Effects of cold spray parameters on microstructure and adhesion of titanium deposited on PEEK

Po-Lun Feng, Steven Nutt
University of Southern California

M.C. Gill Composites Center

Introduction

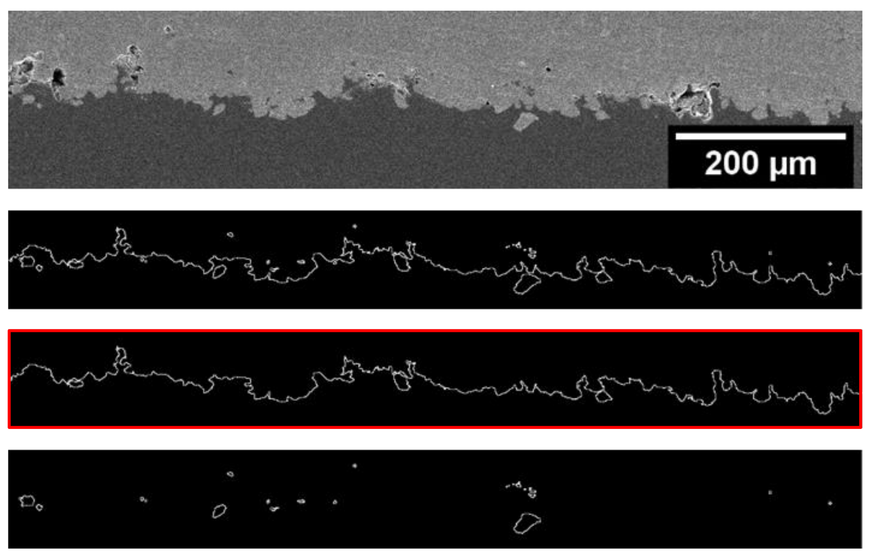
- The objective of this work is to determine the quantitative effects of gas temperature and pressure on the interface microstructure and adhesion of cold-sprayed titanium on PEEK at two powder feed rates.
- Mechanisms of adhesion for cold-sprayed metallic coatings on thermoplastics are not well understood.
- Adhesion of cold-sprayed coating is determined by the particle-substrate and particle-particle bonding.
- Interface roughness and particle coverage of the fracture surface of PEEK were chosen as quantifiable microstructures that strongly influence coating adhesion.

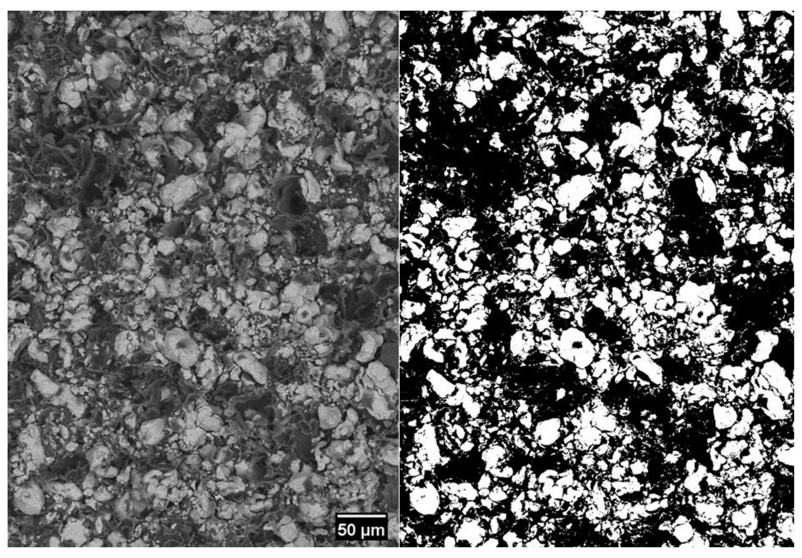
Acknowledgements
This work is led by USC, funded by U.S. Army, and carrier out in collaboration with VRC Metal Systems and C2Si.

Methods

- The interface root-mean-square roughness was calculated from SEM cross sections.
- The residual particle coverage on the substrate was calculated from fracture surfaces produced by adhesion testing.
- Adhesive strength was measured using a tensile adhesive testing instrument.

