Effect of Surface Finish of Additive Manufactured Parts on Plasma Sprayed Coating Microstructure and Adhesion

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Abstract: Surface roughness on an additively manufactured part can drastically affect the performance of thermal barrier coatings (TBCs) for gas turbines. To aid in the bonding ability of the TBC, the surface is often treated with grit blasting to smooth out grooves from the laser bed fusion process. The aim of the study was to evaluate the effect of surface morphology on coating microstructure and bond strength. Preliminary data suggests that surface grooving decreases bond strength, but sufficient grit blasting can increase this bond strength.

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Introduction

- Gas turbines are a major part of the energy and transportation industries. Newer and more efficient gas turbines operate at higher temperatures, requiring new materials.
- Additive manufacturing (AM) techniques are being explored as more efficient alternatives to traditional methods of production.
- Laser Bed Fusion (LBF) is an AM method that uses a controlled laser to melt metal powders in a layer, shown in Figure 2, allowing for tailored microstructures.
- This layer-by-layer fusion produces a "ridged" effect which adds roughness and can reduce the adhesion and performance of TBCs which are applied on top.
- Coatings can be applied using a variety of methods, including plasma spray, high velocity oxygen fuel (HVOF), and suspension plasma spray (SPS). Often included is a bondcoat to aid with both adhesion and CTE differences, as shown in Figure 3.
- Grit blasting (GB) is a common method of post-processing method to smooth out the surface of AM parts and improve bond adhesion.
- Our aim is to evaluate the effect of the ridging effect on coating performance and investigate grit blast mitigation strategies for improved bond adhesion.

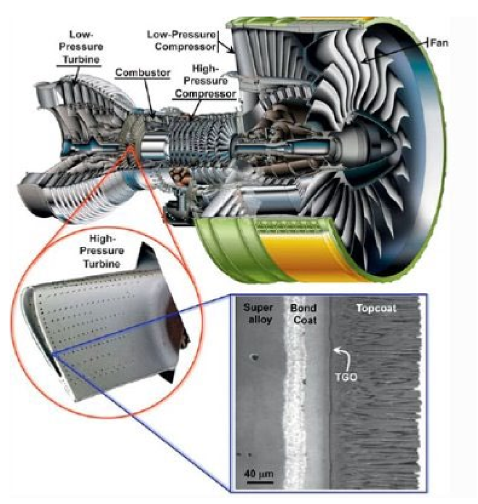


Figure 1: Gas turbine engine diagram including a schematic of the metal alloy, bondcoat, and top coat layers [1].

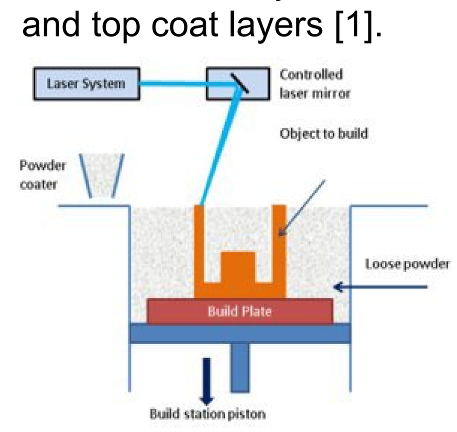


Figure 2: Diagram of the LBF process, illustrating the production of an AM part [2].

