CHARACTERIZATION OF NICKEL IRON CORE MATERIALS FOR EFFICIENT PULSED SEPTUM OF INDUS-2

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Abstract

The Ni-Fe soft magnetic alloys are the most important fast switching core materials for accelerator pulsed magnets involving magnetization rates of ~1 Tesla/microsecond and magnetization reversal of the order of tens of microsecond. Magnet performance greatly depends on pulse magnetization behaviour of Ni-Fe laminations used to construct these pulsed magnets. To improve the injection efficiency of Indus-2 pulsed septum magnets, microstructural and magnetic characterization of the 36Ni-64Fe laminations have been performed. Orientation imaging microscopy using EBSD studies reveal significant grain growth with reduced grain misorientation upon optimization of H_2 annealing and surface oxidation process. Measured pulsed magnetic permeability of these laminations are of the order of 2000 at a peak magnetic induction of 0.9 Tesla and pulsed magnetic field homogeneity of the order of ~ 5 X 10^{-4}. Observed improvement of injection efficiency with high pulse permeability and improved magnetic field homogeneity of the pulsed septum magnets have been assigned to large grain homogeneous microstructure and reduced defect concentration of the annealed Ni-Fe laminations

INTRODUCTION

Injection system of Indus-2 consists of two pulsed septum magnets and four pulsed kicker magnets. In the injection scheme, a compensated bump produced by four kicker magnets and the e-beam is injected through two septum magnets. The Septa are used to deflect the beam coming from the transfer line-2 (TL-2) into the storage ring. Since the septum magnets provide necessary deflections to the incoming beam, a reliable injection operation needs stringent design requirements. An optimum magnet configuration combined with high pulse permeability and high B_{knee} on first magnetization curve of laminated yoke is desirable for high performance of a septum magnet system [1]. Since magnetic permeability is a microstructure dependent extrinsic process parameter, it is necessary to understand the microstructure dependence of pulsed magnetic permeability of the Ni-Fe laminations used for the construction of core yoke of Indus-2 septum magnets. In this paper we reported microstructural characterization of the Ni-Fe laminations in relation to pulse magnetic behaviour for improved injection efficiency of pulsed septum magnets.

PROCESSING & CHARACTERIZATION OF Ni-Fe LAMINATIONS

Ni-Fe laminations of nominal composition 36Ni-64Fe and thickness of 0.1 mm were fabricated by cold rolling at Mishra Dhatu Nigam Limited, Hyderabad. A set of the laminations were annealed at different temperatures at hydrogen atmosphere followed by surface oxidation at 400ºC in air atmosphere. The structural, microstructural and magnetic studies were performed on the as-prepared as well as the annealed and oxidised laminations. The X-Ray diffraction (XRD) studies confirmed bcc crystal structure in all the laminations. Microstructural characterizations have been performed using Optical Microscopy (OM) and Electron Back Scattered Diffraction (EBSD) studies. The EBSD measurements were conducted on electro-polished laminations using a Fei Qunata 200 HV SEM with TSL-EDX OIM system.

The Ni-Fe laminated yokes (Fig.1) were constructed using 0.1 mm thick annealed and oxidised laminations for pulsed magnetic studies. The details of the measurement techniques are discussed elsewhere [1, 2].

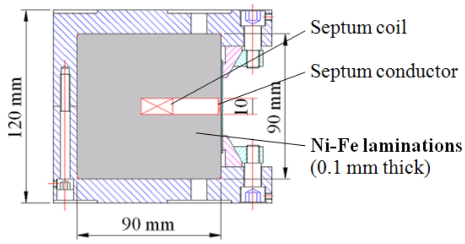

Figure 1: Cross sectional view of septum magnet with Ni-Fe laminated yoke

RESULTS AND DISCUSSION

The plane view as well as cross sectional optical images of the cold rolled un-annealed Ni-Fe laminations, as shown in Fig. 2, reveal elongated grains along rolling axis. The EBSD results of the un-annealed and annealed (1000ºC, 4 hours) laminations are presented in Fig. 3 along with respective grain size and orientation statistics. The orientation image of the cold rolled un-annealed sample (Fig. 3a) yields significantly large grain orientation spread (~ 16º) with large grain misorientation distribution (upto 5º) and grain size distribution upto 40 μm, as shown respectively in Figs 3a1, 3a2 and 3a3. The elongated grain structures are also evident from Fig 3a as seen from optical microscopy. Upon thermal annealing at 1000ºC in hydrogen atmosphere, significant grain growth

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is observed (Figs. 3b and 3b3) resulting significant reduction in grain misorientation (Fig. 3b2) and narrowing grain orientation spread (Fig. 3b1). Since the punching of the laminations induces residual stresses, stress analysis using XRD shows significant reduction in residual stress upon thermal annealing of the punched laminations. This together with EBSD study shows that optimization of processing and annealing condition leads to improved microstructural homogeneity with reduced defect concentration in the 0.1 mm Ni-Fe laminations.

