Cold Spray of Polystyrene Particles on Various Substrates

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Background and Motivation

Cold-spray is a well-known coating technology that has been used since the 1980s for a wide range of applications for metals, polymers, ceramics, and composites on various substrates. During the cold-spray process, particles are accelerated to high speeds through a converging and diverging nozzle with a pre-heated, high-pressure gas. At high enough velocities upon impact on a substrate, particles deposit to form a non-porous coating on the substrate caused by severe plastic deformation of the particle [1]. The cold-spray of polymers has been investigated to a lesser extent than metals. However, since polymers behave significantly differently than metals during the cold-spray process, many unknowns still exist [2].

This study focuses on the cold-spray deposition of polystyrene particles on a variety of polymeric and aluminum substrates. Various process conditions were studied to achieve the buildup of particles on the substrates on an HPCS setup, which is mainly being used for metallic and ceramic CS applications [3].

1. Vilardell, A. M. Cold spray as an emerging technology for biocompatible and antibacterial coatings: state of art.*Journal of Materials*. (2015).
2. Khalkhali, Z. Characterization of the cold spray deposition of a wide variety of polymeric powders.*Surface and Coatings Technology*. (2020).
3. Bhattiprolu, V. S. Influence of feedstock powder and cold spray processing parameters on microstructure and mechanical properties of Ti-6Al-4V cold spray depositions.*Surface and Coatings Technology*. (2018).

Cold Spray Setup and System Variables

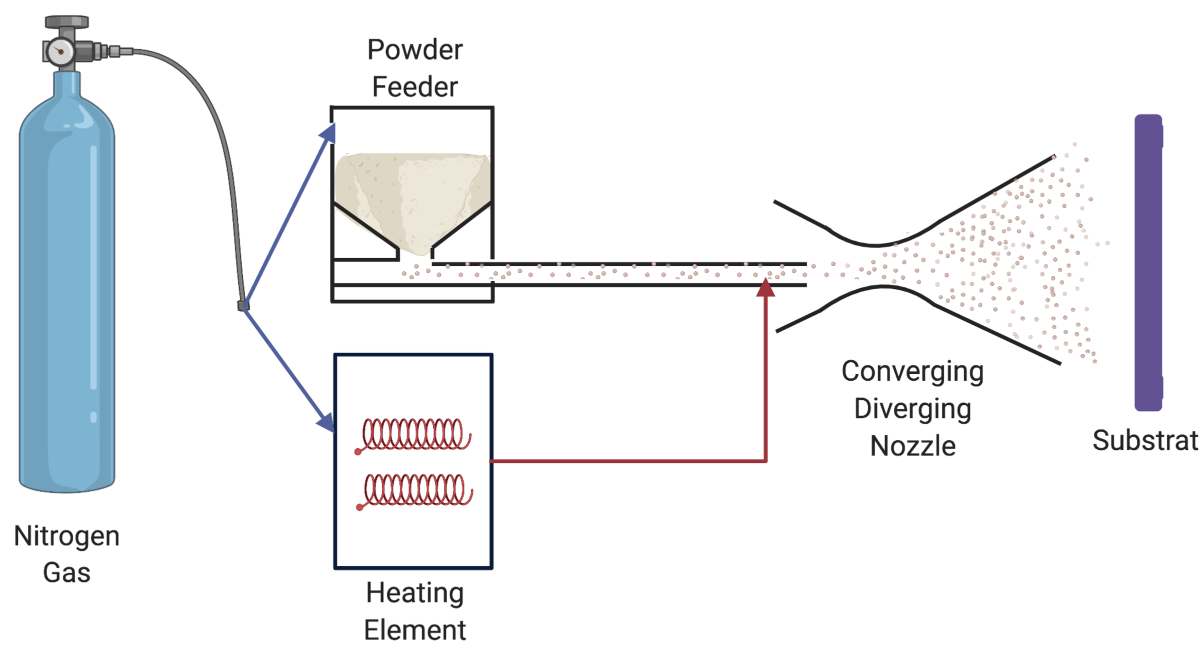


Figure 1: Cold-spray setup.

Three different plastic substrates, PP, PC, and a mixture of ABS and PC, and Al6060 Aluminum substrates were used. Stagnant gas temperature and pressure were varied between 60, 100, and 120 C and 250, 400, and 500 psi, respectively. The gas temperature range was selected according to the glass transition temperature of the PS, which is around 95 degrees Celsius. The gas pressure was kept around it at the low end, knowing that the polymer particles would prefer lower speeds when compared to metal particles. The PS and Al powders used in the experiments have a particle distribution of 50–80 μm and 5–10 μm.

