JTTEE 3:204-207

Fabrication of Advanced Metal and Intermetallic Composite Materials by the Wire Arc Spray Process — An Extended Abstract*

J.W. Pickens

1. Introduction

The use of metal matrix composties and intermetallic matrix composites (MMCs and IMCs) depends on developing fabrication processes and understanding the relationships of process variables to material structure and properties. Composite fabrication processes can be organized into general categories: foil processes, powder metallurgy processes, casting processes, chemical or physical vapor processes, and thermal spray, among others. The relative benefit of any given approach depends in part on the composite material system (matrix and reinforcement type) to be fabricated and the application. This article discusses a thermal spray technique known as the arc spray proc-

Key Words: arc spray, fabrication, fiber, intermetallic matrix composite, metal matrix composite

J.W. Pickens, Sverdrup Technology, Inc., NASA Lewis Research Center Group, Cleveland, OH.
*Extracted from *Symposium on Spray Forming*, National Thermal Spray Conference, Anaheim, June 1993. This abstract has been edited by C.C. Berndt, SUNY at Stony Brook.

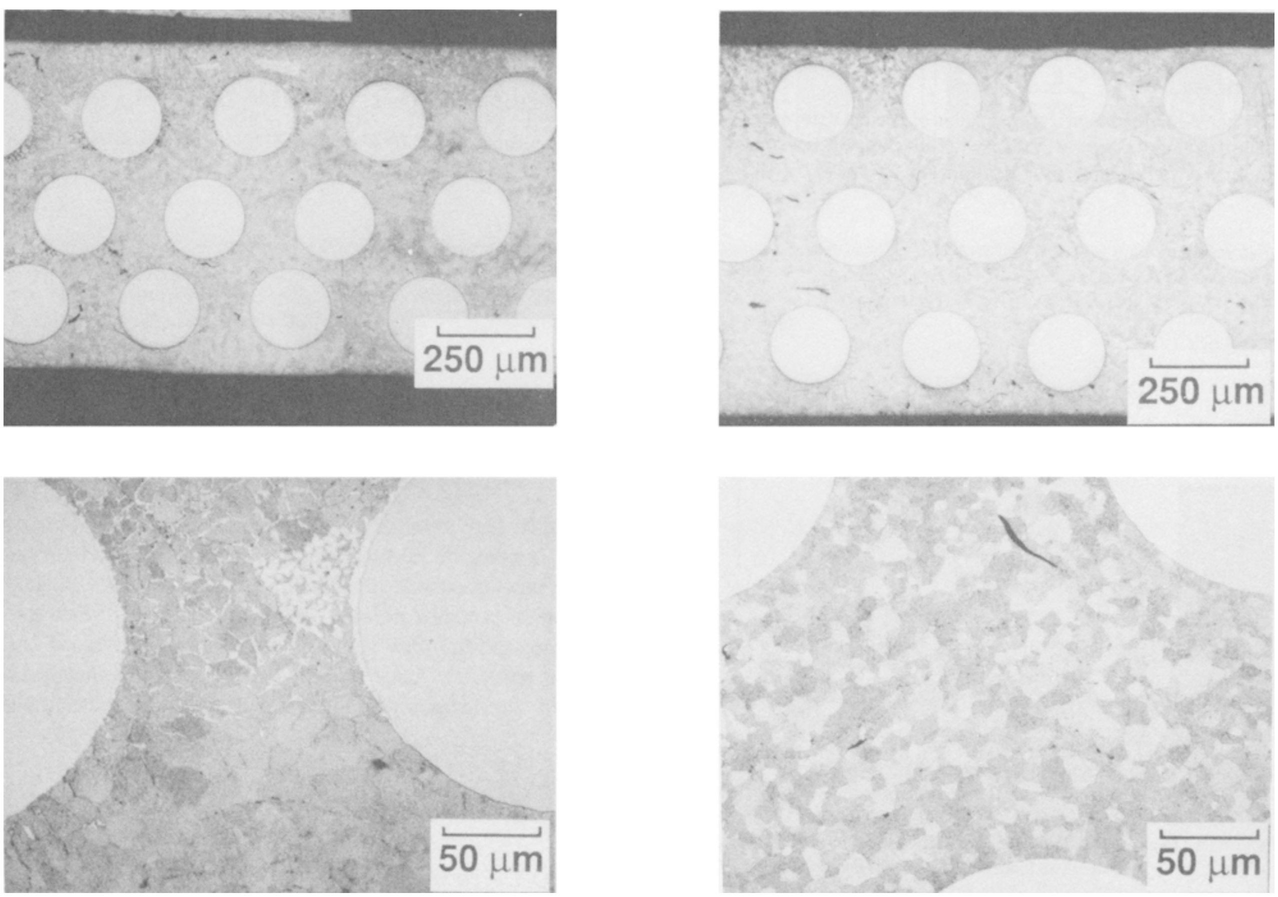

Fig. 1 Effect of powder-core wire diameter on compositional uniformity of arc-sprayed W/NiAl composites. The microstructures, at two magnifications, of coatings produced with two wire diameters are shown. (a)Microstructure of coatings produced with 3.2 mm diam wire. (b) Microstructure of coatings produced with 1.6 mm diam wire.

