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Impact Modeling of HVOF Sprayed Polymer Particles

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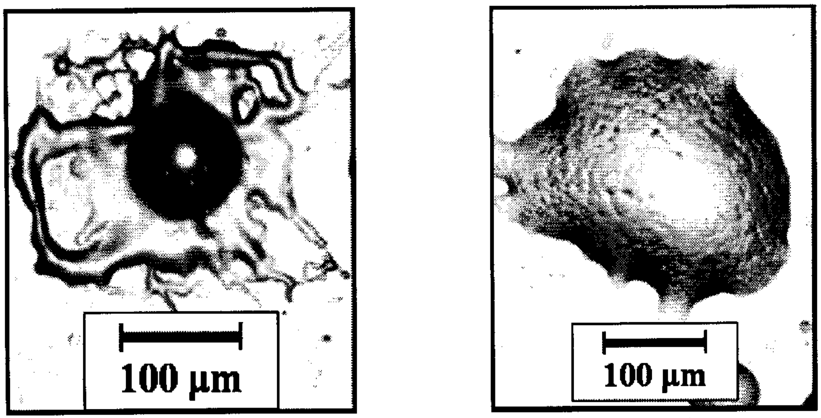
Introduction

Traditionally, thermal spray has been used for the deposition of metallic and/or ceramic coatings, however, it was recently found that high kinetic energy of High Velocity Oxy-Fuel [HVOF] thermal spray processes also enables the solventless processing of high melt viscosity polymers, eliminating the use of harmful, volatile organic compounds [1]. A model of particle deformation and cooling has been developed for HVOF sprayed polymer particles when they impact the substrate at high speeds, i.e. the "splatting" behavior of particles under different physical and thermal conditions. This will enable the coating microstructure evolution to be modeled and correlated to spray conditions and actual coating microstructures.

Experimental Work

The swipe test or "splat test" involved a high speed [> 0.7 m/s] single spray pass over glass slides using minimal powder feed rate [2 g/min]. Swipe tests were used to observe and compare the morphology of individual nylon splats with 3D modeling results and to further understand the influence of external substrate preheating on the deposition properties of the polymer. Splat morphologies sprayed both with, and without, substrate preheating were analyzed using standard metallographic techniques and scanning electron microscope [SEM].

Nylon splats sprayed on a room temperature substrate exhibited a "fried egg" shape with a large nearly-hemispherical core in the center of a thin disk [Figure 1a]. This shape indicated presence of a large difference in radial flow properties of the molten or nearly molten nylon droplets and a radial temperature gradient due to low thermal conductivity of nylon-11 [0.19 W/(mK)] and short dwell time [< 500 μs] in the HVOF spray process. On the other hand, nylon splats sprayed on a preheated substrate exhibited a semi-spherical shape [Figure 1b] due to post deposition flow activated by surface tension or/and residual stress after "fried egg" splats were fully melted by the preheated substrate. It was observed that post-deposition flow of Nylon-11 splats occurred only when substrate was preheated to the temperature above ~ 180 °C which was consistent with the onset of melting of nylon's crystalline phase also indicated by DSC results.



[a] [b]

Figure 1: Optical micrographs of the single Nylon-11 splats on the glass substrate: [a] substrate at room temperature, [b] substrate preheated to 200 °C.

Molten Nylon-11 at high share rate [> 10 s^{-1}] exhibited shear thinning phenomena – viscosity decreases as shear rate increases while at very low rates of deformation [< 1 s^{-1}] viscosity has a constant value. This non-Newtonian polymer flow could be accurately described by Carreau model which was used to predict viscous flow in this project. The four fitting parameters in Carreau model were chosen base on experimental results shown in Figure 2.