Design of Experiments

Variables that are not mentioned in the following table were kept constant for every experiment, such as; standoff distance (10 mm), nozzle angle (90 °), powder feed rate (150 slm), powder temperature (25 °C), and raster speed (25 mm/s).

Run #	Gas Temperature (°C)	Pressure (psi)	Passes	Substrate Heating
1,2,3	60	250,400,500	2	Off
4,5,6	100	250,400,500	2	Off
7,8,9	120	250,400,500	2	Off
10,11,12	Opt. Temp.	250,400,500	10	Off
13,14,15	Opt. Temp.	250,400,500	10	On (120 °C)

First Set of Experiments: Plastic Substrates

The first set of experiments were done to determine the inlet gas temperature, where a total of 9 experiments were conducted on each substrate with varying gas temperature and pressure. After the experiments were run, the coating thickness of PS was measured by a profilometry instrument to determine the optimum gas temperature. For all three plastic substrates, 100 °C gas temperature provided the highest PS thickness. Figure 2 shows the deposition thickness of PS powder on different plastic substrates.

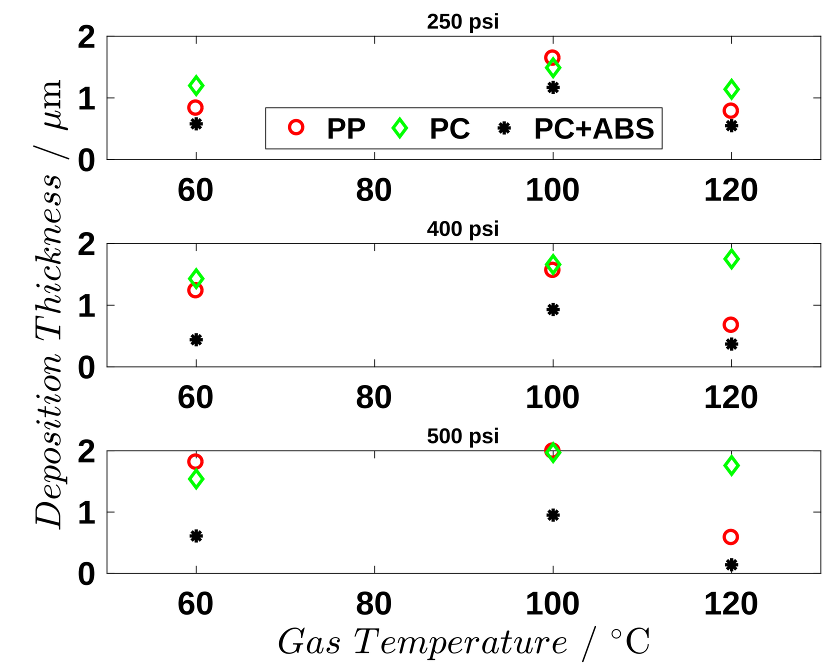


Figure 2: First set of experiments on plastic substrates.

FTIR Analysis: Plastic Substrates

FTIR analysis was an essential step in moving forward while it proved PS attachment on the substrates. In Figure 3, the C-H stretching peaks [1] are highlighted in a red box. There are no peaks observed in the PP substrate (uncoated) inside the red box; however, the same peaks are seen on the coated substrate with the pure PS powder. Therefore FTIR analysis proves that PS particles were sprayed on the substrates successfully with only two passes.

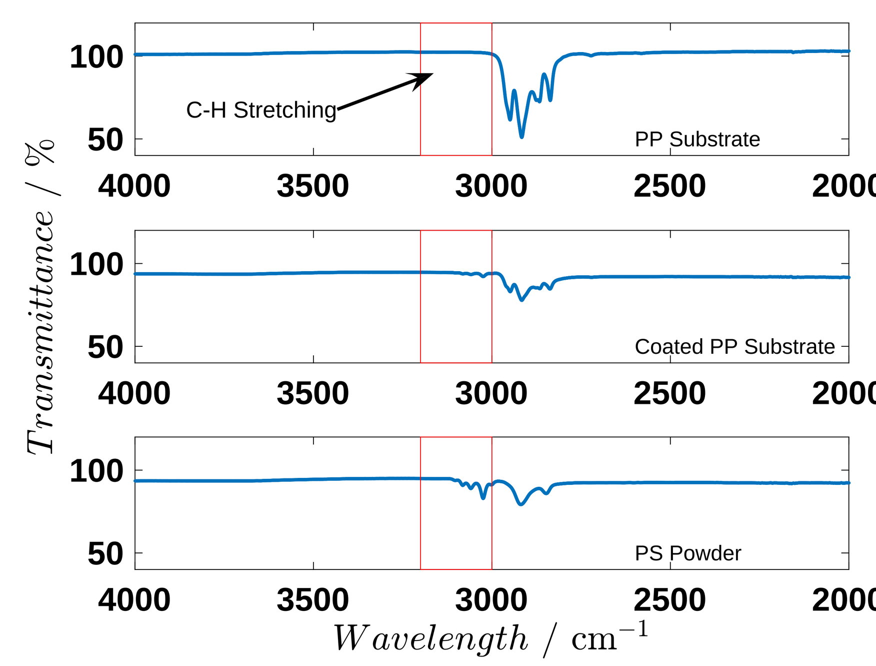


Figure 3: FTIR analysis for PP substrate.