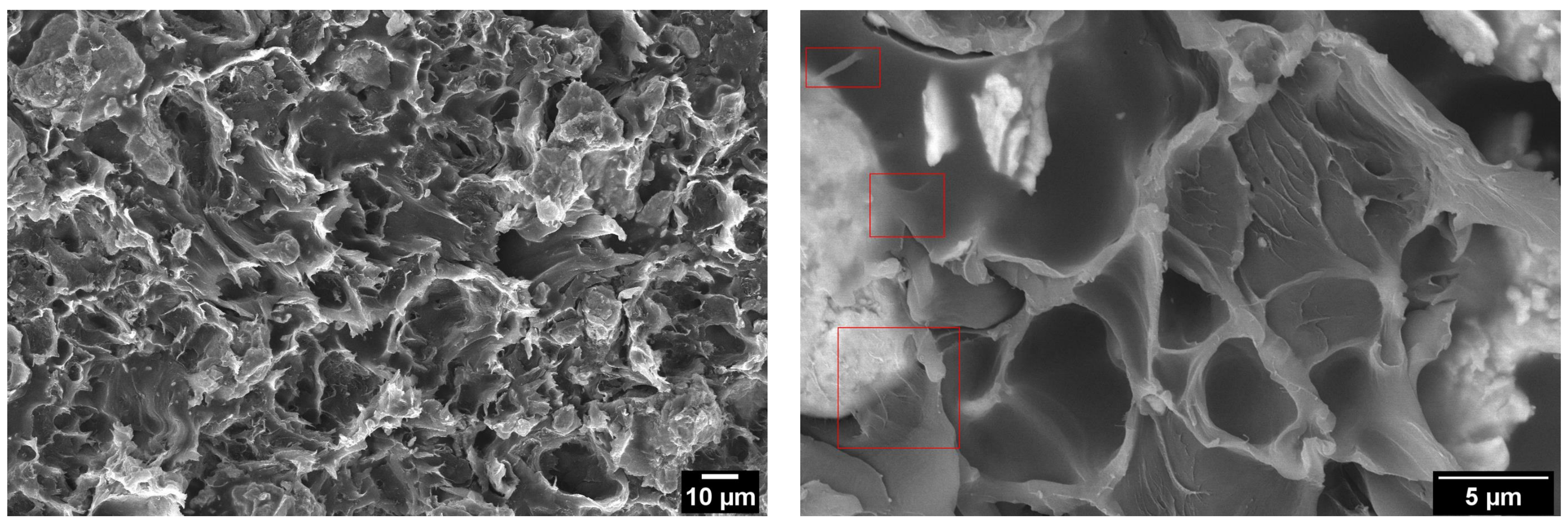
Gas Temperature (°C)	550 (L)	510 (L)	550 (L)	550 (L)	630 (H)	630 (H)	630 (H)	630 (H)
Gas Pressure (MPa)	4.5	4.5	5.2	5.2	4.5	4.5	5.2	5.2
Powder Feed Rate (g/min)	9.7	18	9.7	18	9.7	18	9.7	18





