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Single-Crystal Alumina/Aluminum Alloy Composite Structure Fabrication by RF-Coupled Plasma Spray Processing*

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1. Introduction

VARIOUS plasma spray systems are currently being investigated to determine their viability for fabricating metal-matrix composite (MMC) monotapes. The primary objective of the present work was to demonstrate the feasibility of producing aluminum-matrix monotape, in batch mode, using the radiofrequency (RF) coupled plasma spray process for deposition. Various high-temperature aluminum alloys were deposited on arrays of 0.13 mm (0.005 in.) diam single-crystal alumina (sapphire) fiber. A consolidation study was subsequently undertaken.

Much of the material in a modern gas turbine engine never experiences temperatures above approximately 370 °C (700 °F). Consequently, if the technical barriers relating to strength and fatigue resistance could be overcome, these lower-temperature parts could be fabricated from high-temperature aluminum alloys rather than from more expensive materials such as titanium. One method of enhancing requisite properties is through the long-fiber reinforcement of high-temperature aluminum alloys (such alloys being formulated based on large additions of iron and other elements to aluminum) (Ref 1) by rapid solidification processing (RSP) (Ref 2). This paper discusses work conducted to demonstrate the potential for combining RSP aluminum alloys with alumina fibers through the use of plasma spray processing methods (Ref 3).

2. Experimental Procedure

The RF plasma spray process was chosen because of its soft spray attributes relative to the harsher, higher-velocity dc-type plasma guns. The system used for this work incorporated a 125 kW RF plasma torch assembly manufactured by Tafa, Inc. The equipment utilized a robotic part manipulator with four degrees of freedom for manipulating the substrates under the plasma plume. The single-crystal alumina fiber was manufactured by Saphikon, Inc. The high-temperature aluminum alloy matrices used were Al-8Fe-2Mo-1V, a composition based on alloy 2009 (Al-3.8-Cu-1.3Mg-0.3Ag), and alloy 8009 (Al-8.5Fe-1.3V-1.75Si) (Ref 4). These alloys were in the form of prealloyed metal powder produced by a variety of methods.

Key Words: alumina/aluminum alloy, metal-matrix composite, RF plasma process

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The plasma spray processing parameters were optimized through the use of a design of experiment (DOE) matrix. A process was developed for the successful deposition of high-temperature aluminum alloy powder on arrays of single-crystal alumina fibers wrapped on the surface of stainless steel mandrels. A system was also developed for producing fiberless foil for use in the consolidation processing of the MMC monotape. Attempts were also made to (1) assess the processed alloy composition deviation, (2) assess fiber damage, (3) develop processing parameters and hardware to produce moderately long pieces of monotape, (4) develop/determine multilayer monotape consolidation parameters, and (5) produce and deliver adequate quantities of fabricated monotape and neat foil (i.e., the matrix phase without fibers) for evaluation and consolidation.

The as-sprayed MMC monotapes (Fig. 1) were analyzed for elemental chemistry and fiber damage. Scanning electron microscopy (SEM) analysis of the as-deposited matrix alloy indicated very little, if any, deviation from the starting alloy composition. A fiber damage assessment, using hydrochloric acid dissolution of the matrix alloy, did not reveal any apparent fiber damage (Fig. 2). Several pounds of Al-8Fe-2Mo-1V/single-crystal alumina monotape and fiberless foil were produced for in-house testing and consolidation. Monotapes and fiberless foil of two other high-temperature aluminum alloy compositions (2009 with silver and alloy 8009) were also produced in limited quantities.

A DOE consolidation study was undertaken to determine the consolidation parameters for the alumina fiber/Al-8Fe-2Mo-1V MMC monotape system and to identify the effect of the fiber on

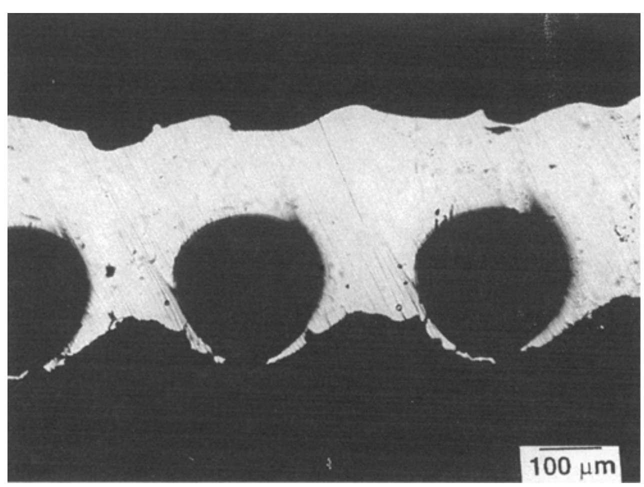

Fig. 1 As-sprayed high-density matrix monotape. The sinusoidal shape replicates that of the mandrel surface.

