CHARACTERIZATION OF DETONATION SPRAYED ALUMINA COATING FOR IMPROVED PERFORMANCE OF SEPTUM MAGNET COILS OF INDUS2

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Abstract

The paper presents results of the investigation carried out after failure of in-service septum coils of INDUS2. Thin profiled section of the septum coil was identified as the most critical part of the component. It was recommended that no machined notch should be provided at the internal 90° corner of the coil while sufficient rounding should be provided at the outer 90° corner edges. With respect to coarser alumina powder (22-45 µm), coating deposited with finer alumina powder (5-22 µm) exhibited greater degree of melting and lower surface stress, although with largely similar hardness and porosity content. The inclination of specimen's surface with respect to spray direction strongly influences adhesion, thickness and porosity content of the coating.

INTRODUCTION

In 2.5 GeV INDUS2 storage ring, injection of 500-600 MeV electron beam is achieved with an assembly of thin and thick pulsed septum magnets and four kicker magnets [1,2]. Septum magnet assembly consists of (i) a core made of Ni-Fe laminates and (ii) septum coil (Fig.1A) made of oxygen free copper conductor with insulating alumina coating provided by detonation spray [1,3]. In August 2009, failure of four-year old in-service septum coil was noticed. Subsequently, two numbers each of thick and thin coils were machined and coated. The newly coated coils also failed during electrical testing. In view of premature failure of new septum coils, a study, involving coating and characterization of septum coils, was carried out. In addition, effects of Al_2O_3 particle size and profile of copper substrate on the resultant coating were also studied.

RESULTS: SEPTUM COILS

Failure of coil was noticed in the form of arcing in the thin section of the coil, marking abrupt transition in the cross-section (Fig.1B). Failure sites exhibited complete removal of the coating with or without signs of surface melting. It has been found that, in general, old septum coils (both thin and thick) carried thinner Al_2O_3 coating (55-190 µm) with lower surface roughness (Ra = 3-4 µm) than new coils (coating thickness = 100-490 µm; Ra = 5.2 – 7.5 µm). Both the coils of "old" batch exhibited considerably lower surface stress than the coils of "new" batch (Table 1).

For qualitative assessment of relative strengths of Al_2O_3 coating, both "old" and "new" coils were subjected to tape

Figure 1: Photographs of (A) thick septum coil - parts "1" and "2" are referred in the text as "thin" and "thick" sections, respectively and (B) defect sites (encircled).

test, involving repeated application and pulling off of ordinary transparent adhesive tape on the flat coated surface. In contrast to old coil, new coil exhibited relatively poor cohesion among particles of the coating.

Table 1: Results of residual stress measurement (in MPa)

Part	Face 1	Face 2
Old coil	+21 to +176	-229 to +66
New coil	+115 to +486	+207 to +369
Specimen (fine powder)	-102 to +71 (Sheet)	+27 to +153 (Cylindrical)
Specimen (coarse powder)	+354 to +493 (Sheet)	+431 to +588 (Cylindrical)

X-ray diffraction of Al_2O_3-coated surface of one of the new coils exhibited γ-Al_2O_3 and α-Al_2O_3 phases, indicating partial melting of Al_2O_3 powder particles during spray deposition. Metastable γ-Al_2O_3 phase in the coating forms under rapid crystallization of molten particles.

Metallographic examination of the specimens extracted from thick section of the "new" coil exhibited about 200 µm thick Al_2O_3 coating with uniformly distributed porosity. Alumina coating at 90° corner of this section exhibited continuous region of debonding at substrate/coating interface, while thin profiled section was associated with sharp machined notch at 90° inside corner (Fig.2). The notch region remained poorly-filled and carried numerous cracks, coating fragmentation and debonding at substrate/coating and coating/coating interfaces. Alumina coating on copper coil exhibited local variation in micro-hardness (Table 2). Reduced micro-hardness of inside surface of thin section of the septum could be caused by angular spray deposition as the surface is shadowed by thick section of the coil.

