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Plasma sprayed alumina coatings for radiation detector development

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Abstract. Conventional design of radiation detectors uses sintered ceramic insulating modules. The major drawback of these ceramic components is their inherent brittleness. Ion chambers, in which these ceramic spacers are replaced by metallic components with plasma spray coated alumina, have been developed in our Research Centre. These components act as thin spacers that have good mechanical strength as well as high electrical insulation and replace alumina insulators with the same dimensions. As a result, the design of the beam loss monitor ion chamber for CAT could be simplified by coating the outer surface of the HT electrode with alumina. One of the chambers developed for isotope calibrator for brachytherapy gamma sources has its outer aluminium electrode (60 mm dia $\times$ 220 mm long) coated with 250 μ thick alumina (97%) + titania (3%).

In view of potential applications in neutron-sensitive ion chambers used in reactor control instrumentation, studies were carried out on alumina 100 μ to 500 μ thick coatings on copper, aluminium and SS components. The electrical insulation varied from 10^8 ohms to 10^{12} ohms for coating thicknesses above 200 μ. The porosity in the coating resulted in some fall in electrical insulation due to moisture absorption. An improvement could be achieved by providing the ceramic surface with moisture-repellent silicone oil coating. Irradiation at Apsara reactor core location showed that the coating on aluminium was found to be unaffected after exposure to 10^{17} nvt fluence.

Keywords. Plasma spray; alumina coating; radiation detector; ion chamber; insulators.

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1. Introduction

Gas-filled radiation detectors like ionisation chambers and proportional counters usually consist of a pair of electrodes electrically insulated from one another [1]. The electrodes are also electrically isolated from the outer envelope that is at ground potential. Although there are many insulating materials available for use in these applications, ceramic-metal seals, consisting of high-purity alumina material fused to SS or nickel flanges, have proved to be superior in many respects. Electronics Division, BARC, has been developing various types of gas-filled detectors for a wide range of neutron and gamma monitoring applications [2–4]. The chamber electrodes are usually cylindrical in shape, and they are anchored to a circular base-plate on which the ceramic-metal seals are mounted. In some detectors high purity alumina insulators in the form of discs and rings and tubes are used. In some cases the insulating spacers lack the mechanical strength to withstand the seismic vibration and shock test specifications. It has been found useful to substitute them with metal spacer plasma spray coated with high purity alumina material. The present paper describes the design of some ion chambers that make use of such components.

2. Plasma spray process

Laser and Plasma Technology Division has developed a method of plasma spray coating of ceramic materials [5]. Plasma spray technology, the process of preparing an overlay coating onto any surface, is one of the most widely used techniques to prepare composite structural parts with improved properties and life-span. In plasma spray process an electric arc is struck between a rod type cathode and a nozzle anode. When the plasma gas flows through the arc it gets ignited. The plasma is initiated when electrons are accelerated from the cathode to the anode. As the electrons speed towards the anode they collide with, excite and ionise the atoms or molecules in the gas. The additional electrons freed by the ionisation are also accelerated causing further ionisation. These collisions transfer the kinetic energy of the electrons to the other species and raise the temperature of the gas. The ignited gas comes out of the nozzle in the form of a jet whose temperature is above 15000°K. Any powder, which is to be sprayed, is injected into the flame where it is melted and accelerated towards the substrate. The molten powder on hitting the substrate cools and anchors together to form a strong adherent coating. The main advantages of plasma spray process are:

- Any powder which melts without sublimation can be coated
- The substrate temperature can be as low as 50°C
- There is no restriction on the size and shape of the job
- The coating process is comparatively fast
- Coating thickness can go from few microns to millimetre
- With additional reinforcement, ceramic coatings with more than 10 mm thick can be prepared
- A mechanical as well as metallurgical bonding is necessary.

