JTTEE5 18:466–467
DOI: 10.1007/s11666-009-9406-2
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Letter to the Editor

Dear Dr. Moreau:

I enjoyed reading the paper you and your co-authors wrote for the December issue of the Spray Journal, entitled ''Review on Cold Spray Process and Technology: Part I—Intellectual Property'' (Ref 1), but I am perplexed why you describe the process, ''….an all-solid-state coating process that uses a high-speed gas jet to accelerate powder particles toward a substrate where they plastically deform and consolidate upon impact,'' as ''cold spray.'' Cold spray (literally) should not include spraying of a high melting point metal where the particles impact the work piece at over 1,000 °F and where the accelerating gas must first be heated to even higher temperature.

To discuss this point further, I shall refer to articles appearing in earlier issues of the journal. For higher melting point materials, the most definitive paper is that of Hanson and Settles (Ref 2), which discusses the optimum conditions for HVOF spraying of 316 stainless steel powder using various impact velocities and particle temperatures. They found temperature much the more important. Some excerpts follow:

''It is apparent from these three micrographs that the coatings are formed almost entirely of particles that remain unmelted in flight.''

''….micrographs of cold-sprayed coatings cross-sections are shown that are remarkably similar to those of HVOF coatings….where particle temperatures are kept below the melting point of the material.''

''Coatings (a) and (b) were formed of particles over 90 °C below the melting temperature. These coatings show no oxidation except on the thin splat boundaries.''

They go on further to state that there is little advantage in lowering particle temperature very far below the melting point. My belief is that the sum of the particle's in-flight temperature and temperature increase upon impact must lead to near-melting conditions at the impact point. If true, extreme velocities can play an important role.

Jacobs, Hyland, and DeBonte (Ref 3) discuss the results obtained using HVAF spraying of WC-cermet coatings. The decrease of flame-jet temperature inhibited de-carburization effects yielding an improved coating sliding-wear behavior (compared to HVOF).

''The HVOF sprayed WC–CO-CR coatings showed a wear rate that was an order of magnitude higher than that of the HVAF WC–CO-CR coatings.''

''This could be explained by the retention of WC particles and the absence of brittle W_2C, which is typical to the HVAF process.''

A long, unhappy history is involved in the commercialization efforts of HVAF. Early in the 1990s, I was operating a prototype HVAF gun and became a bit peeved when my assistant tried to convince me that the powder was flowing. I knew it wasn't—no plume was visible. I was wrong. The impact zone was glowing merrily! This led to a patent (Ref 5) describing ''impact fusion'' and an article, ''Hypersonic Impact Fusion—A Technical Note'' (Ref 4). One quote, ''At 300 psi (20.7 bar) the particles reach a temperature of 2,590 °F (1,420 °C). This is 111 °F (61 °C) below the melting point of the stainless steel powder.

Subsequently; a few HVAF systems were sold. Several customers reported results similar to those described by Ms. Jacobs. Later, the legal department of a large firm selling HVAF systems determined that operation of this equipment could be an explosion hazard. The company recalled the units already in use and discontinued HVAF sales. A simpler engineering-based decision to eliminate the dual flows of oxidizer and fuel through the same enclosed console would have allowed the further growth of the process in the domestic market. Apparently, the use of HVAF is thriving in Japan where they call it ''warm spray.''

Long before I would have believed ''cold spray'' and ''impact fusion'' to be the same basic process, Heinrich Kreye told me that such was the case.

Changing to a different topic, vortex flame stabilization, reported recently in Spraytime (Ref 6), has led to rather startling results. Spray impact widths using wire range down to ¼-in. with molybdenum even less. In the later case, a long single white-hot filament extends well beyond the sharp melting point. After traveling up to an inch break-up and atomization result in a very narrow droplet pattern, I plan to make this new HVOF wire spray method available to users at prices well below those of twin-wire-arc systems of comparable spray rate.

Jim Browning

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Authors' Response

You raised very interesting points in your Commentary following the review paper on Cold Spray published in the December 2008 issue regarding the terminology and nature of the Cold Spray technology. We would like to thank you for sharing your thoughts and views and agree with most of them. In the review article, we used the terminology ''Cold Spray'' as it has been used and accepted for many years by the thermal spray community. The rationale behind this designation is based on the fact that the sprayed particles are not melted (and scarcely heated) during their flight prior to impact as the gas temperature in the De Laval nozzle drops rapidly, as *demonstrated by the 1D isentropic gas dynamic theory and confirmed experimentally by the various cold spray characterization available in the literature. It has been shown that it is only in the strong deceleration zone behind the bow shock wave and at impact that the particle temperature rises notably. However, it has been demonstrated in many instances that only an extremely limited zone (a few nanometres thick) does experience partial melting, and this is not always occurring.*

We agree that HVOF/HVAF and Cold Spray coatings can have similar properties when in-flight particles are not melded during spraying. One simplistic way to look at this is to notice that the Cold Spray process is similar to HVOF with the combustion process switched off, thus the similarities in coatings for some materials/spray parameters combinations.

We agree also that Cold Spray and "impact fusion" may involve the same basic phenomena in some cases, when specific combinations of sprayed particles and sprayed conditions are used, but not in a general way. Indeed, up to now, it has not been established that localized melting upon impact always occurs during cold spray. Other physical phenomena seem to be involved in the coating formation. Indeed, many TEM studies have reported the absence of localized melting but intense material deformation in Cold Spray coatings.

Regardless of all these observations, we would like to highlight the fact that the impact fusion process that you have developed and reported in this Journal in 1992 should have been included in our review paper with the other Cold Spray precursors or related processes. This omission was not intended but rather resulted from the vast amount of literature available.

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