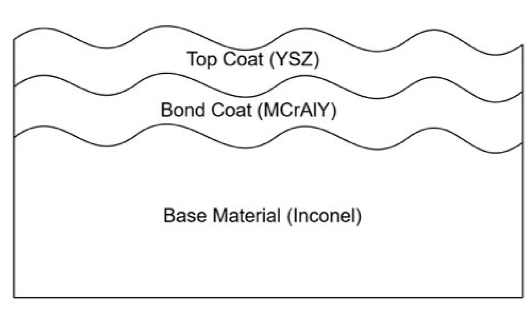


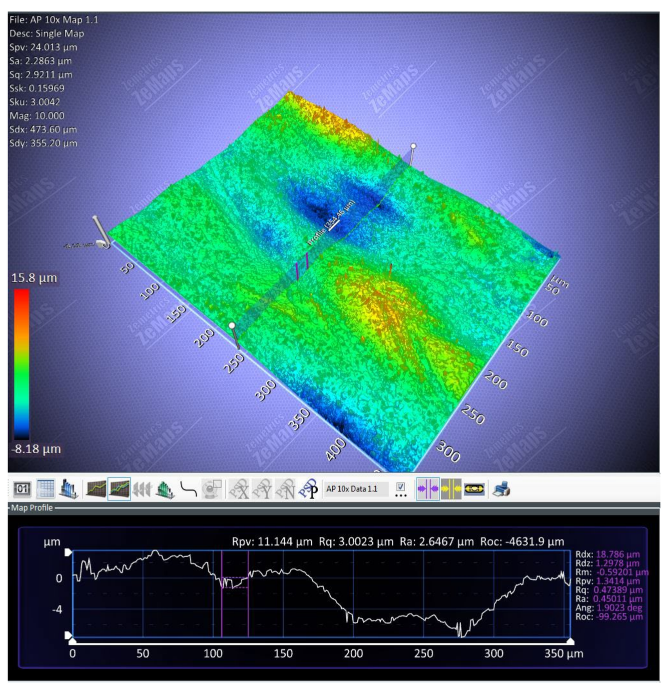
Figure 3: Illustration of changes to the AM surface affecting the bond and top coats on top of it.

Methods

Sample ID	Conditions Description
As-Printed LBF	LBF Inconel, no coatings
Control	Cast Inconel, with fine grit blast.
Fine Grit-blast (GB)	LBF Inconel with a fine grit blast.
Coarse Grit-blast (GB)	LBF Inconel with a coarse grit blast.
Coarse-Fine Grit-blast (GB)	LBF Inconel with a coarse grit blast treatment followed by a fine grit blast treatment.

- Optical profilometry was performed using a Zygo ZeScope at magnifications ranging from 10x to 12.5x and linear interpolation was performed to fill in missing data points.
- SEM imaging was performed on mounted cross sections using a Quanta 3D FEG with a 15-20 kV voltage and between a 1-4 mm spot.
- Stereoscope imaging was performed using an Olympus microscope with a strong side lighting configuration to aid in depth contrast.
- Bond cap testing was performed in tensile load, using an Inconel bond cap mounted using epoxy, and was performed by Linde.

Optical Profilometry



- Surface roughness data was collected from both area and line scans.
- The OP images were useful in making qualitative comparisons between different grit blasts methods on surface characteristics.

Figure 4: Example area and line scan of an uncoated LBF sample.