3. Applications

Studies were carried out on 100 μ to 500 μ thick alumina coatings for use in gamma compensated neutron-sensitive ion chambers developed for reactor control and safety instrumentation. Here the feasibility of using metallic components that were plasma spray-coated with high-purity alumina within as well as outside the sensitive volume has been explored. Aluminium rings machined to the required dimensions and then coated with alumina have helped in a more precise alignment of the electrodes (figure 1). Similarly insulating spacers outside the sensitive volume can be used to provide isolation between the circuit ground and the local electric ground (figure 2). These components combine the mechanical strength of metals with the dielectric properties of alumina. The outer surface of a re-entrant type ion chamber developed for the calibration of brachytherapy gamma sources

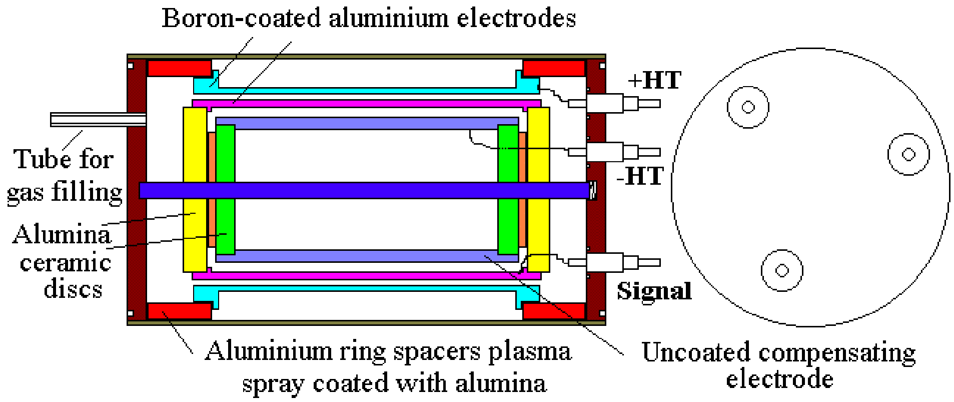

Figure 1. Ion chamber for neutron flux monitoring in reactors.

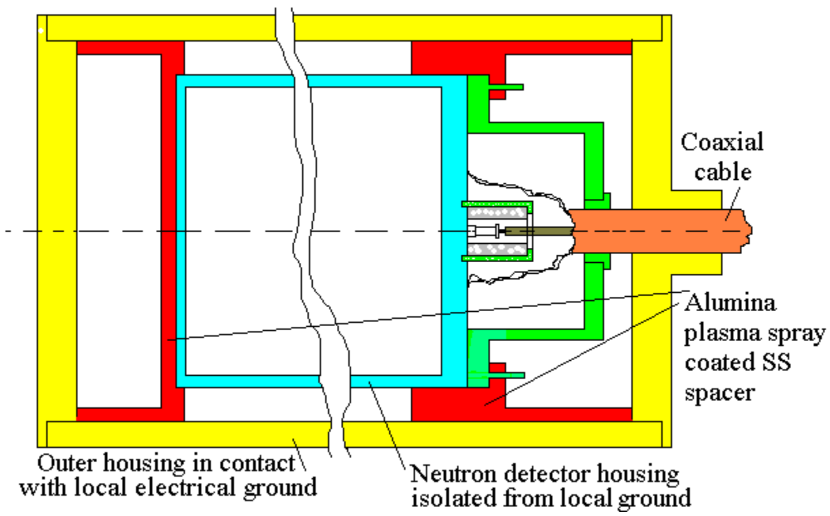

Figure 2. Insulating spacers in neutron detectors for power reactors.

has been plasma spray-coated with 250 μ thick alumina (97%) + titania (3%). This makes the chamber safe to handle because the outer housing carries high voltage. The method is also being tried out on providing electrical insulation between the HT electrode and the outer housing (figure 3). This design helps to avoid cantilever-type mechanical vibration of the HT electrode.

In all these applications the important criterion is that the ceramic coating shows high electrical insulation, good mechanical stability and high radiation tolerance. To check these properties various tests were carried out on coated samples.

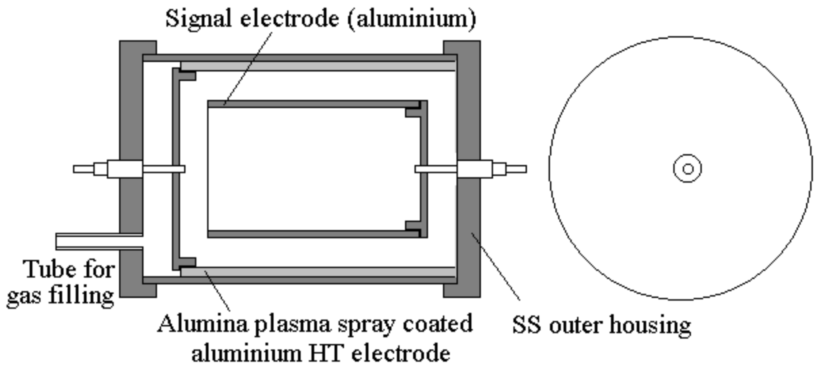

Figure 3. Ion chamber for accelerator beam-spill monitoring.