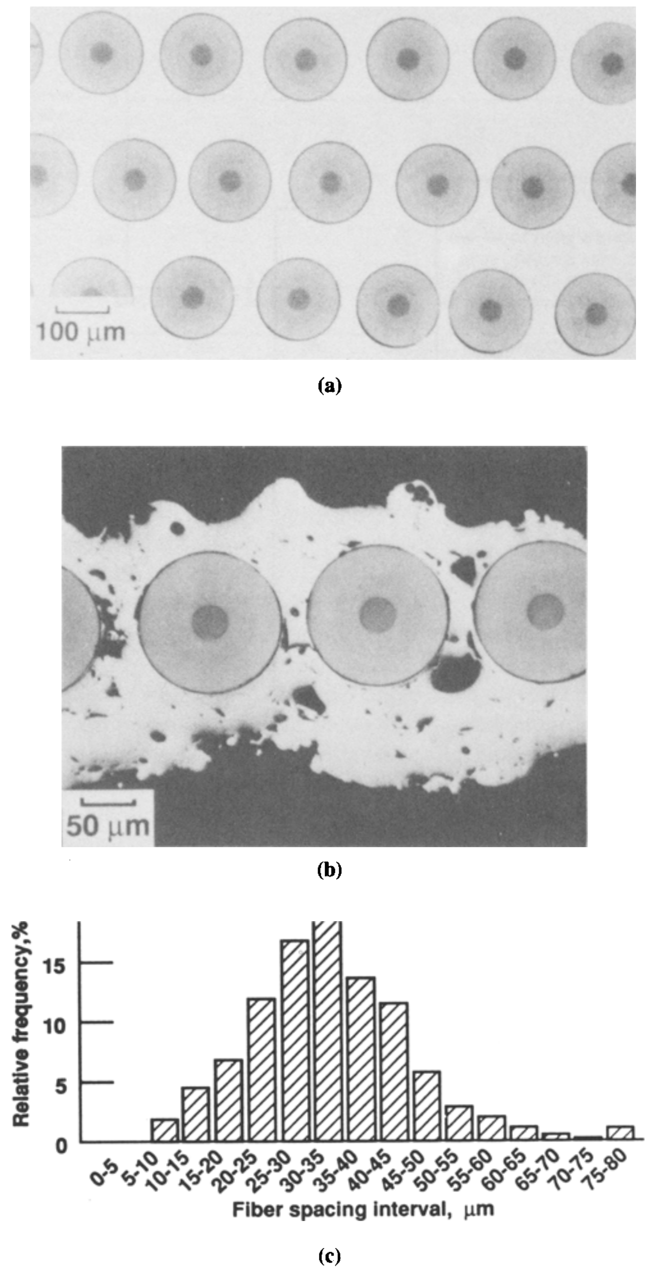

Fig. 2 Fabrication of SiC/Ti_3Al + Nb composites by wire arc spray process. (a) Three-ply consolidated composite arising from the monotape (b). (c) Fiber spacing distribution in the arc-sprayed composite

ess, which is being developed for use with MMC and IMC systems.

2. Overview

The arc spray process is a thermal spray technique. The matrix material, in the form of wire feedstock, is melted within an inert atmosphere in a direct current electric arc between two feed wires, then atomized by an inert gas, and propelled toward a target as a stream of molten droplets. The target is a drum on which the reinforcing fibers for the composite have been wound with the desired number of fibers per unit of width. The drum revolves and is translated during spraying to assure uniform deposition of the matrix onto the fibers. After the front side of the fibers has been coated, the monotape is removed from the drum, turned over, and then sprayed on the back side as well. The completed monotape is then cut into panels and stacked as an assembly for consolidation into a fully dense, multi-ply composite by hot pressing.