Surface Topography

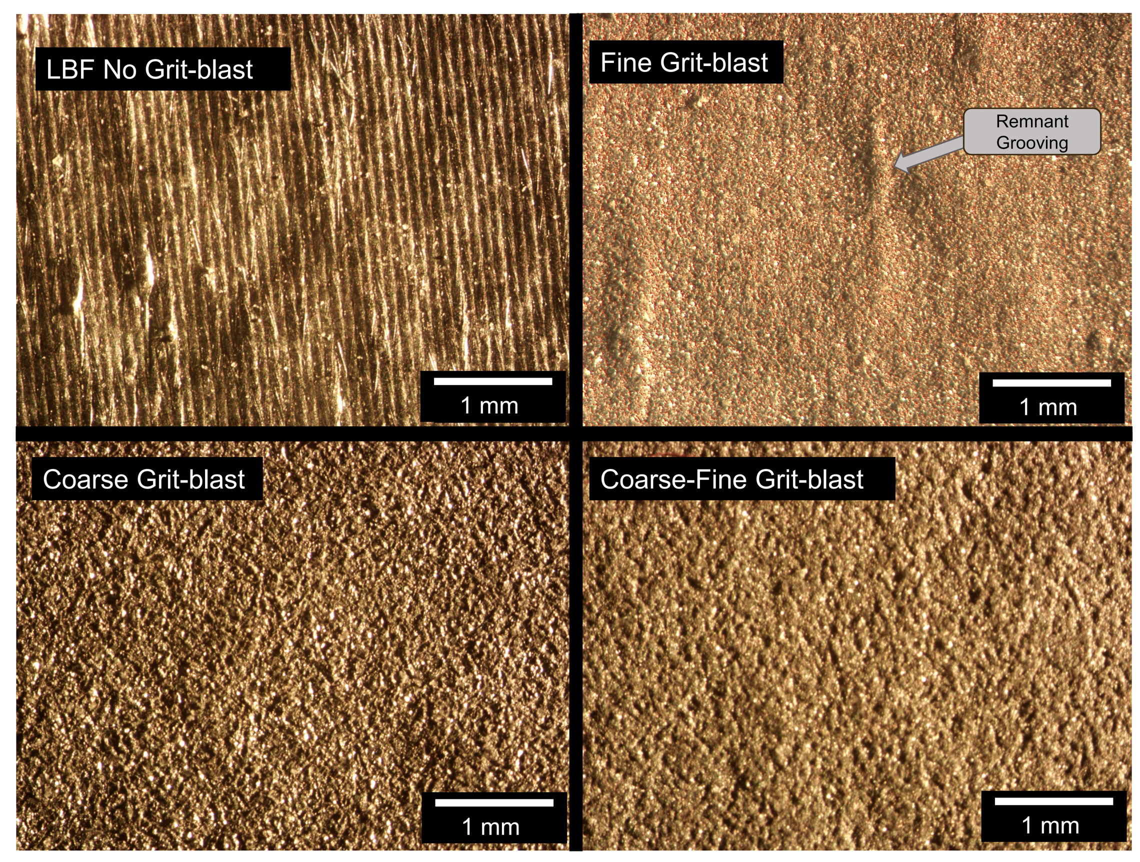


Figure 5: Stereoscope micrographs of surface of uncoated samples. As-printed and fine grit-blasted samples show a ridging effect. Coarse and coarse-fine grit-blasted samples show no remnant ridging effect.