Table 1. Metallic components spray coated with ceramic material.

Material	Sample (mm)	Coating material	Coating thickness	Insulation resistance (ohms) at 1 kVdc	
				Room temp.	200°C
Cu	Plate 25 × 25 × 3	Alumina	200 μ	1.3×10^9	7×10^{11}
		Alumina	300 μ	4×10^9	2×10^{11}
		Alumina	500 μ	2×10^9	2×10^{11}
Al	Plate 25 × 25 × 3	97% Alumina and 3% titania	100 μ	1×10^{10}	-
			200 μ	2×10^{10}	-
	Ring OD78 × ID72 × 25	97% Alumina and 3% titania	100 μ	$< 10^8$	-
			200 μ	1.5×10^{10}	9×10^{12}
SS	Tube OD16 × ID14 × 30	Alumina	200 μ	7×10^9	3×10^{12}

4. Experiments on samples

To study the electrical insulation, integrity of ceramic coating etc, tests were carried out in Electronics Division. Plasma spray coating of alumina was carried out on aluminium, copper and stainless steel metallic components 25.4 mm × 25.4 mm × 3 mm in size. The coating thickness varied from 100 to 500 μ. The insulation resistance was measured at 1 kVdc at room temperature and at 200°C. The results tabulated in table 1 show that the coating on aluminium shows higher insulation. The insulation is better at higher temperatures.

Since the alumina coating has high porosity content it was coated with moisture-repellent coating consisting of 1% solution of silicone oil in acetone. The results (table 2) showed an improvement in insulation resistance after coating in 100% humidity condition.

Table 2. Effect of moisture-repellent coating on ceramic spray coating.

Material	Sample (mm)	Coating material	Coating thickness	Insulation resistence (ohms) at 1 kVdc at room temp.		
				Before moisture-repellent coating	With moisture-repellent coating	
					Dry condition	In 100% humidity
Cu	Plate $25 \times 25 \times 3$	Alumina	200 μ	2×10^9	1×10^{13}	10^{13}
Al	Ring OD78 $\times$ ID72 $\times$ 25	Alumina	200 μ	1.5×10^9	1.3×10^{12}	$< 10^8$

Table 3. Effect of neutron flux on 200 μ thick alumina coating (Apsara E-8 location, irradiation time: 40 hrs, neutron flux: 10^{12} n/cm^2/sec, neutron fluence: 1.5×10^{17} nvt).

1s Al sample (mm)	Insulation resistance (ohms)		
	At room temp. at 1 kVdc		At 125°C after irradiation
	Before irradiation	After irradiation	
Rod OD14 $\times$ 25	1×10^{12}	1×10^9	4×10^9 (1 kV) 1×10^{11} (500 V)
Ring OD18 $\times$ ID16 $\times$ 10	1.5×10^{12}	1.5×10^8	10^{12} (250 V) $< 10^6$ (500 V)

5. Neutron irradiation tests at apsara E-8 location

Tube and rod samples made of 1S aluminium were irradiated in Apsara reactor core E-8 location. The neutron flux at the location was assumed to be 10^{12} nv on the basis of data supplied by RSMD, BARC. The samples were double-sealed in polyethylene and lowered into the core in Harwell can. They were analysed after 40 h of irradiation. In spite of sealing there was moisture ingress resulting in a fall in insulation, which improved after heating (table 3). There was no deterioration in adhesion of ceramic material to the metal surface.

6. Conclusion

The use of plasma spray coated alumina and titania on metal components has the potential for important applications in the development of radiation detectors, particularly in situations where there are designed to withstand severe mechanical shock and vibration. It is observed that coating thickness below 200 μ results in electrical breakdown at 1 kvDC. Moisture-repellent coating mitigates the effect of porosity to some extent.

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