3. Discussion

3.1 *Feedstock and Binder Considerations*

One of the relevant characteristics of the arc spray process is the use of wire as matrix feedstock, which provides potential to reduce contaminants relative to powder-based fabrication processes. Wire is readily available for metal matrices, but for intermetallics, development of wire feedstock is one of the key elements in developing the arc spray process. Directly binding fiber into position with the matrix material rather than with a fugitive binder eliminates the possibility of contamination from binder decomposition products. Because there is no need to accommodate removal of a binder, there is enhanced flexibility in processing options for consolidation, such as direct hot isostatic pressing consolidation of monotapes. Finally, holding the fibers in position with the matrix material rather than with a fugitive binder produces a more uniform distribution of fibers in the final composite. The greater green density of arc-sprayed monotapes relative to that of foil and powder lay ups permits the use of lower consolidation temperatures and helps maintain the improved fiber spacing due to reduced plastic flow of the matrix during consolidation.

Some arc spray process development issues are specific to the composite material system (matrix and fiber combination) of interest. Fabrication of wire feedstock and definition of the process window of operating parameters for maintaining a stable arc are specific to the matrix. Issues that are fiber related include the susceptibility of a given fiber to damage by the molten, atomized spray, and the definition of operating conditions within the process window of the matrix that eliminate or minimize damage to susceptible fibers. Prior work with the SiC/Ti_3Al + Nb system has established key process variables and their effects on arc stability and it has also determined a wide process window of stable operating conditions for evaluating the effects of process variables, such as the flow rates of the atomizing gas and matrix feed wire, arc voltage, and nozzle diameter[Ref 1, 2]. Metal matrix composites reinforced with refractory metal wire have been successfully developed and are fairly mature relative to the current emphasis in IMCs and MMCs containing monofilament, ceramic fiber. The bulk of this emphasis has been in SiC/titanium aluminide composites.[Ref 1-4]. Excellent progress has been made in producing high-strength materials with uniform fiber distributions and in defining the relationships of processing variables to structure and properties. The least mature area being studied is fabrication of nickel aluminide IMCs and superalloy MMCs reinforced with single crystal, monofilament Al_2O_3 fiber.

