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Plasma Spray Forming of Intermetallics and Their Composites*

H. Herman, S. Sampath, R. Tiwari, and R. Neiser

1. Introduction

PLASMA spray processing, a well-established technique for producing protective coatings, is well suited for spray forming applications. It combines the processes of melting, rapid solidification, and consolidation in a single step. Low-pressure or vacuum plasma spraying (VPS) has been widely used for spray forming because it yields dense and relatively oxide-free deposits. During VPS, the deposits undergo continuous annealing due to exposure to high temperatures (>800 °C). This self-annealing is beneficial as it provides stress relief, recrystallization, and enhanced interparticle bonding (Ref 1). The reduction in residual stresses permits the buildup of thick, oxide-free deposits of reactive metals. Thus, VPS can be viewed as a viable technique for consolidation of powders and composites for the production of freestanding deposits of high-performance materials.

A key advantage of VPS is the ability to produce rapidly solidified freestanding near-net shapes, thus obviating the need for postspray thermomechanical processing. Chang et al. (Ref 2) have observed that plasma-sprayed nickel-base alloys and intermetallics yield better mechanical properties than melt-spun and hot isostatically pressed materials. In an extensive study undertaken at Stony Brook, Ni_3Al, NiAl-Ni_3Al, and $MoSi_2$ intermetallics and their composites have been spray formed using VPS processing (Ref 3, 4). The microstructure and room-temperature mechanical properties of the monolithic and composite deposits in the as-sprayed and heat-treated conditions have been examined.

2. Results and Discussion

Dense deposits of unreinforced and composite matrices of Ni_3Al alloy and $MoSi_2$ were obtained by the VPS process. The unreinforced Ni_3Al matrix was chemically homogeneous, as evidenced by the uniform distribution of boron in the matrix. However, post-VPS annealing led to the segregation of boron to the grain boundaries. The unreinforced deposits were fine grained and had high yield strength values. As shown in Fig. 1, post-deposition annealing led to an increase in fracture strains and a reduction in yield strength. The yield strength/grain size dependence obeyed the Hall-Petch relationship. In the case of Ni_3Al-base composites, a uniform distribution of TiB_2 reinforcements was also obtained (Fig. 2). Room-temperature mechanical properties indicated significant strengthening due to the inclusion of the diboride particulates (see Table 1). Failure in the VPS-processed composites occurred by matrix/particle decohesion.

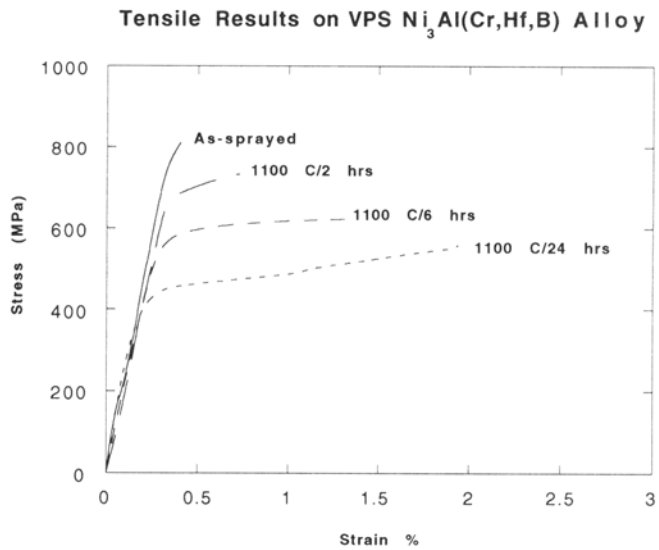

Fig. 1 Tensile stress-strain behavior of vacuum-plasma-sprayed and annealed Ni_3Al(Cr, Hf, B) alloy

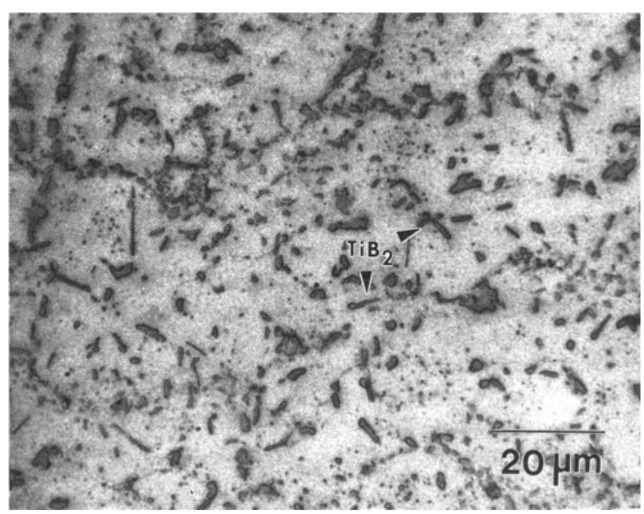

Fig. 2 Vacuum-plasma-sprayed Ni_3Al deposit showing a uniform distribution of TiB_2 reinforcement particles

Key Words: spray forming, intermetallics, composites

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Table 1 **Room-temperature mechanical properties of annealed (1100 °C for 2 h in argon) VPS-processed unreinforced alloy and TiB_2-particle-reinforced Ni_3Al-base composites**

