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Metallurgical Characteristics of As-Deposited RF-Coupled Plasma-Sprayed Aluminum Alloys*

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1. Introduction

ALUMINUM alloys were investigated for use in low-cost fiberreinforced composite materials. Radiofrequency (RF) coupled plasma spraying was used for integrating the aluminum matrix into arrays of alumina reinforcing fibers manufactured by Saphikon Inc. An analytical transmission electron microscope (TEM) with a hot stage was used to study the microstructure of plasma-sprayed Al-8Fe-2Mo-1V and alloy 8009 (Ref 1). The study revealed that the rapid cooling rate of the spraying process was able to almost completely suppress precipitation of the second-phase particles normally present in the alloy microstructure. Thermal exposure on the hot stage was observed to precipitate such particle phases. The ability to generate the particle phases via heat treatment or by optimizing the plasma spray processing parameters suggests the possibility for enhanced control of the microstructure and properties.

A design of experiment (DOE) methodology was used in a first-order optimization of parameters (Ref 2). As would be expected, the plasma spray process and parameters were found to have a significant effect on material properties. Many important microstructural features in aluminum-iron systems require magnifications of 10,000× to 100,000× for study, and thus a TEM must be used. For example, Fig. 1 is a micrograph taken at 22,000× showing the microstructure expected in an Al-8Fe-2Mo-1V powder billet that has been extruded and forged. The microstructure consists of matrix grains (white) that are 99% pure aluminum, with iron-rich particles (dark) including $Al_{13}Fe_4$ (needles), Al_6Fe (blocky), $Al_{12}Mo$ (globular), and a large metastable nodular phase.

Key Words: Radiofrequency (RF) coupled plasma spraying, TEM—aluminum alloys, microstructure of the as-deposited aluminum alloys, rapid solidification processing (RSP), TEM—hot-stage

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2. Experimental Procedure

The plasma-sprayed Al-8Fe-2Mo-1V and alloy 8009 materials were produced in two forms: (1) "neat foils" (matrix without fibers) measuring 0.20 mm (0.008 in.) thick, and (2) monotape material also measuring 0.20 mm (0.008 in.) thick. The plasma-sprayed TEM foils were electropolished (jet thinned at approxi-

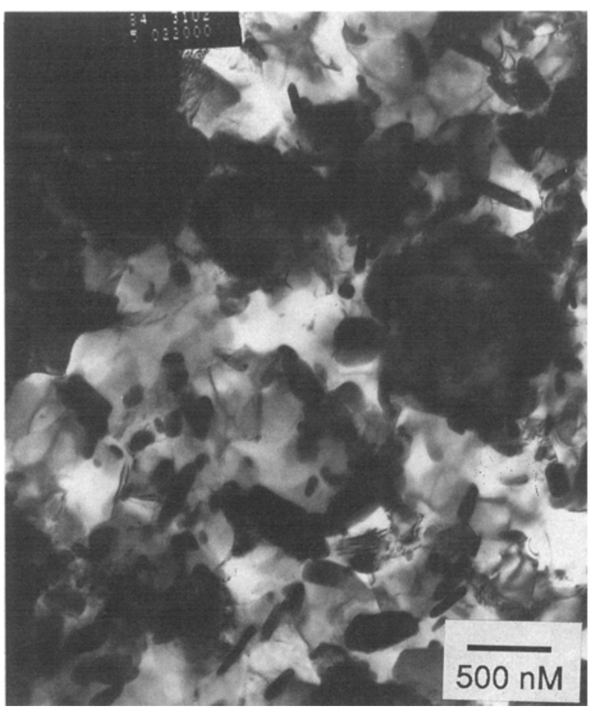

Fig. 1 TEM micrograph of extruded and forged Al-8Fe-2Mo-1V

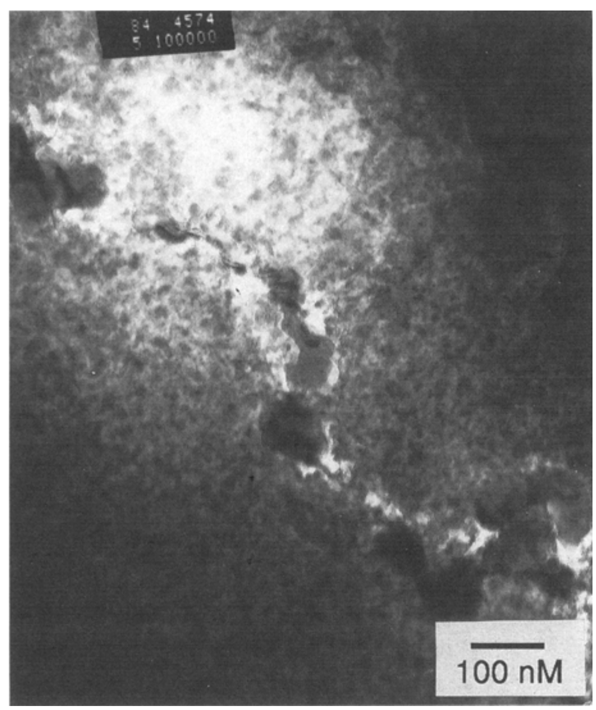

Fig. 2 As-deposited monolithic Al-8Fe-2Mo-1V (neat foil)