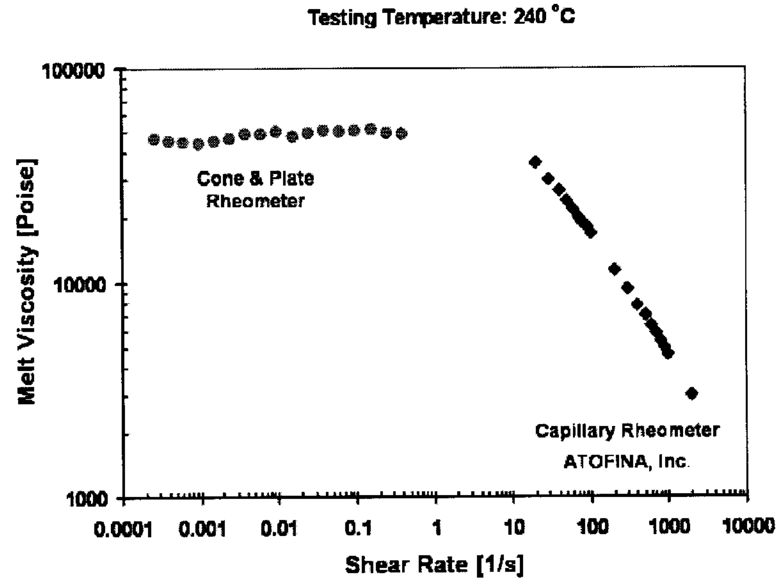


Figure 2: Dynamic melt viscosity of Nylon-11 in function of shear rate at 240 °C.

Modeling Work

Because of the complex three-dimensional shapes of "splats" formed during thermal spraying, a commercially available Volume-of-Fluid [VOF] computational fluid mechanics package, Flow3D®, was chosen to model the fluid mechanics and heat transfer during particle impact with a steel substrate. Initially, fluid flow of the deforming molten polymer droplets was predicted as a Newtonian which generated rounded splats with the constant thickness after droplet was deformed into a static splat. However, experimental results indicated that nylon splats immediately after the impact had a "fried egg" shape which could be predicted only with a shear thinning fluid flow model and temperature-dependent viscosity. Customized routines in Flow3D® have been created to generate polymer particles with a radial temperature profile – a low temperature, high viscosity core and high temperature, low viscosity at the surface [Figure 3]. This way predicted shapes of deformed particles exhibited a large nearly hemispherical core in the center of a thin disk [Figure 4 and 5b] which was consistent with experimental observations of thermally sprayed splats using optical and scanning electron microscopes [Figure 1a and Figure 5a]. Modeling post deposition flow of the nylon splats on a preheated substrate is in the progress.