1. Olmos, D. New Molecular-Scale Information of Polystyrene Dynamics in PS and PS-BaTiO3 composites from FTIR spectroscopy.*Physical Chemistry Chemical Physics*. (2014).

Effect of Substrate Heating: Plastic Substrates

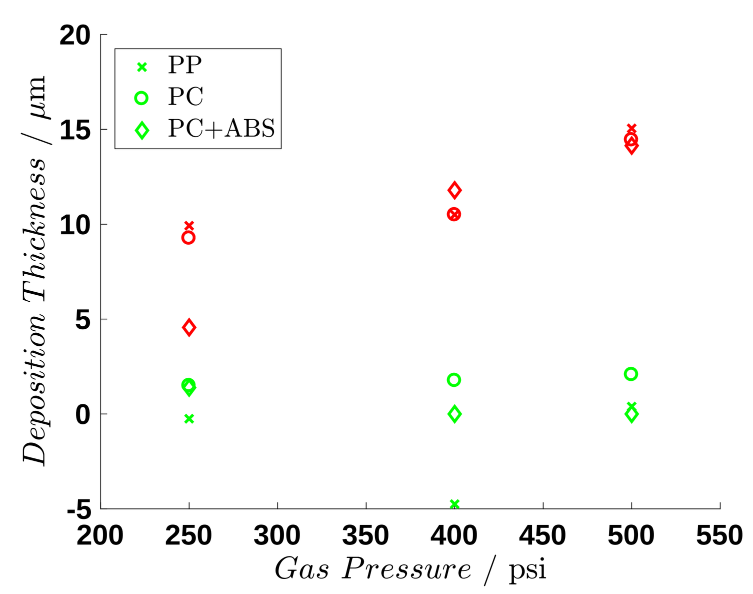
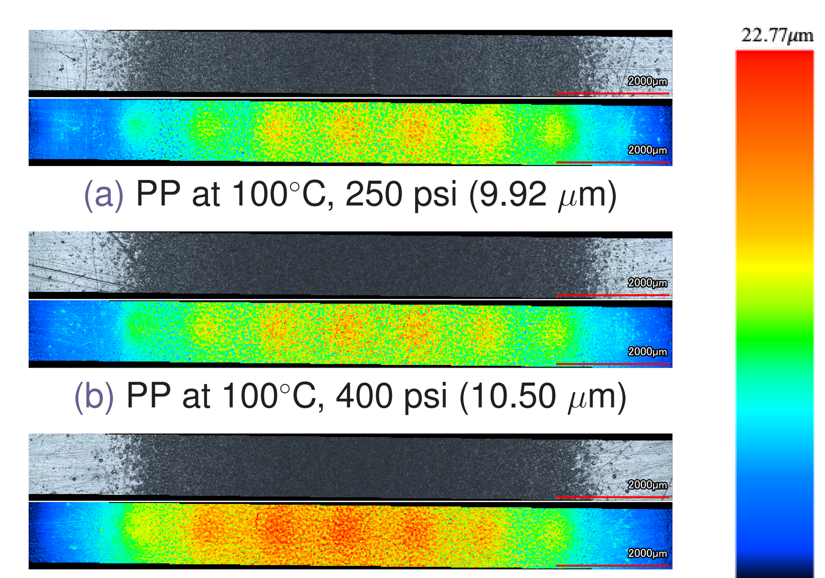


Figure 4: Deposition thickness with respect to pressure on polymer substrates, red markers are with substrate heating and green markers are without substrate heating.



