Influence of Shot Peening on the Microstructure and Mechanical Properties of Nitrogen-Cold-Sprayed Al6061

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Abstract: This project investigates whether shot peening can enhance the mechanical properties of nitrogen-cold-sprayed 6061 aluminum. Cold spray, a process commonly used in aerospace repair, avoids heat-affected zones typical in welding. However, nitrogen-sprayed deposits often suffer from high porosity and reduced mechanical performance when compared to helium-based methods. Steel shot peening is applied to densify these lower-cost nitrogen deposits and improve yield strength and ductility. The study includes microstructural evaluation and porosity analysis before and after peening.

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Background & Objectives

Cold spray is a **solid-state deposition process** that accelerates metal powders to supersonic speeds using carrier gases like nitrogen or helium, forming dense coatings **via plastic deformation**. Helium-sprayed samples were provided by Rolls Royce and nitrogen-sprayed samples were ordered from VRC Metal Systems.

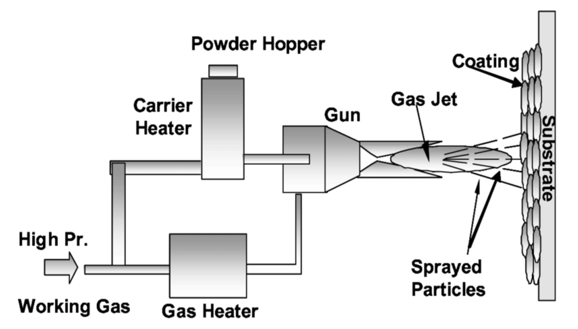


Diagram of how the aluminum particles are deposited onto the substrate via cold spray [1]

To improve the properties of the nitrogen-sprayed samples, shot peening was applied. Shot peening is a **surface enhancement process** that bombards a material with spherical media to **induce residual compressive stresses, improving mechanical properties**. S230 cast steel shot was used in the Sentenso Process Master machine to treat the cold-sprayed Al6061 samples.

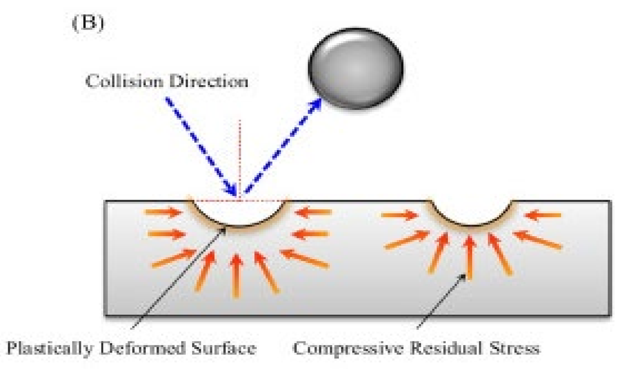
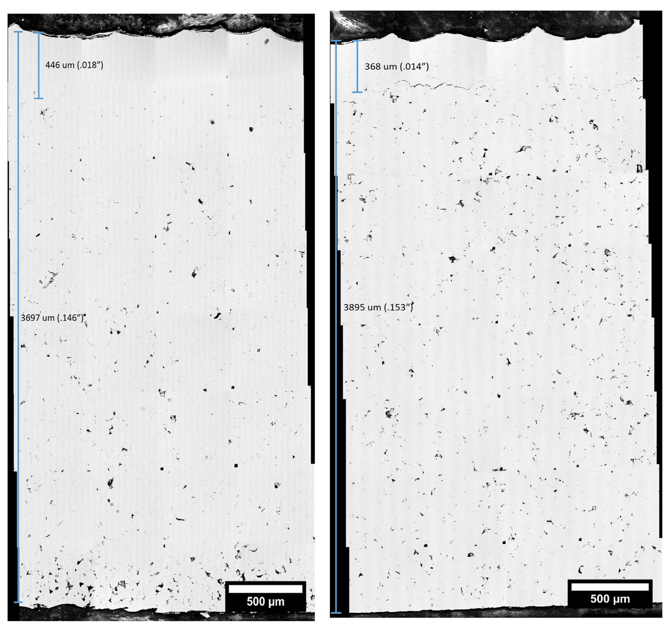


Diagram of the process and effect of shot peening [2]

Our subgoals are:

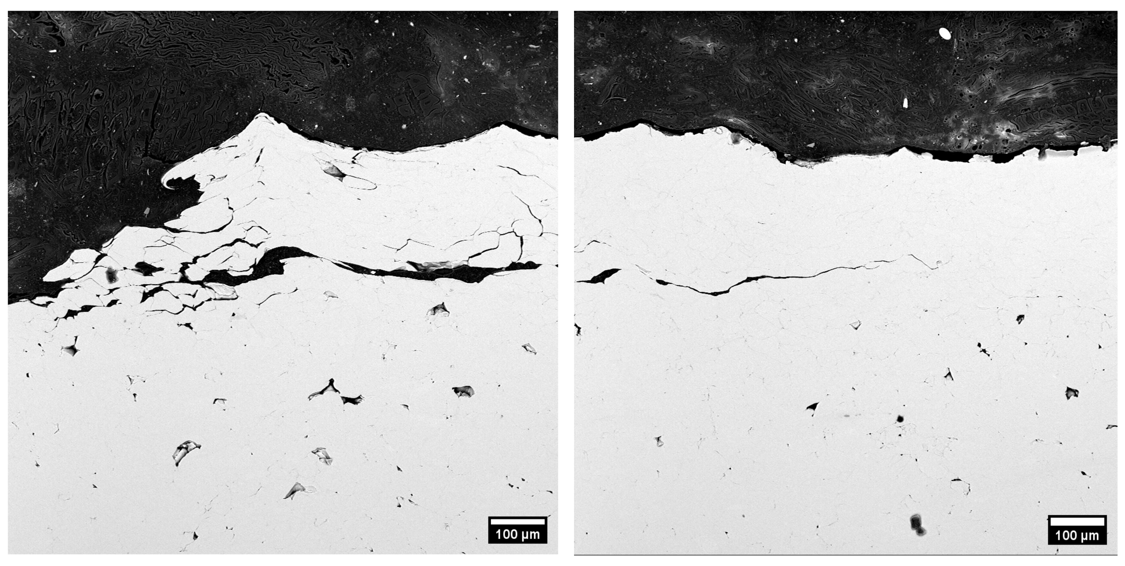
- Utilize shot peening to densify the nitrogen cold sprayed Al6061
- Understand how the microstructure and mechanical properties are affected by shot peening
- Use SEM to visually demonstrate changes in microstructure, specifically density and porosity

Image Analysis



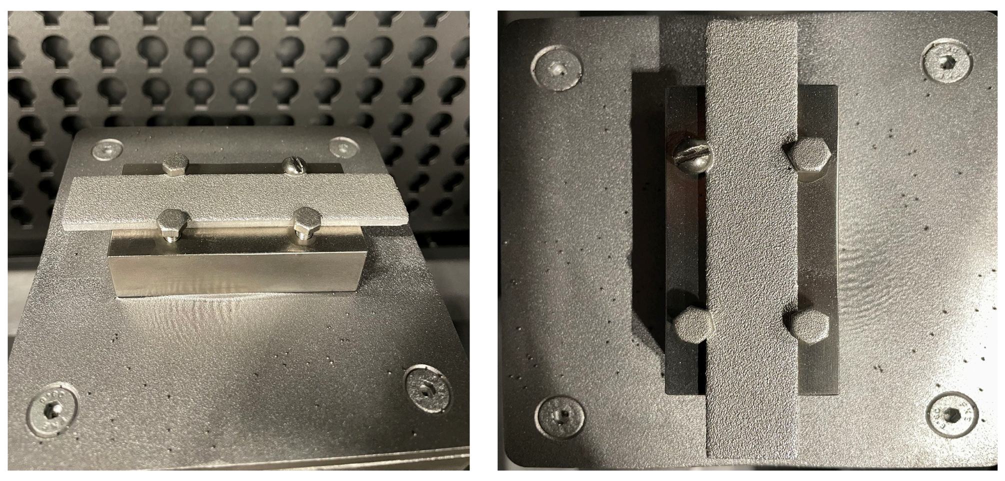
Post-peen image analysis showed 2 bar, 30 seconds (left) to have the largest densification depth, and 3 bar, 10 seconds started to show signs of cracking. The cracking in 3 bar peening may be an indication of "over-peening"

Sample Number	Peening Parameter	Densification Depth (μm)	Densification Depth (in.)
2	1 bar, 10 seconds	236	.009
4	1 bar, 20 seconds	306	.012
6	2 bar, 10 seconds	292	.011
8	2 bar, 30 seconds	446	.018
10	3 bar, 10 seconds	368	.014
12	3 bar, 30 seconds	428	.017
14	Control	-	-