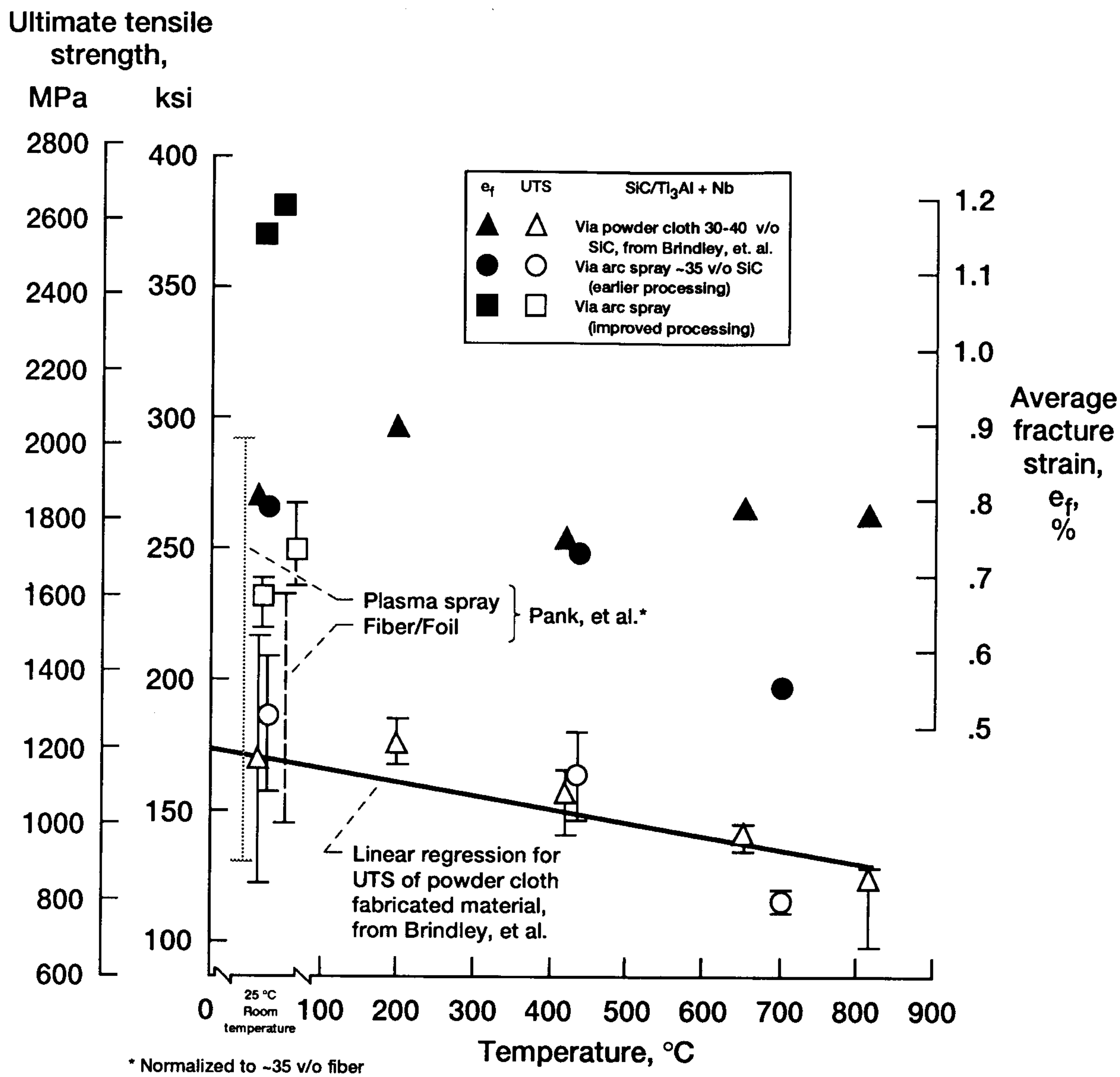

Fig. 3 Comparison of arc-sprayed SiC/Ti$_3$Al + Nb properties with properties of materials produced by other processes [Ref. 10]

Two approaches have been used to produce wire for IMCs: prealloyed intermetallic wire and reactive elemental wire. Intermetallic matrix composites have been fabricated using prealloyed intermetallic wire produced from Ti$_3$Al + Nb, FeAl, and NiAl by a gang extrusion technique. A reactive elemental approach was used to fabricate nickel aluminide composites from powder cored wire produced over a range of diameters by swaging. Figure 1 shows the beneficial effect of increased degree of mixing in homogenizing the microstructure when the wire diameter is decreased[Ref 5].

3.2 *Microstructural Considerations*

The microstructure of a SiC/Ti$_3$Al + Nb arc-sprayed monotape is shown in Fig. 2, with evidence of the excellent uniformity obtained in fiber spacing after consolidation. The tensile properties of this arc-sprayed material are among the best reported for this material system when fabricated by a variety of methods. Figure 3 compares the mechanical properties of SiC/Ti$_3$Al + Nb composites fabricated by arc spray, plasma spray, powder cloth, and fiber/foil processes [Ref 10].

3.3 *Fiber/Mechanical Property Relationships*

Fiber can experience damage during composite fabrication that depends not only on the process being used, but also on the fiber. The type of fiber used may have a greater or lesser susceptibility to damage than another. Thermal spray processes that coat fibers with a spray of molten droplets have been shown to cause some surface damage to the SCS-6 SiC fiber [Ref 1-9], but composites with good mechanical properties can still be fabricated. There can be damage to the SiC fiber during arc spraying,

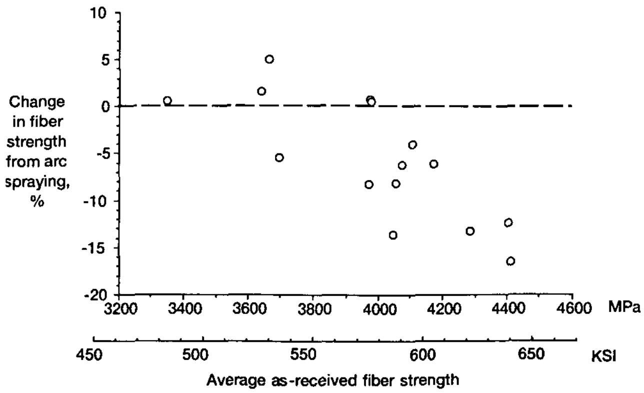

Fig. 4 Effects of arc spray processing on fiber strength

but the degree of damage can be controlled by adjusting process variables, and the damage has only a small effect on the strength of the fiber and the resulting composite. Although the fiber strength can be reduced by arc spraying, the reduction depends on the starting fiber strength and not on the amount of surface damage (Fig. 4). There appears to be a threshold around 3800 MPa, above which the fiber experiences strength reduction. Fibers with a starting strength above this threshold typically fall back to near the 3800 to 4000 MPa range after being sprayed. Fibers with strength around 3800 MPa and lower experience little to no reduction. Variations in process conditions, therefore, do not control fiber strength.