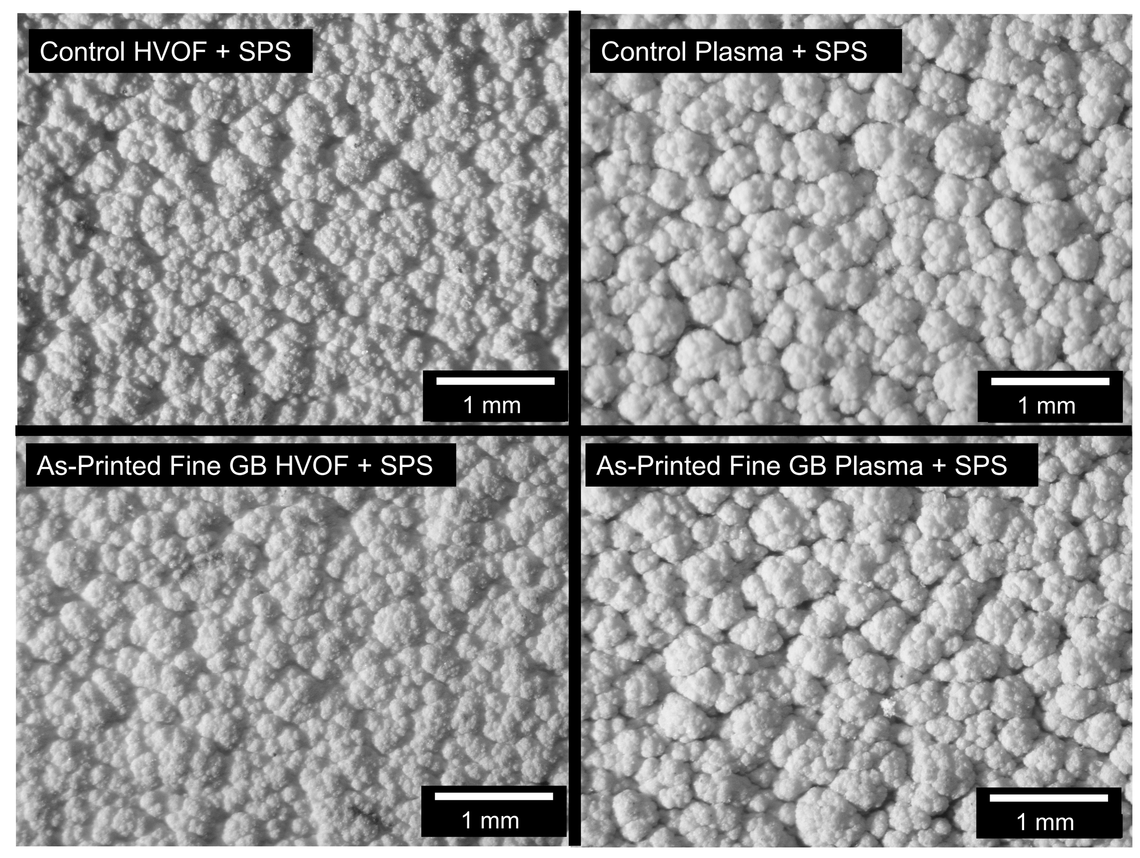


Figure 6: Stereoscope micrographs of samples coated with TBCs for HVOF bondcoats on left, and plasma sprayed bondcoats on the right. Top images show the morphology of the TBCs on control samples, while bottom images show equivalent coatings on the fine grit-blast LBF substrates. No clear difference observed as function of LBF ridging effect.

