COMPOSITE SOLID ARMATURE CONSOLIDATION BY PULSE POWER PROCESSING:
A NOVEL HOMOPOLAR GENERATOR APPLICATION IN EML TECHNOLOGY

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ABSTRACT

Some of the desirable characteristics for the solid armatures used in railguns appear feasible through the use of composite materials. Graded electrical resistance, and assured sliding contact are among these characteristics. Metal-metal, metal-ceramic, and metal-polymer composites are generic types of potential solid armature materials. Copper-tungsten and aluminum-alumina are example composite systems, of the metal-metal and metal-ceramic types respectively, which have been employed in the demonstration of the versatility of the Homopolar Generator as a materials processing tool for composites. Powder metallurgy and laminate bonding approaches have been utilized. In conventional processing, energy deposition is prolonged and the bulk heating which results often destroys the structural and chemical integrity of the starting materials. Composite solid armature materials have been consolidated with subsecond high temperature exposure. Densification in the solid state proceeds by a warm/hot forging mechanism and fully dense composites are obtained by a combined application of pressure and a controlled energy input.

INTRODUCTION

Performance evaluation of railguns depends on availability of suitable solid armatures. Rail/armature combinations which promote efficient energy transfer also minimize bore damage. Less flexibility exists in the choice of rail materials than in armatures. In the search for optimum performance, it is therefore logical to focus on alternative armature designs, and on methods for their processing and fabrication.

A broad-based, integrated approach to solid armature development has evolved over the last several years. At the Center for Electromechanics at the University of Texas (CEM-UT), predictive electrothermal models have been developed and successfully applied to actual armature performance. The models have confirmed the desirability of conductivity grading for improving the current distribution within these ultrahigh speed, variably-loaded sliding contacts. The requirements can probably best be met by composite armatures.

The underlying concepts have been tested in a series of preliminary experiments [1]. These experiments employed a macro-composite solid armature constructed of leaves of materials with different electrical conductivities. Subsequently, fabrication techniques for a more controlled and customized grading of electrical conductivity were proposed. Solid

armatures from powder-based metal-ceramic microcomposites, and from metal-metal laminar composites were candidates.

Such composites have been produced by a novel experimental approach which employs a homopolar generator in a pulse-powered materials consolidation system. The feasibility of this approach has been demonstrated for a wide variety of engineering materials [2,3]. A relevant composite system is the binderless copper-graphite composite brush material, which shows application potential for high-speed, high-current duty [4,5].

EXPERIMENTAL PROCEDURE

The Consolidation Process

Figure 1 shows the schematic tooling configuration of the consolidation process. A 10 MJ homopolar generator dedicated to industrial applications was the pulsed power source used, in conjunction with a modified 100 ton vertical axis hydraulic press. The operating characteristics of the HPG as a powder processing tool are described elsewhere [2].

For the powder-based metal-ceramic composite consolidation, powders were mechanically mixed in batches, with ceramic mass fractions of 1% to 10%. Predetermined amounts of each batch were loaded into the cavity of the die to produce an eleven layer stack with graded composition (0% to 10% ceramic mass fraction). The insulated die cavity was lined with a dense alumina tube with an inner diameter of 50 mm.

The laminar copper-tungsten composite was constructed from copper foils and tungsten mesh. These materials were stacked such that the controlled variation in spacing between the exposed tungsten fibers in the consolidated composite would yield a graded electrical resistivity. The concept is illustrated in Figure 2.

The dies and starting materials were initially at ambient temperature. Consolidation was performed in laboratory air. For consolidations performed at pressures ≤ 300 MPa (45 ksi), copper electrode/plungers were used for energy/pressure transfer to the precursors. For pressures > 300 MPa (45 ksi) AISI 416 stainless steel electrodes were employed.

After compacting the precursors to a desired pressure, the large current pulse was used to heat and consolidate the composite material. Following the discharge, the pressure was

Figure 1. Schematic of the arrangement of the HPG powered consolidation apparatus.

maintained for a holding period, permitting conductive heat transfer through the plungers to massive copper platens. The die was then unloaded and the consolidated compact was ejected.

The voltage drop across the compact and the magnitude of the current were recorded during the pulse. The product of these values was used to obtain the power during the pulse. The power was numerically integrated to produce the total energy input to the specimen. Division of the total energy input by the mass consolidated yields the specific energy input (SEI) in units of J/g. A set of curves for a copper-tungsten consolidation are shown in Figure 3.

Evaluation

Microstructure and density measurements were used in the preliminary evaluation of these composites. The consolidated composite materials were sectioned in the radial direction, metallographically prepared, and then examined by scanning electron microscopy.

RESULTS AND DISCUSSION

Microstructures

Highly dense microstructures were observed throughout the cross-sections of the consolidated composite materials examined by SEM as shown in Figure 4 for the copper-tungsten composite. Excellent conformity between copper and tungsten indicates the potential for a highly conductive interface. An etched cross section is shown at three magnifications in Figure 4 (a), (b), and (c). Figure 4 (c) also indicates the retention of the interfiber spacing of the starting material. For both material systems, densities greater than 95% of theoretical were achieved in the preliminary experiments.

Alternative precursors

One potential difficulty with these materials in high speed sliding duty is the relatively large scale of the constituents. The apparent sliding contact behavior, in which 5-20 point contacts actively carry current at any instant [6], suggests that more finely dispersed structures may produce better performance. Furthermore, in the refractory-metal skeleton systems, such as copper-infiltrated tungsten, where the vaporization of the infiltrant effectively controls wear, the need is for many micro-islands of tungsten each surrounded by copper.