SEM imaging showing deformation of the 3 bar, 10 second sample. Deformation and cracking was also found in the 2 bar samples. The cracks and surface deformation display the potential destructive effects of shot peening that may be avoidable with the right peen parameters

Shot Peening

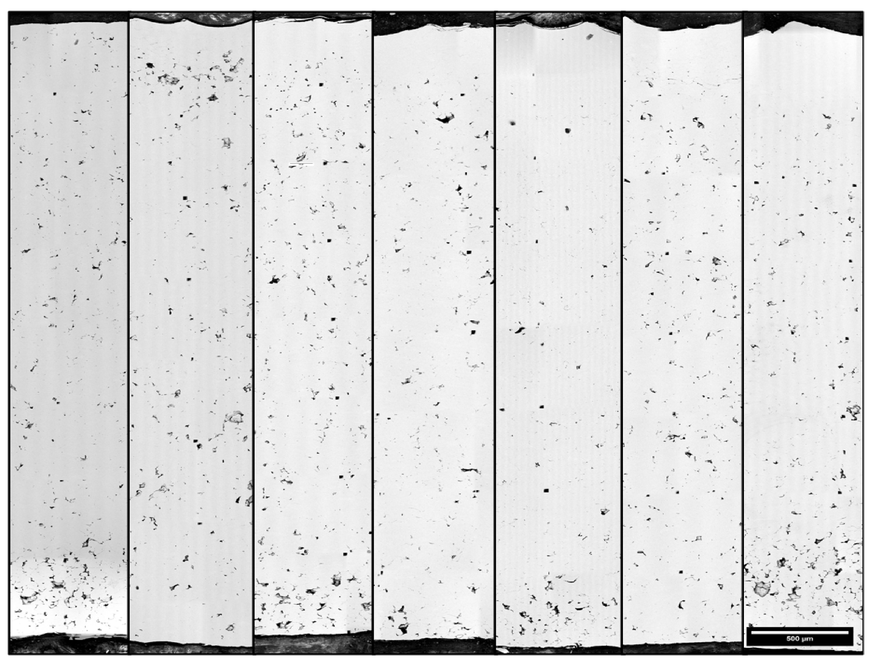


Sample loading into the Sentenso machine

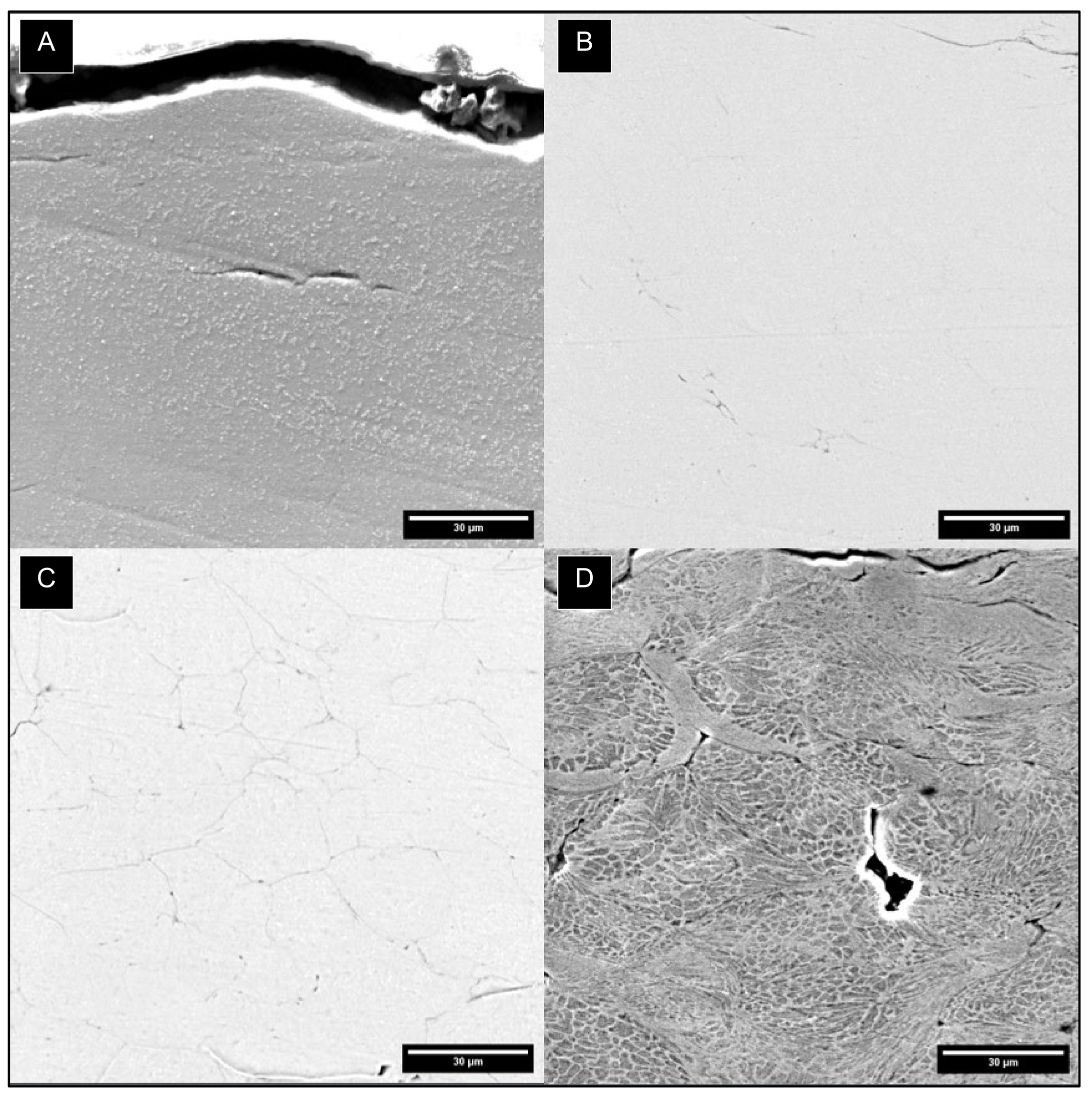
- Shot peening used for densification of cold spray
- Multiple parameters were used to analyze the penetration depth of the shot peening
- Two samples were taken at each parameter, one used for tensile testing and the other used for characterization