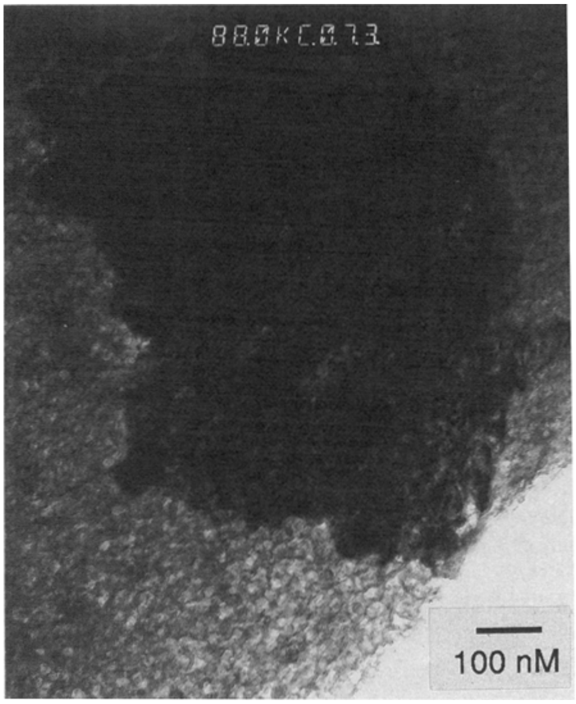

Fig. 3 As-deposited monolithic Al-8Fe-2Mo-1V monotape

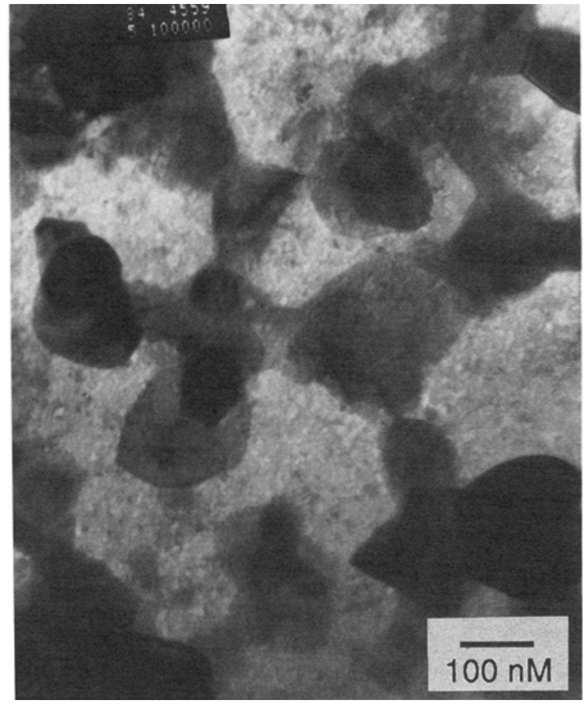

Fig. 4 Monolithic plasma-sprayed Al-8Fe-2Mo-1V after heat treatment at 400 °C (750 °F) for 2 h

mately 250 to 300 V dc) to perforation using a 5 vol% solution of perchloric acid in reagent alcohol chilled to about −30 °C (−22 °F). The majority of the work, including all hot-stage exposure, was performed on a Philips (Philips Lighting Co., Somerset, NJ) EM400T TEM operated at 100 kV. A Philips (Philips Lighting Co., Somerset, NJ) CM20 TEM/STEM, capable of 200 kV, was also used for some observations.

3. Results

The as-deposited alloy microstructures were found to be highly solutioned and nonequilibrium, essentially free of the second-phase particles normally present in the microstructures (Fig. 2 and 3). At higher magnifications (~100,000×), however, a dense distribution of 50 to 100 Å precipitates could be observed. These nuclei were more densely populated in localized areas around the larger phases in the structure. These occasional larger particle phases do not appear to be completely solutioned by the plasma spray process and were frequently located near the rapid solidification processing (RSP) powder particle boundaries (Fig. 2) (Ref 3). As-deposited structures in Al-8Fe-2Mo-1V were found to be brittle, exhibiting a microhardness of about 260 HV. The solutioned micrograin size varied from approximately 1 μm to as large as 10 μm. The dark micrograin in Fig. 3 is oriented to conditions of high diffraction contrast.

Samples heat treated at 400 °C (750 °F) for 2 h were less brittle and of about 129 HV. A sample heat treated for 30 min at 400 °C (750 °F) exhibited moderately well-developed precipitates with less particle growth and a hardness of 167 HV.

Several TEM samples of Al-8Fe-2Mo-1V (both monolithic and with fibers) were observed during various thermal exposures on the hot stage of the TEM. Soon after reaching approximately 370 °C (700 °F), the 50 to 100 Å particles in the as-deposited structure became more distinct and slightly coarser. Shortly afterward, iron-rich particles evolved (Fig. 4) that did not exhibit the large thermally unstable iron-rich nodules (compare Fig. 1 and 4). Almost all of the 50 to 100 Å particles disappeared within 2 h at 400 °C (750 °F).

The localized variations in coarse and fine structure resembled the Zone A and Zone B-type areas usually observed in RSP extruded-plus-forged material (Ref 4). Zone A areas often consist of entire powder particles and aluminum grains that are smaller than a Zone B structure. Also, when etched and observed at optical magnifications, the structure appears less distinct than Zone B materials. Zone B areas characteristically exhibit fully precipitated and well-defined larger particles and larger aluminum grains than Zone A areas. Some localized areas would not precipitate until exposed to approximately 480 °C (900 °F), after which they usually exhibited structures with a fine needle phase similar to a slightly decomposed Zone A structure observed for RSP material. Dislocations were noticed in some samples. Material previously heated at 400 °C (750 °F) for 2 h, when subsequently exposed to 480 °C (900 °F) exhibited approximately 10 to 20% coarsening (particle linear dimensions) in 2 h.

4. Conclusions

The metallurgical characteristics of as-deposited RF plasma-sprayed aluminum material may vary, depending on plasma spray parameters. However, the characteristically rapid cooling rates of the process will cause the material to display a brittle tendency, exhibiting a microstructurally solutioned condition. It has been shown that it is possible using subsequent heat treatment to modify the mechanical properties and microstructure of the as-deposited aluminum alloy.

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