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The purpose of this work was to gain an improved understanding of the critical parameters of the rapid solidification process known as Liquid Dynamic Compaction (LDC). This was to be accomplished by a series of experiments on an important alloy			
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Both of these objectives were met.

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FINAL REPORT

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6. AUTHORS OF REPORT: R.C. O'Handley and N.J. Grant
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Attached as "Publications" at end of report

8. PATENT APPLICATIONS FILED:

- 1) "Permanent Magnets Made by Liquid Dynamic Compaction of Iron-Rare-Earth Alloys," R.C. O'Handley, N.J. Grant, E. Lavernia and Y. Hara, MIT Case No. 4008A, Patent Office Serial No. 922,730.
- 2) "Method and Apparatus for Making Polycrystalline Flakes of Magnetic Materials Having Strong Grain Orientation," T. Kuji, R.C. O'Handley and N.J. Grant, MIT Case 4875, Patent Office Serial No. 301,868, filed Jan. 1989.

9. SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT AND DEGREES AWARDED DURING THIS REPORTING PERIOD:

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Statement of Problem

The purpose of this work was to gain an improved understanding of the critical parameters of the rapid solidification process known as Liquid Dynamic Compaction (LDC). This was to be accomplished by a series of experiments on an important alloy system, Fe-Nd-B, known to show property instabilities with small variations in processing conditions. As a secondary objective it was considered desirable if in the course of the program we developed permanent magnets with improved properties.

Both of these objectives were met.

Summary of Progress July 1, 1988 - Dec. 31, 1988

Our progress during this period has been on three fronts. 1) Exploration of twin-roller quenching, as a concomitant to our development of Liquid Dynamic Compaction (LDC), to enhance magnetic orientation and remanence. 2) Re-examination of LDC over a range of atomization gas pressures and pour-tube diameters not yet explored and 3) Investigation of the role of reversal domain nucleation in the Fe-enriched subsurface layer of Fe-Nd-B sintered magnets by magneto-optic Kerr effect.

1) Twin-roller quenching

We described in the last report how twin roller quenching of Fe₇₇Nd₁₅B₈ produced flakes with significant crystallographic (00 m) texture and 50% increased remanence normal to the flake surface. A patent application has been filed on this important result.

We have studied the effect of roller pressure (at constant rotation speed of 1000 rpm) on magnetic properties of $\text{Fe}_{77}\text{Nd}_{15}\text{B}_8$ flakes. Increased pressure increases iH_C to over 12 and over 14 kOe in perpendicular and parallel fields, respectively. However, for both orientations, B_r remains at or below 5 kG, decreasing with increasing pressure for H perpendicular. This suggests that the enhanced remanence in twin-roller-quenched material relative to melt spun ribbon is more a consequence of directional heat flow than of deformation induced (00 m) texture.

2) Liquid Dynamic Compaction

Several LDC runs have been made with a multiple platform substrate using atomization pressures $p = 150$ and 200 psi and pour tube diameters $D = 3$ and 5 mm. The most important result is that thick (2 to 3 mm), amorphous compacts of Fe-Nd-B have been obtained for $p = 200$ psi and $D = 3$ or 5 mm that appear fully amorphous by X-ray scattering on their top surface. While the permanent magnet properties of the amorphous material are poor as expected, when annealed at 600 to 800°C coercivities H_{Cj} approaching 10 kOe and remanances of 5 to 6 kG were achieved in $H = \pm 14$ kOe. After premagnetization in 100 kOe $H_{Cj} = 12.7$ kOe and remanence doubled in some samples. There is much to be explored in terms of directional precipitation and grain growth from these "bulk" amorphous precursors.

3) Surface nucleation

We have addressed the problem of the coercivity mechanism in Fe-Nd-B sintered

magnets focussing on the role of the surface layer as a possible site for nucleation of reversal domains. Using longitudinal Kerr effect we found that the surface layer is always magnetically soft ($H_C < 0.6$ kOe). The sintered magnets only showed high bulk coercivity if they were driven to near saturation (i.e. no domain walls left in most interior grains) and had a composition slightly rich in Nd ($\text{Fe}_{77}\text{Nd}_{15}\text{B}_8$ as opposed to $\text{Fe}_{79}\text{Nd}_{13}\text{B}_8$). Presumably the excess Nd segregates to the grain boundaries where it forms a non-magnetic phase. This non-magnetic phase effectively breaks the exchange coupling between the grains and inhibits magnetization reversal in one grain from propagating to adjacent grains. If a Nd_{13} sample is saturated it is still easily demagnetized in a few hundred Oe because the domain walls are continuous from one grain to the next. If a Nd_{15} sample is driven only to 6 kOe - a field more than enough to saturate the surface but inadequate to remove all domain walls from the bulk ($B/B_S \approx 70\%$) - it again can be demagnetized in a few hundred Oe. We believe these to be the first direct measurements of the soft magnetic character of the surface of an Fe-Nd-B sintered magnet.

Publications

1. '(FeCo)-Nd-B Permanent Magnets Made by Liquid Dynamic Compaction,' T.S. Chin, Y. Hara, E.L. Lavernia, R.C. O'Handley and N.J. Grant, J. Appl. Phys. 59, 1297 (1986).
2. 'Fe-Nd-B Permanent Magnets Made by Liquid Dynamic Compaction,' S. Tanigawa, Y. Hara, T.S. Chin, E.J. Lavernia, R.C. O'Handley and N.J. Grant, IEEE Trans. MAG. 22, No. 5, 746 (1986).
3. 'Physics of Ferromagnetic Amorphous Alloys,' R.C. O'Handley, Invited review paper, J. Appl. Phys. 62, R15 (1987).
4. 'Magnetic Hardening in Melt-spun Fe-R-B alloys,' C.J. Wang, R. Ray and R.C. O'Handley, Materials Science and Engineering 99, 137 (1988).
5. 'Optimization of Liquid Dynamic Compaction for Fe-Nd-B Magnet Alloys,' M. Veistinen, Y. Hara, E.J. Lavernia, R.C. O'Handley and N.J. Grant, in High Performance Permanent Magnet Materials, ed. S.G. Sankar, J.F. Herbst and N.C. Koon (Materials Research Society, Pittsburgh, PA 1987), p. 93.
6. 'Sintered Magnets Made from Moderately Overquenched Fe-Nd-B-Based Powders,' C.J. Yang and R.C. O'Handley, Mat. Sci. and Eng. 100, 97 (1988).
7. 'Microstructure and properties of Liquid Dynamically Compacted (Fe,Co)-Nd-B Magnets,' T.S. Chin, R.C. O'Handley, Y. Hara, S. Tanigawa and N.J. Grant, J. Magn. Mater. 75, 130 (1988).
8. 'Magnetic Anisotropy of Nd₁₅Fe₇₇B₈ Flakes made by twin-roller quenching,' T. Kuji, R.C. O'Handley and N.J. Grant, submitted for publication to Applied Phys. Lett.
9. 'Surface Magnetic Properties of Nd-Fe-B Sintered Magnets,' A. Fukuno and R.C. O'Handley, submitted for publication to J. Appl. Phys.