Single-crystal, monofilament Al_2O_3 fiber is much more sensitive to processing damage than the polycrystalline SiC fiber. The Al_2O_3 fiber is highly susceptible to immediate fracture upon impingement of the molten, atomized matrix spray. Recent process development efforts have identified conditions that now allow successful spraying without fracturing the fibers. Figure 5 is the microstructure of a four-ply, Al_2O_3/IN718 superalloy MMC panel consolidated from arc-sprayed monotape fabricated under these conditions. There is, however, a significant reduction in fiber strength still evident for fibers etched from the monotape. If this cannot be solved by further control of process conditions, the presence of a functional coating on the fiber, which may be required for other purposes as well, may be needed.

4. Conclusion

The wire arc spray process is a viable method for fabricating advanced MMCs and IMCs. A significant degree of maturity has been developed in fabricating refractory wire-reinforced MMCs and SiC-reinforced titanium-base composites, the properties of the latter being among the best reported for that material system. Approaches for using the process in fabricating Al_2O_3-reinforced composites have been demonstrated and warrant further development.

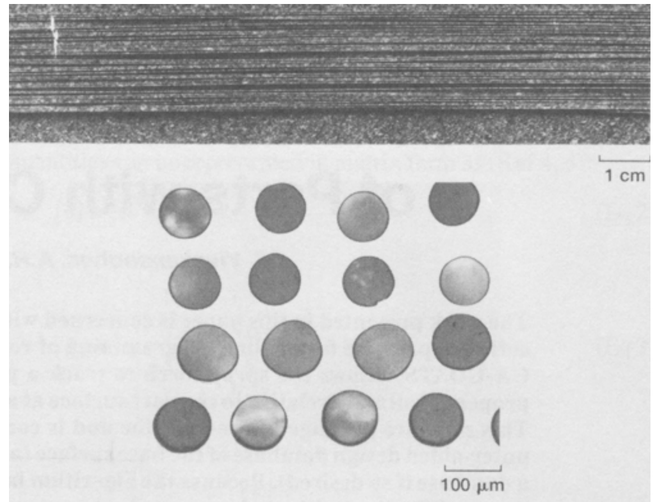

Fig. 5 Microstructure of Saphikon/IN718 superalloy MMC panel consolidated from wire arc-spray monotape

References

1. J.W. Pickens, A Study of the Arc Spray Process for Fabricating Titanium Aluminide Composites, *4th Annual HITEMP Review*, NASA CP-10082, 1991, p 40-1 to 40-18
2. J.W. Pickens, J.W. Smith, and B.A. Lerch, Relationships among Processing, Surface Structure, and Properties of Arc Sprayed Fibers and Composites, *5th Annual HITEMP Review*, NASA CP-10104, 1992, p 31-1 to 31-17
3. J.W. Pickens and G.K. Watson, SiC/Ti_3Al + Nb Composite Fabrication by the Arc Spray Process, *14th Conf. Metal Matrix, Carbon, and Ceramic Composites*, J.D. Buckley, Ed., NASA CP-3097-PT-2, 1990, p 711-732
4. J.W. Pickens and G.K. Watson, Fabrication of Titanium Aluminide Composites, *Proc. Titanium Aluminide Composite Workshop*, P.R. Smith, S.J. Balsone, and T. Nickolas, Ed., Wright Laboratory TR-91-4020
5. G.K. Watson and J.W. Pickens, Fabrication of Intermetallic Matrix Composites, *Second Annual HITEMP Review, NASA CP-10039, 1989, p 50-1 to 50-11*
6. "Titanium Aluminide Composites," Interim Report No. 3, Contract F33657-86-C-2136, 12 Mar 1988 through 9 Sept 1988, G.E. Aircraft Engines for Materials Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson AFB
7. "Titanium Aluminide Composites," Interim Report No. 4. Contract F33657-86-C-2136, 10 Sept 1988 through 15 June 1989, G.E. Aircraft Engines for Materials Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson AFB
8. D.G. Backman et al., Intelligent Processing for Metal Matrix Composites, *Intelligent Processing of Materials*, H.N.G. Wadley and W.E. Eckhart, Ed., Minerals Metals and Materials Society, 1990, p 17-39
9. D.G. Backman, Metal Matrix Composites and IPM: A Modeling Perspective, *J. Met.*, Vol 42 (No. 7), July 1990, p 17-20
10. D.R. Pank, A.M. Ritter, R.A. Amato, and J.J. Jackson, Structure-Property Relationships in Ti_3Al/SCS-6 Composites, *Titanium Aluminide Composites*, P.R. Smith, S.J. Balsone, and T. Nicholas, Ed.,Wright Laboratory TR-91-4020