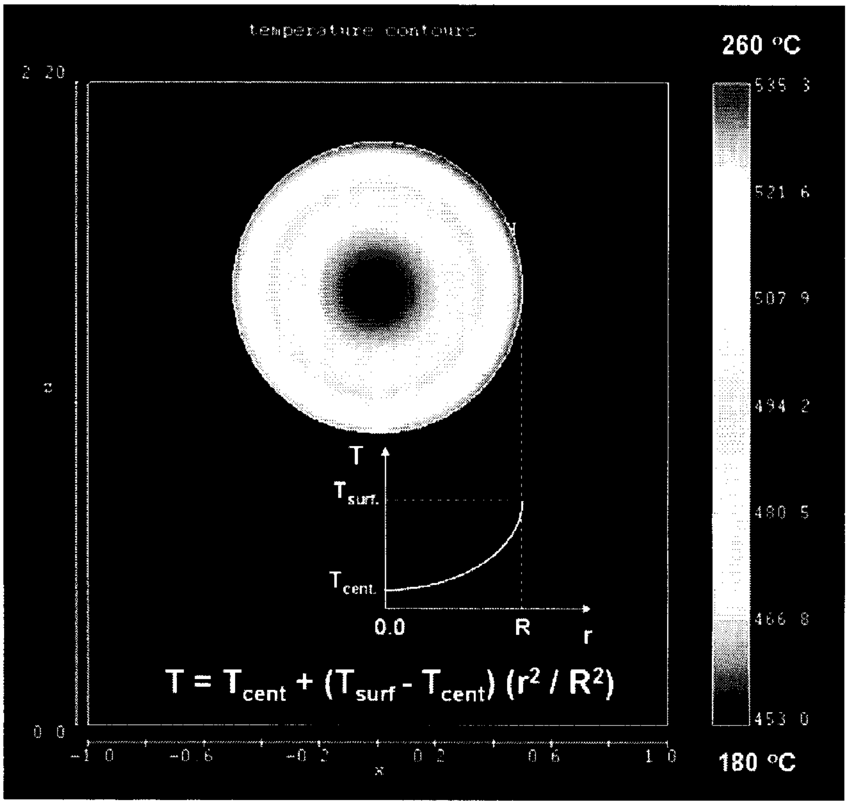
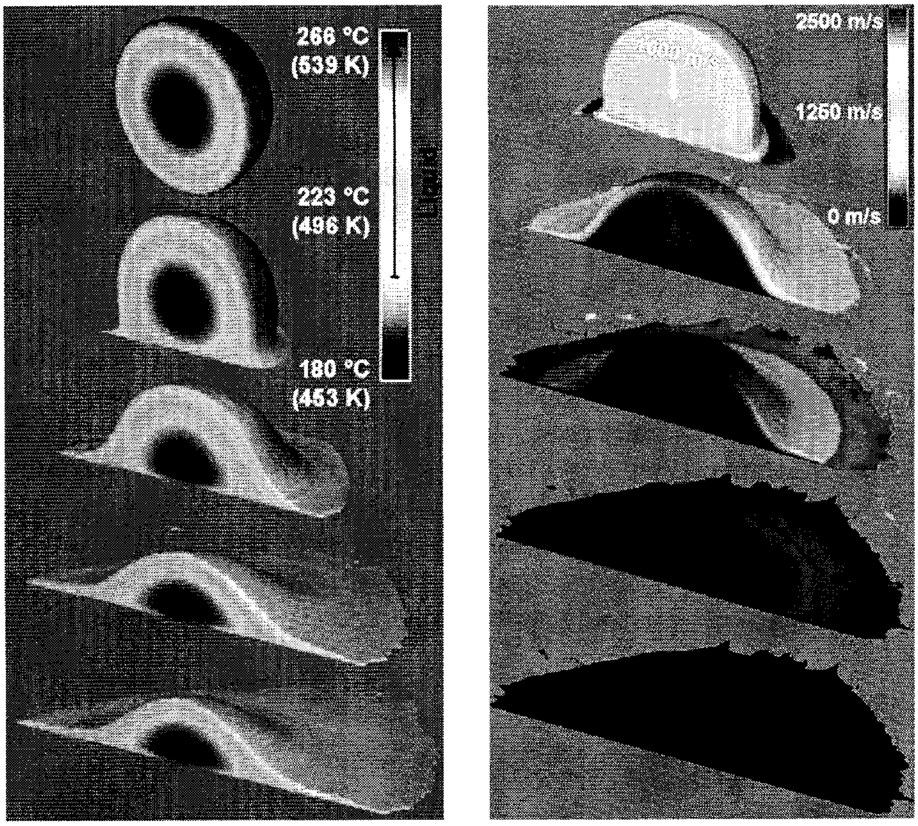
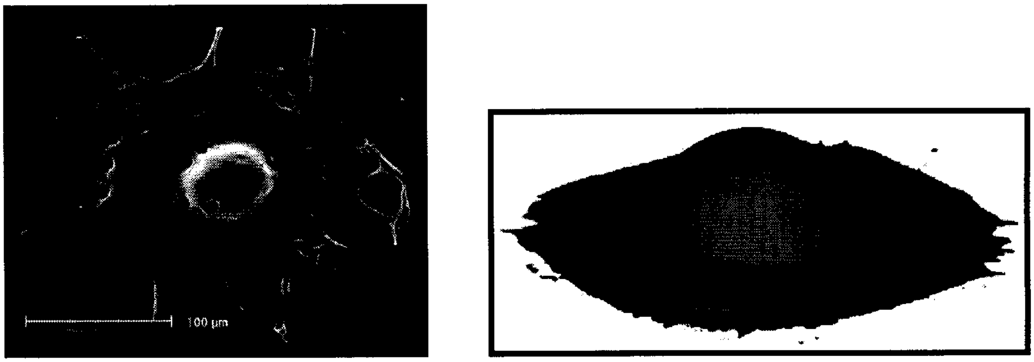


Figure 3: A parabolic radial model of temperature gradient assigned to the nylon droplet before impact with the substrate.



[a] [b]

Figure 4: Splat simulations for a nylon droplet with the radial temperature gradient and viscosity in function of temperature; [a] color variation indicates temperature field; [b] color variation indicates flow velocity.



[a] [b]

Figure 5: Static Nylon-11 splats on a room temperature flat substrate; [a] SEM micrograph, [b] 3D simulation.

References

[1] Petrovicova, E., Schadler L. S., "Thermal Spray of Polymers," International Materials Review, Vol. 47, (4), pp. 169-190, [2002].