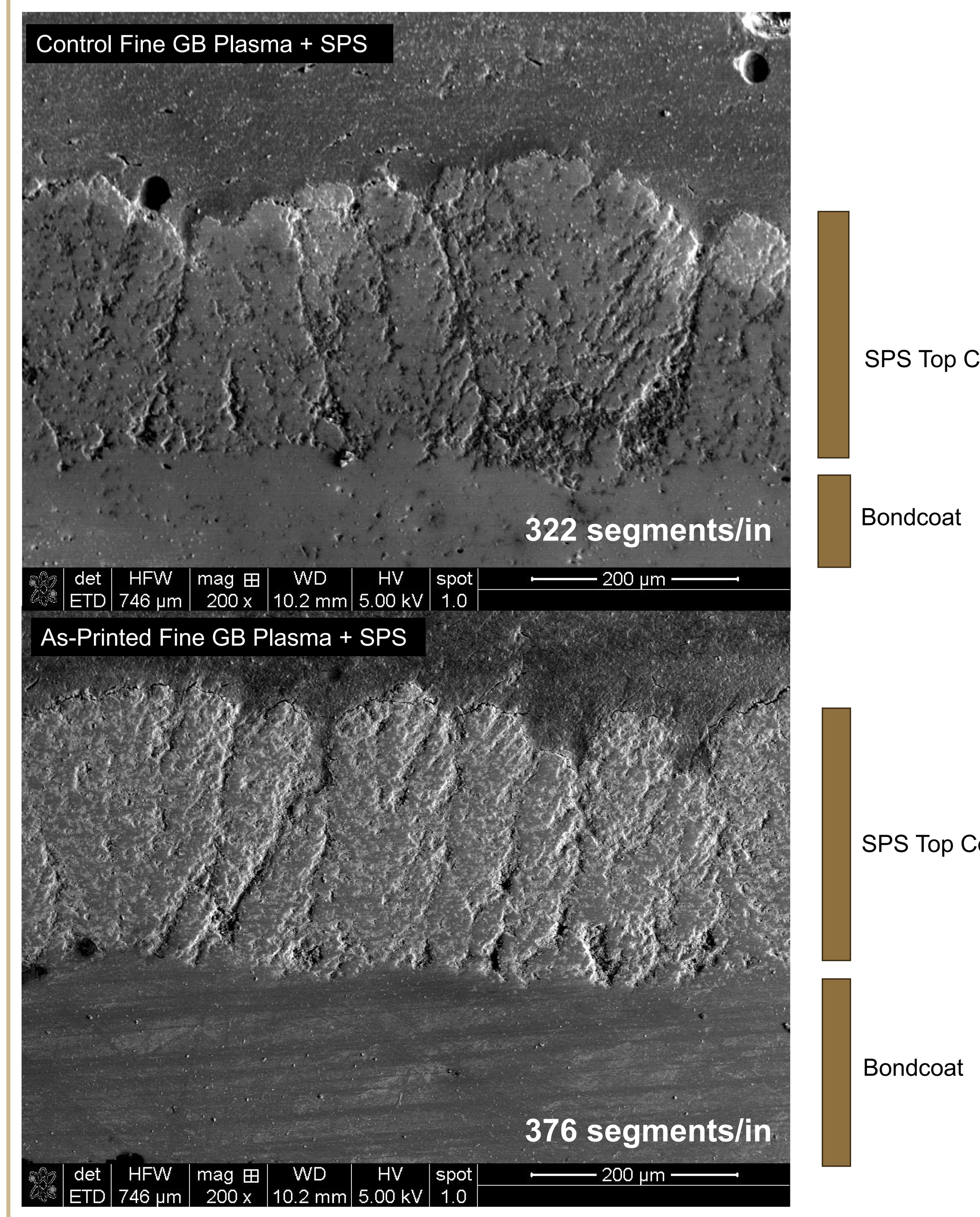


Figure 7: SEM imaging of sample cross-sections, consisting of an Inconel substrate, a plasma sprayed MCrAlY bondcoat, and an EBC top coat. The columnar microstructure of the SPS TBC is apparent.