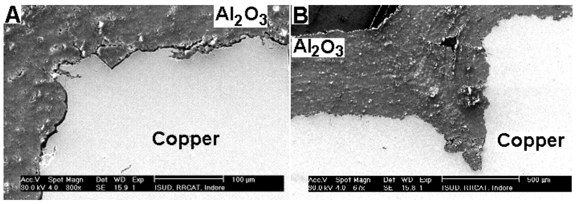

Figure 2: Magnified view of defects at (A) external and (B) internal corners.

Table 2: Results of micro-hardness measurement

Part		VHN (load = 1.961 N)	
		Range	Average
New septum coil	Thick section	859 - 1404	1144
	Thin section 1. Inside edge 2. Outside edge	 541 – 1180 906-1316	 850 1012
Sheet specimen	Fine powder	738-110 874 - 1183	894 1064
	Coarse powder	985 - 1226	1134

RESULTS: Al_2O_3-COATED SPECIMENS

Detonation spray coating of copper specimens was performed with DNIEPR-3 model equipment of horizontal orientation with Al_2O_3 powder of two different size range: 5-22 µm and 22-45 µm. Copper specimens used for Al_2O_3 coating were: (i) sheet specimens (30x25x3 mm^3), (ii) 37 mm long cylindrical copper specimens of 25 mm diameter - coated on one of the end faces and (iii) L-profiled specimens. With respect to coarser Al_2O_3 powder particles (22-45 µm), finer particles (5-22 µm) yielded coating with larger degree of melting and lower surface stress, although

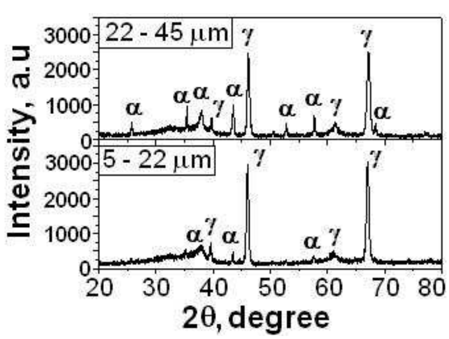

Figure 3: X-ray diffraction patterns of alumina coatings deposited with powders of different powder size.

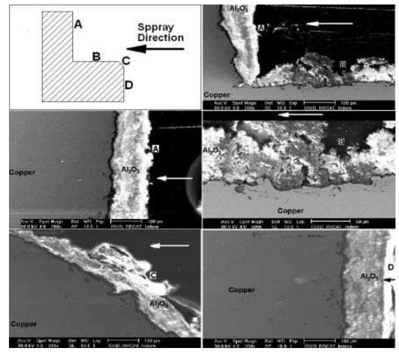

Figure 4: Cross-section of profiled Al_2O_3-coated copper specimen. Spray direction is marked with arrow.

with similar micro-hardness and porosity content. Relatively lower proportion of α-Al_2O_3 in the coating deposited with finer alumina powder (Fig.3) is indicative of higher degree of associated melting. In Al_2O_3-coated profiled specimens, surface normal to spray direction exhibited thick and well-bonded coating while porous and poorly bonded coating was deposited on the surface parallel to the spray direction. On the curved surface, nature of Al_2O_3 coating continuously changed with change in surface inclination with respect to spray direction (Fig.4).

CONCLUSION

Failure of the coating in the old septum coil were found at thin profiled section of the septum coil, marking abrupt transition in cross-section along the sharp inside as well as outside 90° corners. On the basis of the results of the study it was inferred that no notch should be provided at the internal 90° corner of the coil while sufficient radius (≥ 0.75 mm) or chamfering (at 45º) should be provided at 90° corner edges [4]. The inclination of specimen's surface with respect to spray direction strongly influences adhesion, thickness and porosity content of the coating. Spray coating with 5-22 µm alumina powder yielded low stress coating than that produced with 22-45 µm powder.

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