(a) PP at 100°C, 250 psi (9.92 μm)

(b) PP at 100°C, 400 psi (10.50 μm)

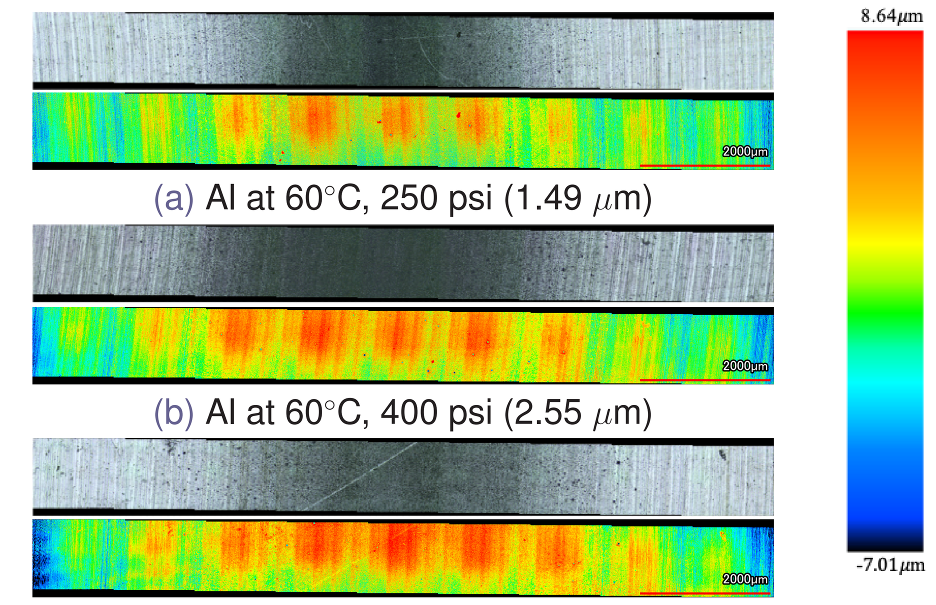
(c) PP at 100°C, 500 psi (15.05 μm)

Figure 5: Profilometry images of the plastic substrates after 10 passes with substrate heating.

In order to study the effect of substrate heating on the deposition thickness, six more experiments were conducted with ten passes at 100 °C inlet gas temperature. The substrate heating was also selected as 100 °C, which is around the glass transition temperature of PS powder.

Aluminum Substrates

In order to study the effect of surface roughness on the deposition efficiency, three different surface preparation methods have been used for the Al substrates (milling, sandblasting, sanding with Scotch Brite). The first set of experiments were conducted on all three aluminum substrates to investigate the optimum gas temperature.



(a) Al at 60°C, 250 psi (1.49 μm)

(b) Al at 60°C, 400 psi (2.55 μm)

(c) Al at 60°C, 500 psi (4.34 μm)

Figure 6: Profilometry images of the milled aluminum substrates after 2 passes without substrate heating.

For milled substrates (as shown in Figure 6), the deposition thickness was the highest when the inlet gas temperature was at 60 °C, and it increased with increasing gas pressure. However, for the sandblasted and Scotch Brite treated aluminum substrates, the deposition thickness decreased as the gas pressure increased at 60 °C gas temperature. In order to overcome this problem, substrate heating experiments were done on aluminum substrates as well. However, substrate heating is determined as a non-viable option because of the low deposition thickness it has provided.

Future Work: Aluminum Substrates First Layer Adhesion

Polymer particles deposits successfully on different substrates when the particle temperature is high, and the velocity is low. However, when the inlet gas temperature is increased to bring the particle temperature high, the particle velocity increases as well. Therefore, to avoid the particle velocity increase, a powder heater will be used to bring the powder to a higher temperature at a moderate gas temperature. Another approach with a PS/Al powder mixture will be investigated to increase the deposition thickness on aluminum substrates. Figure 7 shows the preliminary results of the second approach. The rationale behind this approach is to decorate the PS particles with Al particles, where similar studies have been done in the literature [1].

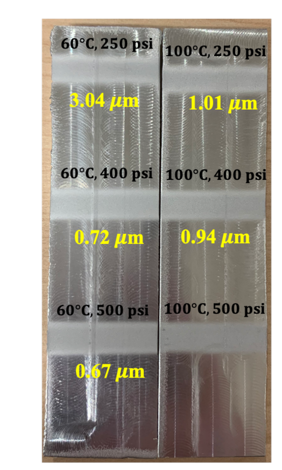


Figure 7: Al substrates sprayed with PS/Al powder mixture.

1. Ravi, K. Development of Ultra-High Molecular Weight Polyethylene (UHMWPE) Coating by Cold Spray Technique.*Journal of Thermal Spray Technology*. (2015).

Conclusion

This study was focused on the deposition of PS particles on different types of plastic and aluminum substrates. Plastic substrates were coated successfully when the substrate heating and gas temperature was around the glass transition temperature of PS powder. For aluminum substrates, PS and PS/cAl powder mixtures were sprayed; however, as the gas pressure increased, the particles started eroding each other. Therefore, the deposition on the aluminum substrates is still an ongoing investigation mainly focused on the first-layer adhesion since the first couple of layers of deposited particles play a crucial role in cold spraying.

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