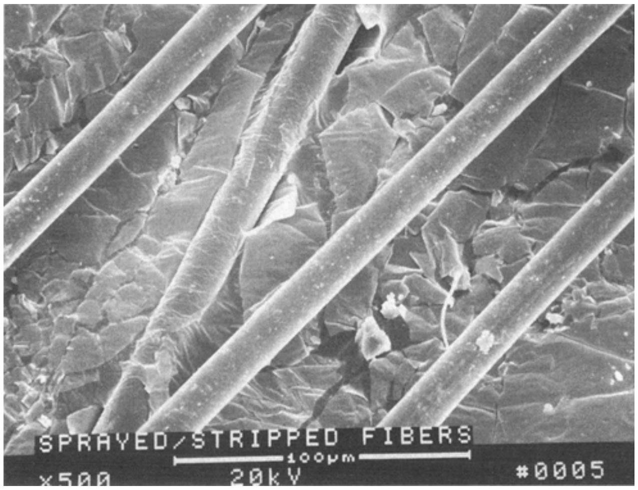

Fig. 2 Acid (HCl) dissolved matrix stripped from the Sapikon fiber. The fiber has been undamaged by plasma spray processing.

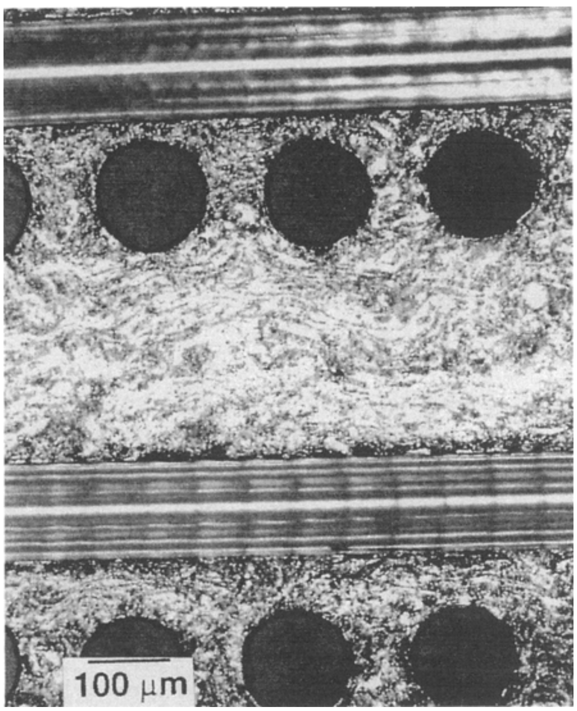

Fig. 3 Consolidated monotape and fiberless foil at 510 °C/103 MPa/60 min (950 °F/15 ksi/60 min). The fiber orientation is 0°/90° biaxial. Unetched

consolidation. Each panel consisted of six monotapes (each 0.20 mm, or 0.008 in., thick) and one fiberless foil (0.10 mm, or 0.004 in., thick). The monotapes had a uniaxial fiber orientation. Three monotapes were placed on either side of fiberless foil, with the fiber side toward the monolithic tape.

Each panel was inspected by x-ray and ultrasonic techniques. A sample was also cut from the end of each panel and inspected metallographically. These evaluations determined that temperature had the greatest effect on consolidation quality. High pressure and long consolidation times also proved to be beneficial;

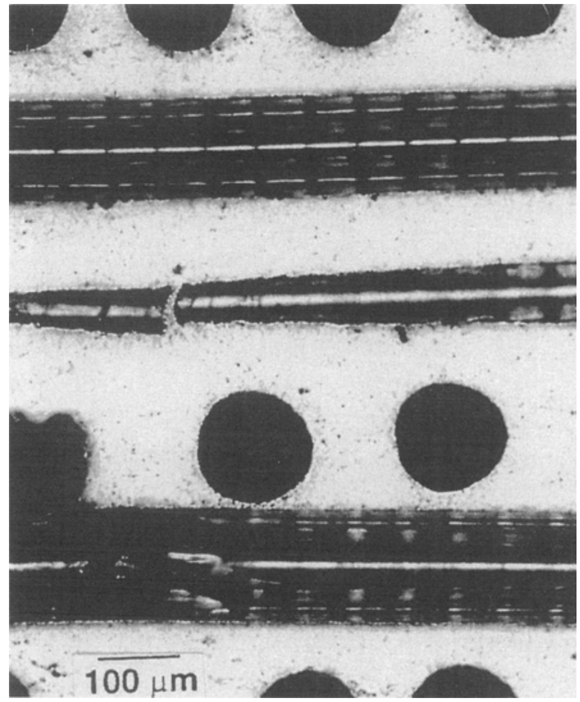

Fig. 4 Consolidated monotape and fiberless foil at 510 °C/103 MPa/60 min (950 °F/15 ksi/60 min). The fiber orientation is 0°/90° biaxial. Etched

510 °C (950 °F) and 124 MPa (18 ksi) for 120 min were the best consolidation parameters. However, for metallurgical considerations, 510 °C (950 °F) and 103 MPa (15 ksi) for 60 min resulted in the best overall parameters (Fig. 3 and 4).

3. Conclusion

Aluminum/single-crystal alumina monotape and neat foil have been produced in quantity by the RF-coupled plasma spray process. Subsequent consolidation has also been successfully achieved. The batch-mode parameters and processing scheme lend themselves to process automation. Continuous-mode monotape fabrication is also deemed feasible.

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