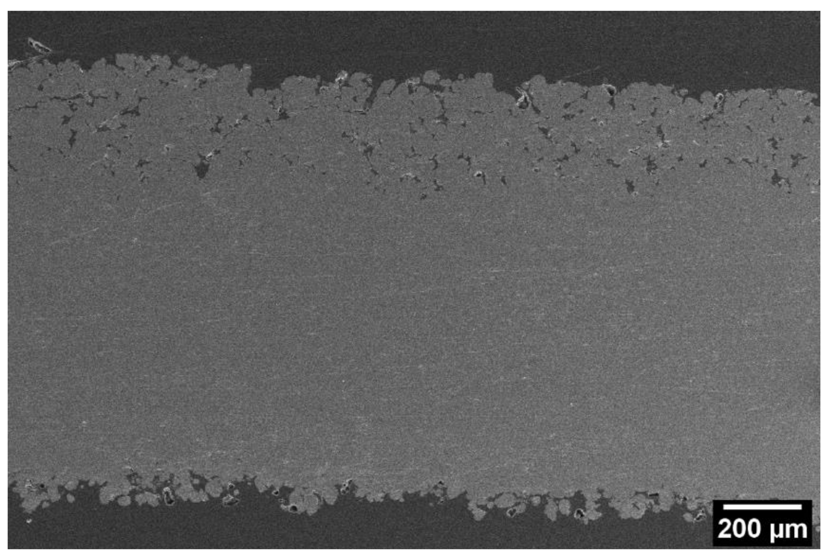
Localized Melting

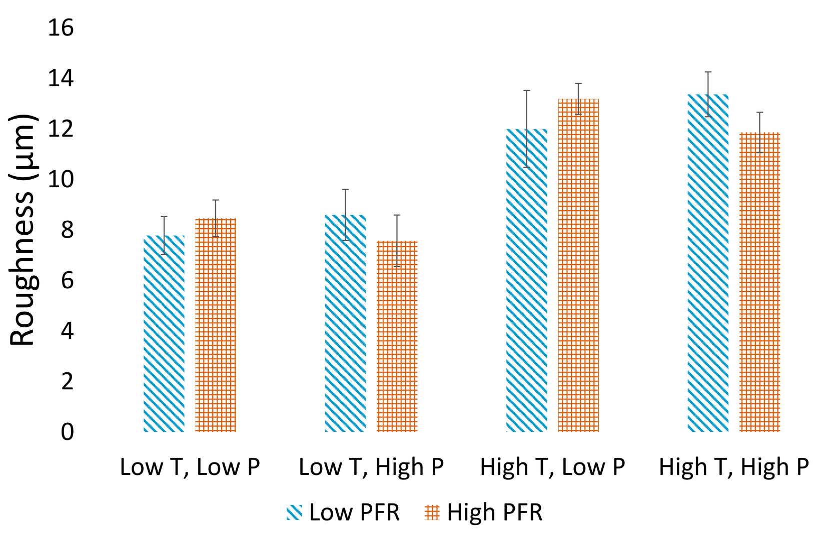
- Localized melting of PEEK can occur because of low thermal diffusivity and accumulation of heat.
- Ductile failure of PEEK indicates attachment of PEEK to CP Ti deposits prior to adhesion testing.
- Filament-like features suggests localized PEEK melting on the fracture surface.



Interface Roughness

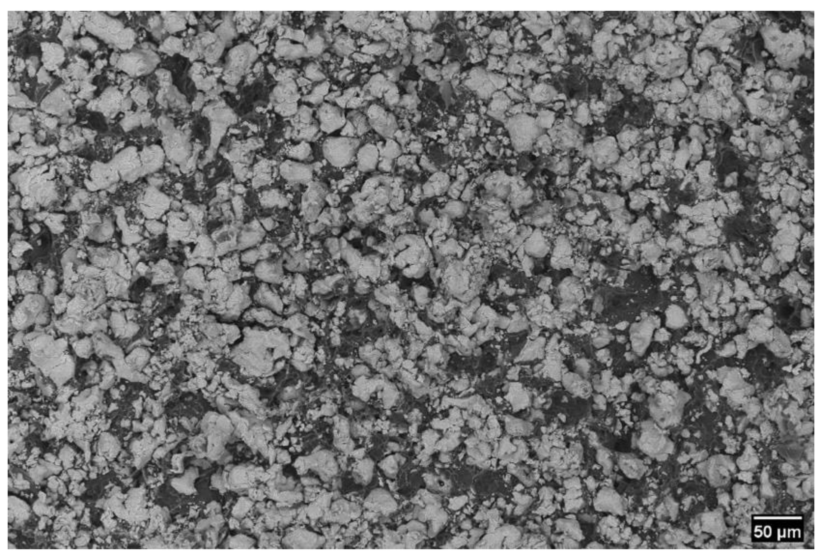
- The porosity in the uppermost region was attributed to the lack of shot peening that densifies and cold welds particle layers.
- The bond layer was formed by anchored particles that were not severely deformed.
- Deeply embedded particles that are completely enclosed by PEEK do not contribute to coating adhesion.
- Interface roughness depended more on gas temperature, less on gas pressure and powder feed rate.
- The elevated gas temperature thermally softened the thermoplastic substrate, reducing the effects of gas pressure and powder feed rate.
- A rougher interface resulted in stronger mechanical interlocking and adhesion.