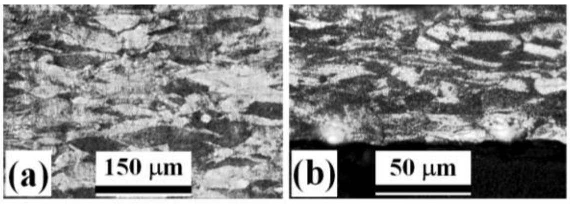

Figure 2: a) Plane view and b) cross-sectional optical micrographs of 0.1 mm un-annealed 36Ni-64Fe laminations

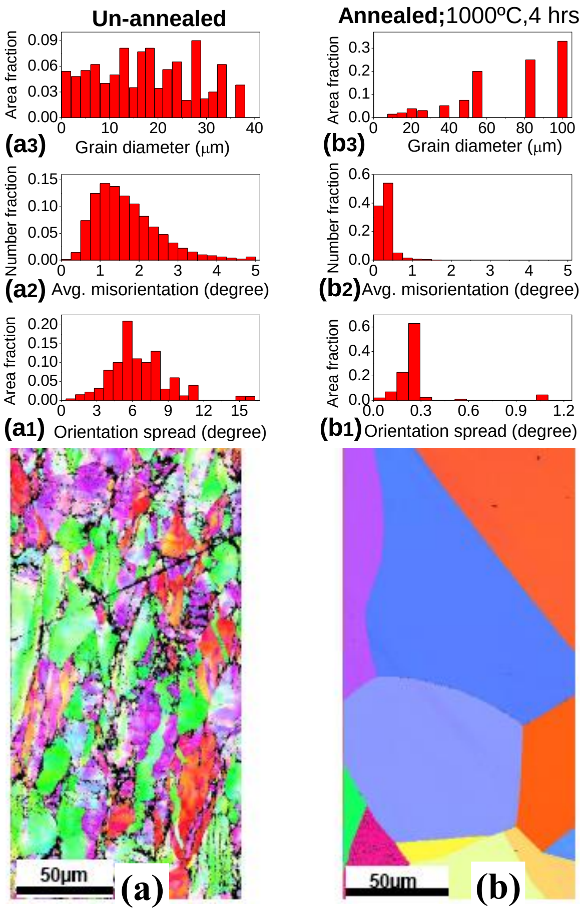

Figure 3: EBSD patterns of the (a) un-annealed and (b) annealed 0.1 mm 36Ni-64Fe laminations with respective grain size and orientation statistics

Pulsed magnetic permeability of the Ni-Fe laminated yoke is shown in Fig. 4 as a function of peak magnetic induction. Significant improvement in permeability spectrum is observed with maxima of ~ 2000 at the B_{peak} of ~0.9 Tesla. The measured pulsed magnetic field homogeneity along beam direction is also improved significantly with ΔB/B of the order of ~ 5 X 10^{-4}, as shown in Fig. 5. The improved pulse permeability and field homogeneity can be ascribed to improved microstructural homogeneity with reduced defect concentration in the Ni-Fe laminations.

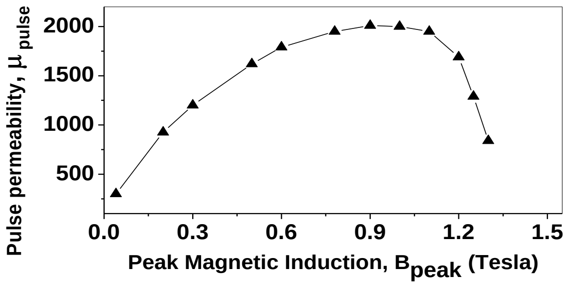

Figure 4: Pulse permeability as a function of B_{peak}

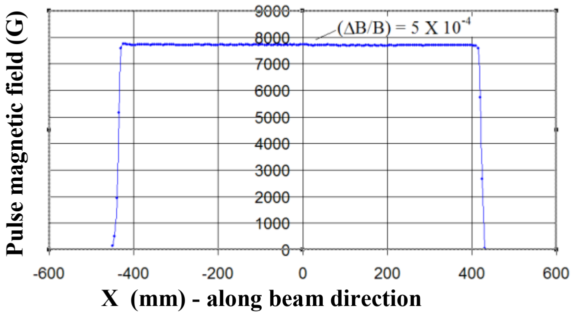

Figure 5: Pulsed field homogeneity in thick septum

CONCLUSIONS

Pulse magnetic permeability and pulsed magnetic field homogeneity of the pulsed septum magnets have been effectively monitored and improved by optimization of thermal annealing and surface oxidation process of 36Ni-64Fe laminations. Microstructural studies of the laminations using EBSD, OM and XRD shows significant grain growth and remarkable stress relaxation upon optimization of the annealing process. Improved microstructural homogeneity of the Ni-Fe laminations with reduced defect concentration is attributed to the improved pulse permeability and field homogeneity which is very promising for improvement of injection efficiency of Indus-2 pulsed septum magnets.

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