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Spray-Cast Monolithic and Composite Materials: Distinguishing Features in Their Microstructure and Metallurgy—An Extended Abstract*

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1. Background

SPRAY casting via the Osprey process has emerged as a viable near-net shape technique for the processing of monolithic alloys and composites with attendant integrity of microstructure and properties. The process involves sequential gas atomization and consolidation of droplets on a substrate to produce a near-net shape preform in a single processing step, as shown schematically in Fig. 1. Composites are generated by injecting second-phase particulates into the spray of droplets or by reacting the droplet with a suitable gas during flight. This droplet consolidation technology is considered a viable alternative to current processing routes because of cost savings from a reduction in the number of processing steps, an improvement in the cleanliness and microstructure relative to powder metallurgy and casting, respectively, and higher pouring rates than with conventional thermal spray processes. The as-sprayed microstructure is composed of fine equiaxed grains (<50 μm) with residual porosity of <3% and is devoid of macrosegregation or prior particle boundaries. Composites manifest the same structure, with the reinforcing phase either dispersed uniformly or located at grain boundaries.

2. Microstructural Features

This contribution discusses the metallurgical and microstructural features that distinguish spray casting of monolithic alloys and composites from other manufacturing processes. The metallurgy of spray casting incorporates in its different stages aspects of casting, powder metallurgy, and plasma spraying. As shown in Fig. 1, the alloy charge is initially molten, thus involving the issues of melt cleanliness and composition control inherent to casting.

Typically, compositions are limited to meltable alloys for spray casting in the standard form, but higher levels of alloying elements can be incorporated. Currently, nonstandard forms utilizing more than a single melt nozzle are being developed that can further extend this capability. The spray resulting from atomization comprises a very large surface area that can pick up from 200 to 1000 ppm of nitrogen and oxygen. Therefore, as in plasma and powder processing, special care has to be taken to minimize contamination by using an inert atomizing gas such as argon (Ref 1). Alternately, such contamination can be gettered by a reactive element such as titanium to yield composites reinforced by fine (0.2 to 0.5 μm) nitrides or carbides of titanium (Ref 2). During consolidation, the droplets impinge and adhere to a mushy preform surface in a process analogous to thermal spraying, except at a much higher deposition rate.

Particulate injection is affected by physical properties such as shape, density, diameter, surface tension, and wettability, which influence the flow dynamics of the particulates. For example, fine particles <5 μm tend to be swept away by the gas flow, or nonwetting particles are not captured by molten droplets, resulting in lower yields. Solutions under study include injection of agglomerated fines and alloying or gas additions to change particle wettability. Unless the particles are concentrated at the grain boundaries with the liquid, interfacial reaction is not a limiting problem as in casting.

Heat extraction is via the gas for both droplets and the preform, resulting in rapid cooling of droplets and not-so-rapid solidification of the preform. As a consequence, the typical recrystallized splat structure seen in plasma-sprayed deposits/coatings is replaced by an equiaxed one. Nearly 80% of the material is solidified in flight, and during preform solidification of a few seconds to a few minutes, most of the liquid is swept out to the grain boundaries. Unless sprayed under very hot conditions, the preforms never exhibit dendritic structures (Ref 1). Spraying at cold conditions yields a slight refinement in grain size and slight increase in porosity. Addition of particulates to form composites has a similar effect, which must be compensated for appropriately by adjusting the gas-to-metal flow ratio (Ref 3).

The volume fraction and the uniformity of the distribution of reinforcements is thus limited by the process and particulate properties, which is not the case in powder metallurgy. During preform cooling, nonwetting particles can get swept along with liquid to grain boundaries, resulting in undesirable structures. In situ reinforcements, such as those formed by a reaction between reactive species in the alloy and gas or an injected particle, are typically less than 2 vol% because of the time scales involved (Ref 2). An alternative dispersion strengthening technique is to precipitate fine second-phase particles by rapid in-flight solidification of a hypereutectic alloy (Ref 1). This approach has the twin benefits of uniform distribution and fine size (<0.1 μm).

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