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Meet Our New Colleagues

This column presents selected currently graduating Ph.D. students in the thermal spray field from around the world. Students planning to graduate in the area of thermal spray within the next 3 to 6 months are encouraged to submit a short description (1 to 2 pages, preferably as Word document) of the projects they performed during their studies to Jan Ilavsky, JTST Associate Editor, address: Argonne National Laboratory, Advanced Photon Source, 9700 S. Cass Ave., Argonne, IL, 60439; e-mail: JTST.Ilavsky@aps.anl.gov. After limited review and corrections and with agreement of the student's thesis advisor, selected submissions will be published in the upcoming issues of JTST.

Visualization and Analysis of the Impact of Plasma-Sprayed Particles

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Background and Motivation

Extensive studies of plasma-spray coating processes have shown that the temperature of the substrate on which molten particles impact influences their size, morphology, and degree of fragmentation/splashing during spreading (Ref 1, 2). Photographs of plasma sprayed particles on nonheated substrates, taken after impact, spreading, and solidification, showed significant splat fragmentation and splashing (Ref 1, 2). It has been shown that on nonheated surfaces, the overall coating quality deteriorates due to decreased coating adhesion strength and increased coating porosity (Ref 3). Heating the substrates reduced splat fragmentation and splashing, producing disklike splats. Photographs that show the splat morphologies long after the spreading and solidification events offer limited information to understand fully the mechanisms of splat spreading and fragmentation. Photographing the droplets in a plasma spray at different stages during impact will provide insight into the dynamics of splat formation on nonheated and heated surfaces.

It has been found the microstructure of plasma sprayed nickel on heated stainless steel was fine, columnar, flat, and nonporous, while on nonheated stainless steel, it was composed of isotropic coarse grains, indicating that the cooling rate of the splats on the heated substrate was larger than that on the nonheated substrate (Ref 2). Moreau et al. (Ref 4) measured the temperature evolution of molybdenum droplets that impacted and spread on nonheated and heated glass. It was found that the cooling rate of the splats on heated glass was on the order of 10^8 K/s, an order of magnitude larger than splats on nonheated glass (10^7 K/s). The order of magnitude smaller cooling rate and significant splat fragmentation on nonheated substrates have led to speculations that the splat-substrate contact is poor and the thermal contact resistance is high (Ref 1, 2). However, no direct experimental evidence is available to justify these speculations. Mathematical models, coupled with images and temperature evolutions of the splat during spreading, may support these speculations.

The primary objectives of this program were to: (a) develop a novel method of photographing plasma sprayed particles during impact and spreading, (b) measure the splat temperature evolutions and cooling rates, and (c) develop mathematical models to explain the observed splat morphologies and occurrence of splashing/fragmentation on substrates held at various temperatures.

Methodology

A schematic of the experimental assembly used to photograph particles that impacted glass is shown in Fig. 1. Three barriers were used to protect the substrate from excess particles and heat, allowing only particles with a horizontal trajectory to impact the substrate. The in-flight particle triggered a 5 ns Nd-YAG laser, which illuminated the substrate. After a known time-delay, a 12-bit charge-coupled device (CCD) camera was triggered to capture images of the spreading splats at different times during spreading (Fig. 1). A rapid two-color pyrometer was used to collect thermal radiation from the splat at two different wavelengths. The thermal radiation collected during splat spreading was converted to thermal emission voltage signals and recorded on an oscilloscope. The thermal emission signals provided information on the splat temperature and size evolutions during spreading.