These difficulties may be resolved by the adoption of novel materials engineering approaches. For the refractory-metal-based systems, the ultrafine filamentary composites described by Bevk [7] is an attractive technical alternative. These materials are

Figure 2. Schematic showing the interleaving concept applied to the copper foil/ tungsten weave composite starting materials.

characterized by dense and uniform dispersions (10^6 to $10^{10}/\text{cm}^2$) of fine filaments (5 to 100 nm thick). In this approach a powder metallurgy product may be used as the starting material. This material is deformation-processed by rolling, swaging, drawing, or extrusion to very large strains until the *in-situ* formed filaments are sufficiently small.

Another approach to microstructural refinement is to derive the metal powder blend from the reduction of a complex metal oxide precursor. Suitable copper tungstates and copper molybdates for this purpose have been identified. The challenge is then to consolidate these finely distributed, homogeneous powder blends into useful forms without structural coarsening. This is a task to which the high-energy high-rate consolidation processing may be well matched.

In the case of the aluminum-alumina system, two alternative approaches may be taken to distribution of the alumina in the metal matrix. One is by heat treatment of air-atomized powder particles after compaction to intermediate densities ($\approx 85\%$). This leads to spheroidization of the alumina in a continuous aluminum matrix, which can then be consolidated to full density. The second approach is by mechanical alloying. The continuous welding and fracturing of an aluminum powder assemblage, and the rapid oxidation of the freshly-fractured surfaces leads to a fine and uniform dispersion of the alumina [8]. These composite powder particles could then be consolidated processed into desired shapes.

Metal-polymer composites

The widespread use of polycarbonate cubes as the accelerated load in plasma-driven railguns indicates the survival potential of polymer-on-metal sliding couples in the hypervelocity regime. Recent advances in conducting polymers raise the question of the potential benefit of the incorporation of such materials into solid armatures. It has been reported that on a mass basis a new, iodine-doped polyacetylene polymer is as conductive as copper. More recently, Lockheed has developed the polyanilines which in large scale production may be dollar-a-pound material. These materials are claimed to be less difficult to process than other conducting polymers and they do not ignite upon exposure to air [9].

The potential exists to incorporate these advances in polymer technology into the development of a composite solid armature design which matches the high-speed, high-current duty demanded of these components. One approach may be the use of a tubular skeleton made of a fine tungsten powder, infiltrated with a suitable conducting polymer and fitted over an aluminum or aluminum-alumina composite core. Such an arrangement takes advantage of the tribological and conducting properties of the polymer, the high melting temperature of the tungsten, and the low mass of the core. Other interesting possibilities exist for grading the mechanical, electrical and tribological properties in the radial and longitudinal direction.

Figure 3. Current, power and total consolidation energy waveforms applied to the copper foil/tungsten weave composite starting materials.

Figure 4. Scanning electron micrographs at (a) low (b) intermediate and (c) high magnification of an etched cross section of a copper foil/tungsten weave based planar composite.

SUMMARY

Some of the desirable characteristics for the solid armatures used in railguns appear feasible through the use of composite materials. Graded electrical resistance, and assured sliding contact are among these characteristics. Metal-metal, metal-ceramic, and metal-polymer composites are generic types of potential solid armature materials. Copper-tungsten and aluminum-alumina are example composite systems, of the metal-metal and metal-ceramic types respectively, which have been employed in the demonstration of the versatility of the Homopolar Generator as a materials processing tool for composites.

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REFERENCES

1. C.J. Lund, C. Persad, Z. Eliezer, D. R. Peterson, and J. Hahne, " Composite Solid Armatures for Railguns", Paper #13, Proceedings of the 3rd. Int. Current Collector Conference, Austin, TX, Nov. 1987.
2. H. L. Marcus, D. L. Bourell, Z. Eliezer, C. Persad, and W. F. Weldon, "High-Energy High-Rate Processing", Journal of Metals, December 1987, pp 6-10.
3. H. L. Marcus, C. Persad, Z. Eliezer, D. L. Bourell, and W. F. Weldon, "High-Energy High-Rate Processing of Composites", Proceedings of the AIME Northeast Meeting, Hoboken, NJ, May 1987.
4. K. C. Owen, M. J. Wang, C. Persad and Z. Eliezer, "Preparation and Tribological Evaluation of Copper-Graphite Composites by High-Energy/High-Rate Consolidation", Wear 120, 1987, pp. 117-121.
5. M. J. Wang, C. Persad, Z. Eliezer, and W.F. Weldon, "High-Energy / High-Rate Consolidation of Copper-Graphite Composite Brushes for High Speed, High Current Applications", Paper #20, Proceedings of the 3rd. Int. Current Collector Conference, Austin, TX, Nov. 1987.
6. I. R. McNab, " Pulsed High Power Brush Research II. Interpretation of Experimental Data", in High Power-High Energy Pulse Production and Application, ed. E.K. Inall, Australian National University Press, (Canberra) 1978. pp 201-215.

7. J. Bevk, "Ultrafine Filamentary Composites", in Annual Reviews of Materials Science, 13, 1983 edited by R. A. Huggins, R. H. Bube, and D. A. Vermilyea (Annual Reviews Inc., Palo Alto, CA) pp. 319-338).
8. P. S. Gilman and W. D. Nix, "The Structure and Properties of Aluminum Alloys Produced by Mechanical Alloying: Powder Processing and Resultant Powder Structures", Metall. Trans., 12A, May 1981, pp. 813-824.
9. T.S. Kuan, 'Conducting Plastics Sell for \$1 a Pound', in SUPERCONDUCTIVITY Flash Report, Vol. 1, No. 9, Jan. 11, 1988. p.8.