.0528	0.0042	Hf	0.0448	0.0035
CaO	0.0521	0.0043	Ca	0.0373	0.0031
Fe ₂ O ₃	0.0454	0.0023	Fe	0.0318	0.0016
PdO	0.0376	0.0027	Pd	0.0327	0.0024
MoO ₃	0.0262	0.0013	Mo	0.0175	0.0009
TiO ₂	0.0206	0.0027	Ti	0.0123	0.0016
WO ₃	0.0129	0.0035	W	0.0102	0.0028
CuO	0.0120	0.0022	Cu	0.0096	0.0018
NiO	0.110	0.0013	Ni	0.0086	0.0010
Y ₂ O ₃	0.0093	0.0007	Y	0.0073	0.0005
Ag ₂ O	0.0065	0.0026	Ag	0.0061	0.0024

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Ga ₂ O ₃	0.0064	0.0009	Ga	0.0048	0.0007
K ₂ O	0.0050	0.0017	K	0.0042	0.0014
ZnO	0.0045	0.0009	Zn	0.0036	0.0007
Am ₂ O ₃	0.0038	0.0012	Am	0.0035	0.0011
U ₃ O ₈	0.0032	0.0013	U	0.0027	0.0011
Co ₃ O ₄	0.0015	0.0007	Co	0.0011	0.0005

From Table 4 we may also see that there are traces of materials that can produce small amounts of hazardous gases in presence of strong heat in the form of fume such as SO₃, P₂O₅ [14][15]. These gases may not affect human beings if soldering process is performed in a confined space. Therefore, it will be very helpful for getting the environmental clearance, which is the primary requirement for making use of it and other materials in any underground laboratory.

VII. RESULTS AND CONCLUSION

The Silicon Fiber Sheet is found to be good for gluing the strips and a new suitable material for making charge pick up strip panel for various gaseous detectors such as Resistive Plate Chamber. This material is heat and flame resistant as well as water resistant. Up to 100 °C temperatures Silicon Fiber Sheets has no effect in its physical and chemical behaviour. Therefore it will be much more suitable for any underground laboratory operated by human beings. Work is in progress for making and studying basic properties of such pickup strip panels. Therefore, Silicon Fiber Sheet seems to be a good dielectric material to be used in making pickup strip panel for RPC Detector.

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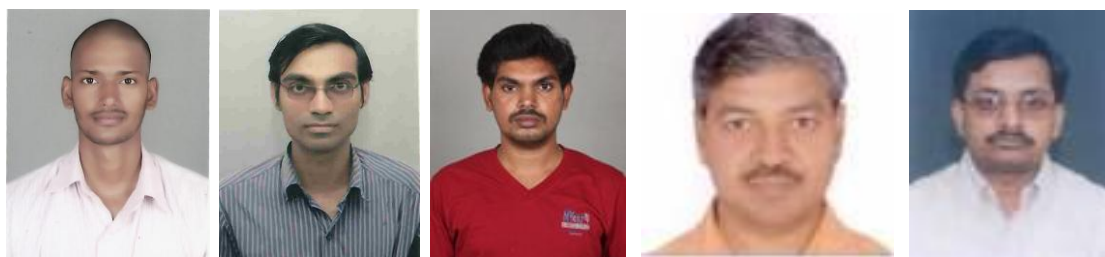
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