Main Results

Figure 2 shows different images of molybdenum splats at different times during spreading on nonheated and heated glass. The thermal emission signals are also shown. On nonheated glass, the images

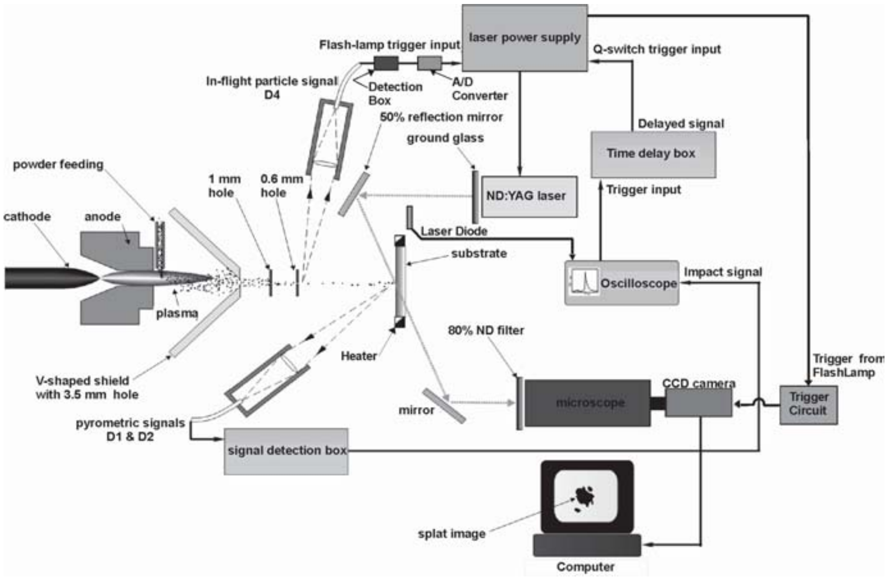

Fig. 1 Schematic of the experimental assembly

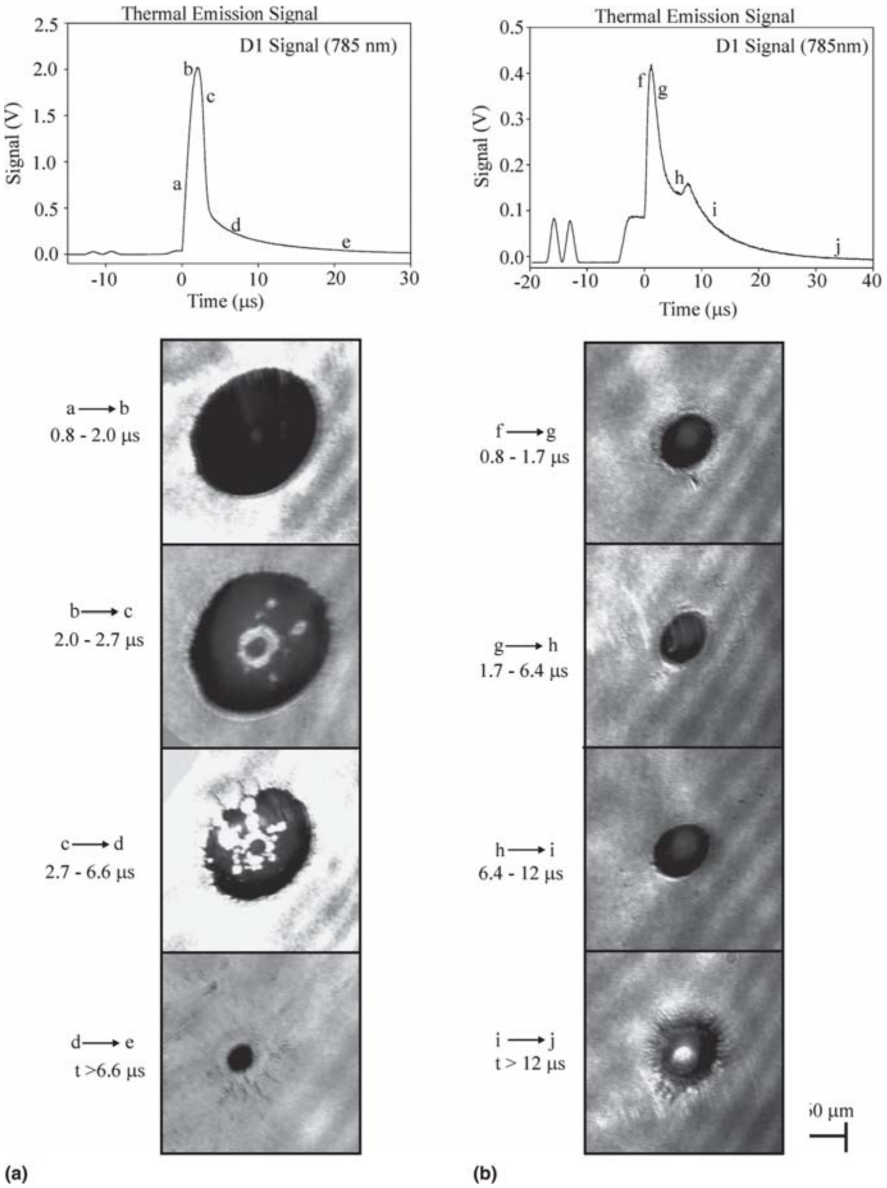

Fig. 2 Typical thermal emission signals and images of molybdenum splats at different times after impact on (a) nonheated and (b) heated glass

and thermal emission signal show that the splat spread to the maximum diameter (sequence b to c) of about 370 µm, rupturing from the central portion of the splat (Fig. 2a). The splat fragmented and material was lost until only the solidified central core remained attached to the surface. On heated glass, the splat maximum diameter was smaller (130 µm) and splat fragmentation was significantly reduced (Fig. 2b). Calculation of the cooling rates from the splat temperature evolution showed that on heated glass, the cooling rate was nearly an order of magnitude (3.2×10^8 K/s) larger than on nonheated glass (5.8×10^7 K/s). Similar results were obtained for amorphous steel and zirconia on glass and for molybdenum on Inconel 625 alloy.

It has been proposed that on nonheated surfaces, a gas barrier forms beneath the splat due to vaporization of adsorbates on the surface (Ref 1). This gas barrier reduces the true splat-substrate contact area on the nonheated surface. The gas barrier also reduced heat flow from the splat to the substrate. Heating the substrate vaporized these adsorbates prior to impact, so the splat-substrate contact on the heated substrate was improved, which increased the splat cooling rate. To test this hypothesis, a simple energy conservation model was developed to estimate the area of contact between the splat and the nonheated glass. The conservation of energy between the droplet and the splat at the maximum extent