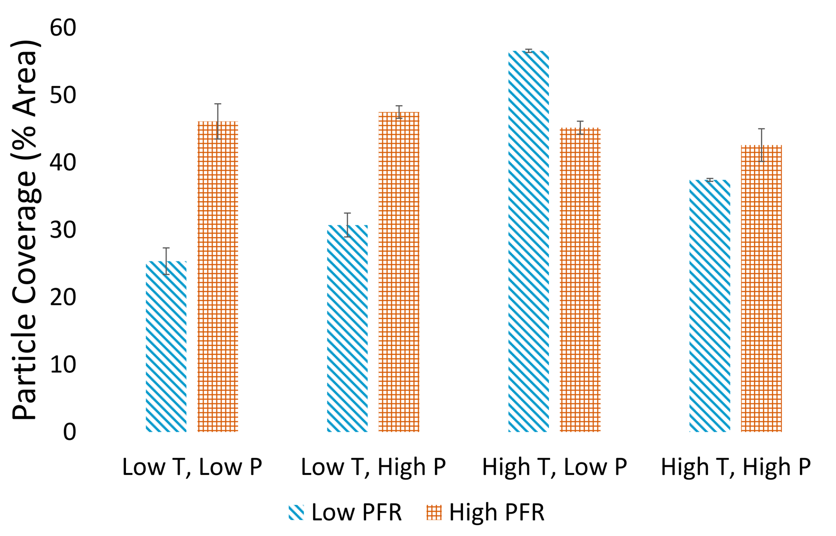




Particle Coverage

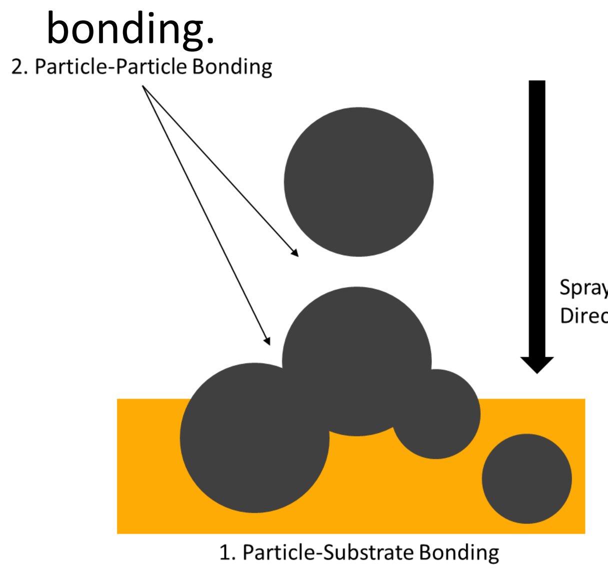
- Residual particles do not appear to be significantly flattened.
- Dimples and pits show locations at which particles were embedded.
- Particle coverage of the fracture surface indicates the relative bond strength of particle-substrate vs particle-particle.
- A reduced particle coverage with change in gas pressure indicates less effective embedment of particles.
- Inadequate depth of penetration, deformation, and localized melting can reduce the coverage of effectively embedded particles.
- Deposited particles can be dislodged and expelled or trapped in the deposit through erosion but remain weakly attached.

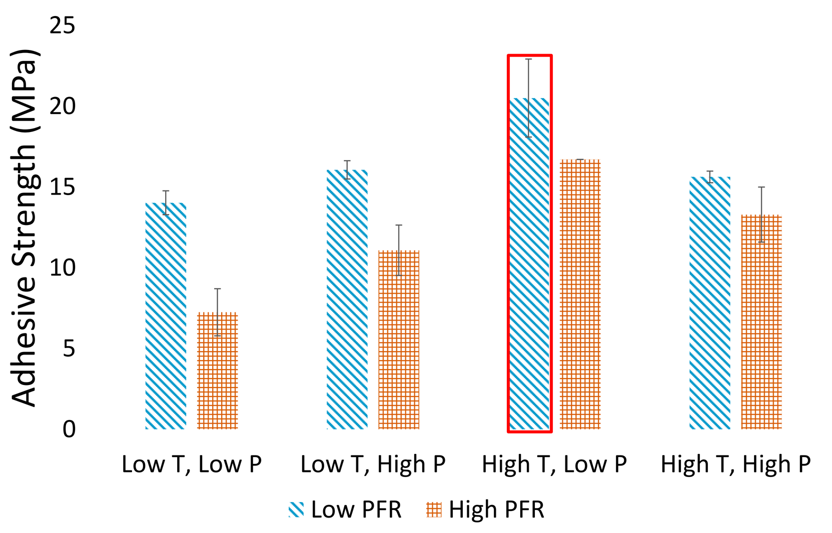




Steps to Increase Adhesive Strength

1. Increase the degree of mechanical interlocking by adjusting gas temperature for stronger particle-substrate bonding.
2. Increase the particle coverage of the fracture surface by adjusting gas pressure for stronger particle-substrate bonding.
3. Increase the particle flattening ratio near the substrate by applying the metal-metal cold spray parameters on the bond layer for stronger particle-particle bonding.





Conclusions

- Understanding coating-substrate adhesion is the first step to metallizing and functionalizing polymers.
- Quantified microstructures provide guidance in the selection of cold spray parameters for an adherent metal coating on polymer substrates.
- Interface roughness mainly depends on gas temperature.
- Reduced particle coverage indicates less effective embedment of particles.
- The second cold spray recipe should be used on top of the bond layer.
- Steps to increase the adhesive strength of cold-sprayed titanium on PEEK through quantifiable microstructures have been demonstrated, allowing more efficient selection of cold spray parameters.
- This approach could be applicable to different metal and thermoplastic combinations.
- This approach could accelerate material screening for applications that require well-adhered metal overlayers on thermoplastic substrates.
- Interface engineering of the bond layer microstructure is essential to cold spraying well-adhered metal overlayers on polymers.