Specimen	Bend strength, MPa	Tensile strength, MPa
Unreinforced matrix	...	700
Composite 1	1200	900
Composite 2	1820	1200

Table 2 **Room-temperature mechanical properties of VPS $MoSi_2$ and its composites in the as-sprayed and annealed conditions (1100 °C for 24 h in argon)**

Material (condition)	Vickers hardness, HV	Fracture toughness, $MPa\sqrt{m}$	Flexural strength, MPa
$MoSi_2$ (as sprayed)	1201 ± 45	4.7	280
$MoSi_2$ (heat treated)	1093 ± 25	5.9	364
$MoSi_2$-TiB_2 (as sprayed)	1057 ± 27	6.1	380
$MoSi_2$-SiC (as sprayed)	1228 ± 61	5.4	300
$MoSi_2$-SiC (heat treated)	1160 ± 38	7.5	410

Deposits of the two-phase nickel aluminide alloy Ni-16Al (29 at.% Al) were produced by vacuum plasma spray forming of the material on graphite substrates. Postdeposition annealing at 1100 °C was used to reduce porosity, transform martensitic phases into more stable ordered phases, and homogenize the microstructure. Tensile test specimens were electrodischarge machined from the spray-formed and annealed plates and tested at room temperature and at 600, 700, and 800 °C. Specimens tested at the two lower temperatures exhibited no ductility. At 700 °C, a 1.5% elongation to failure was observed. At 800 °C and a strain rate of 0.4 mm/min, the Ni-16Al became superplastic. A specimen elongated 75% at 800 °C is compared with the smaller as-received specimen in Fig. 3.

The $MoSi_2$-base composites with TiB_2 reinforcements had splatlike reinforcements due to the melting of the diboride particulates during VPS processing (Fig. 4). Also, very high densities (>98%) and high hardness (1203 HV) of the as-sprayed, unreinforced $MoSi_2$ deposits were obtained via this processing technique. The incorporation of diboride and silicon carbide reinforcements led to the strengthening and toughening of the plasma-spray-formed $MoSi_2$ deposits (Table 2). The degree of strengthening in the VPS-processed composites was greater than that obtained using other techniques, implying improved matrix-reinforcement bonding. Thus, VPS processing of composites represents a synthesis of rapid solidification and composite materials technologies.

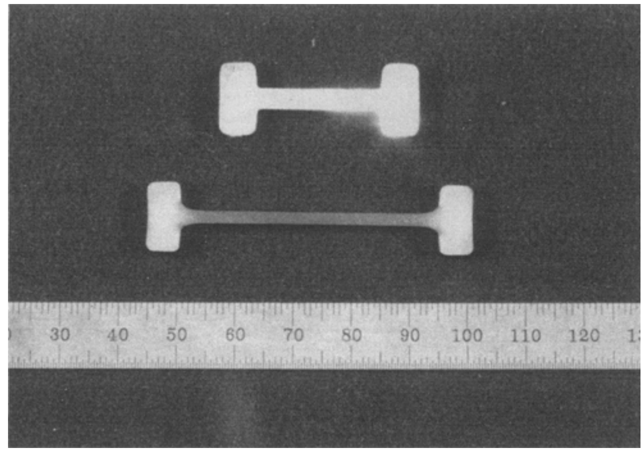

Fig. 3 Vacuum-plasma-sprayed Ni-16Al deposits. The tensile test specimen shown at top has been electrodischarge machined and polished. The lower specimen has been elongated 75% at 800 °C.

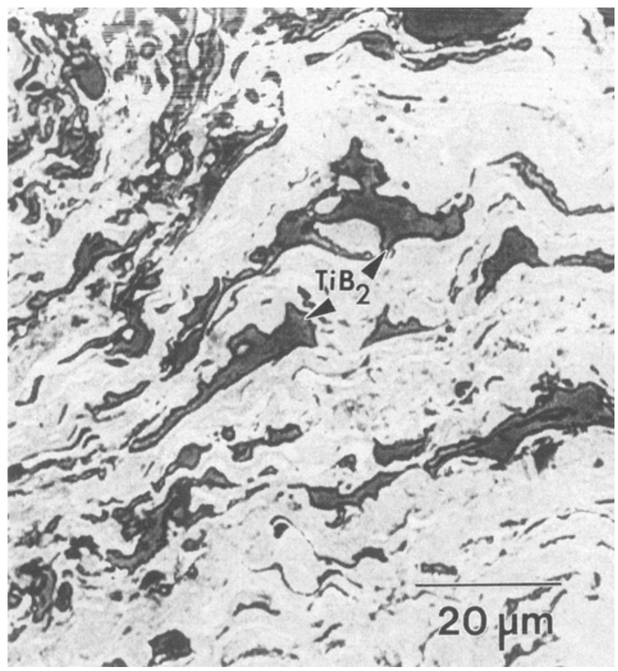

Fig. 4 Backscattered electron image of VPS-processed TiB_2reinforced $MoSi_2$ composite. The TiB_2 has a splatlike morphology, indicating melting during the VPS processing of the composite.

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