was used to show that only 40% of the area of the splat on nonheated glass was in contact with the surface. This was equivalent to a circular diameter of 90 µm. The diameter of the central core in the last image of Fig. 2(a) was approximately 80 µm. This agreement suggests that only the fluid in the central core of the splat on nonheated glass was in good contact. The rest of the splat, which remained liquid for a longer period of time, spread to a large extent, becoming so thin that it ruptured and flew off the surface.

The order of magnitude lower cooling rate supported the hypothesis that only a small area of the splat was in good contact with the nonheated surface. On heated glass, the larger cooling rate suggested that the splat-substrate contact area was significantly larger. The large difference in the cooling rates on these surfaces also suggest that the thermal contact resistance was different, being larger on the nonheated surface. A one-dimensional heat conduction model was developed to estimate the thermal contact resistance between the splat and substrate. The splat and substrate were assumed to be finite solids in a two-layer composite solid. The orthogonal expansion technique was used to find the cooling rate, which was dependent on the splat and substrate material properties and the thermal contact resistance. It was found that on non-heated glass, the thermal contact resistance was almost two orders of magnitude larger (4.6×10^{-5} m^{2}K/W) than on heated glass (8.0×10^{-7} m^{2}K/W). These estimates of the thermal contact resistance explain the observed differences in the splat cooling rates on the heated and nonheated surfaces and support the hypothesis that the splat was separated from the nonheated glass by a gas barrier. Similar results were obtained for zirconia splats on glass and molybdenum splats on Inconel 625 alloy.

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