Bond Strength

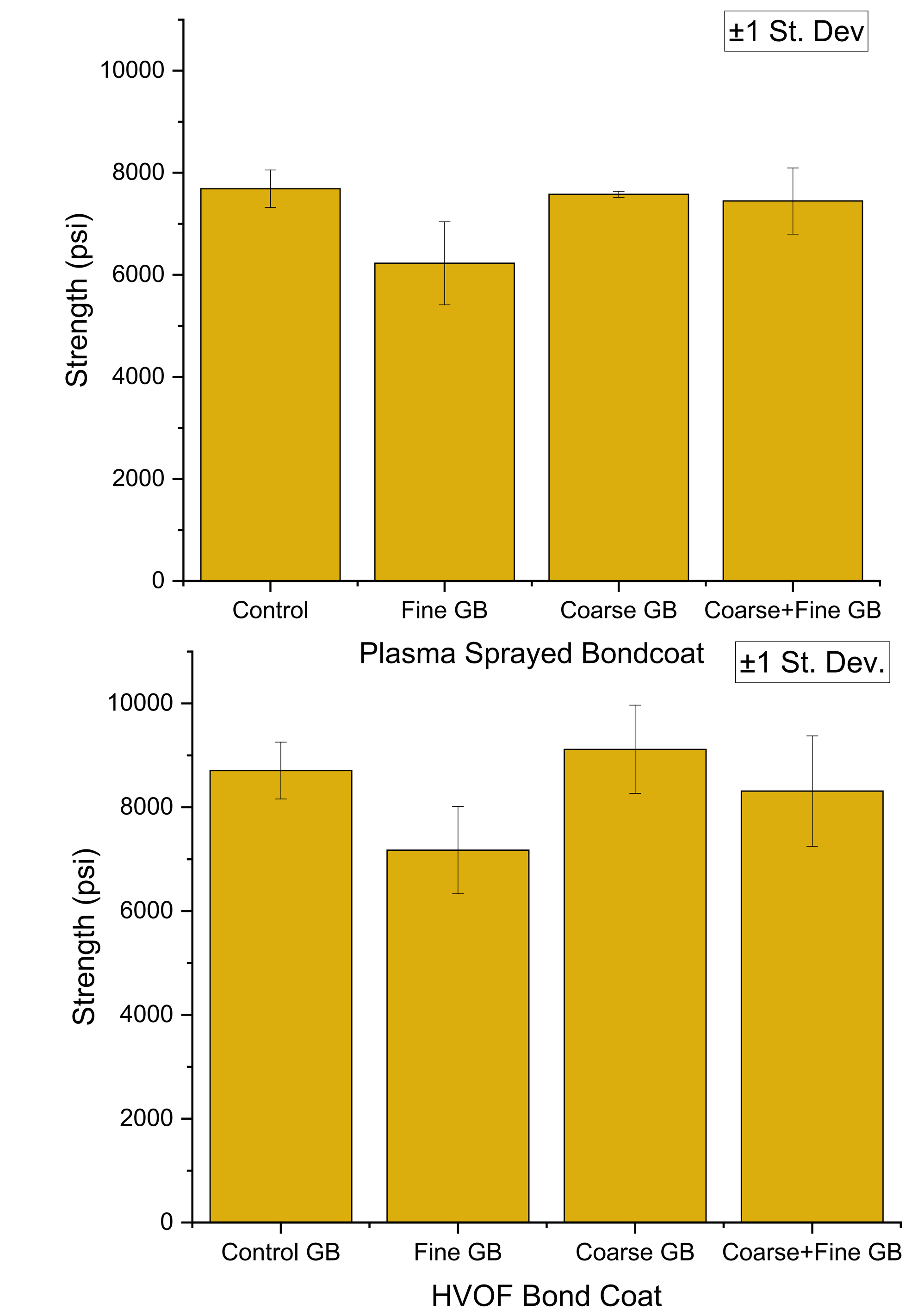


Figure 8: Results from bond cap (ASTM-C633) testing (n=3) for each surface condition, coated with both a bondcoat and top coat. In all cases failure occurred within the top coat. For both samples with HVOF and plasma sprayed bond coats on LBF substrates, standard fine grit-blast showed a debit in bond strength when compared to the control samples. That debit could be recovered by implementing a coarse grit blast, with or without a fine grit-blast following.

Conclusions

- Laser bed fusion generates surfaces with significant surface roughness in the form of ridges, shown in Figure 5, which persist after a fine grit blast.
- Coarse grit blast appears to remove any remnants of this surface ridging effect.
- The use of LBF substrates with standard fine grit-blasts, where the remnants of surface ridges are still observed, results in a decrease in adhesion strength compared to control cast substrates with the same grit blast.
- The decrease in adhesion is believed to be related to the presence of ridges on the surface generated during the laser melting of the LBF process.
- The debit in bond strength resulting from the use of AM parts can be mitigated by the implementation of an additional coarse grit blast or coarse grit blast followed by fine grit blast.
- The Purdue University team's recommendation to the sponsors is to utilize at least coarse grit blasting when preparing additively manufactured samples for coating.
- Future work may include additional evaluation of the bondcoat-substrate interface for changes in grit inclusion as well as studies to verify any effects on coating morphology with modified grit blasts.

References

[1] Clarke, D. R., Oechsner, M., & Padture, N. P. (2012, October 1). *Thermal-barrier coatings for more efficient gas-turbine engines - mrs bulletin*. SpringerLink.
[2] Bamberg, Joachim & Dillhöfer, Alexander & Rieder, H. & Hess, Thomas. (2014). Online Monitoring of Additive Manufacturing Processes Using Ultrasound.

Acknowledgements

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