Sample	Before Weight (g)	Length (mm)	Width (mm)	Height (mm)	Peening Parameter	After Weight (g)
1	19.76	104.00	19.00	3.84	1 bar, 10 seconds	19.71
2	19.84	103.94	18.95	3.87	1 bar, 10 seconds	19.84
3	20.05	104.00	19.05	3.95	1 bar, 30 seconds	20.00
4	20.05	104.10	19.00	3.92	1 bar, 30 seconds	20.00
5	20.00	104.00	19.00	4.00	2 bar, 10 seconds	19.94
6	19.50	104.00	19.00	3.85	2 bar, 10 seconds	19.54
7	20.00	104.00	19.00	3.90	2 bar, 30 seconds	20.00
8	19.65	104.00	19.00	3.90	2 bar, 30 seconds	19.63
9	19.93	104.00	19.10	3.90	3 bar, 10 seconds	19.82
10	20.00	104.00	19.00	3.90	3 bar, 10 seconds	19.82
11	20.00	104.00	19.00	4.00	3 bar, 30 seconds	19.88
12	20.00	104.00	19.00	3.90	3 bar, 30 seconds	18.60

Metallography



SEM imaging of Nitrogen Cold Spray Al6061 after shot-peening. From left to right: Control Sample, Sample 2, Sample 4, Sample 6, Sample 8, Sample 10, Sample 12

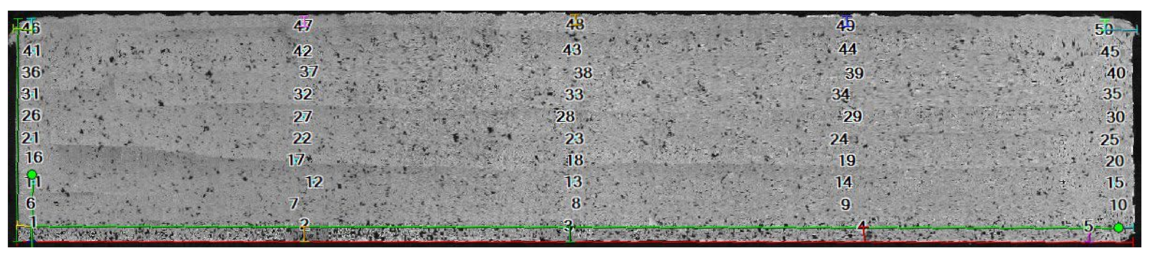


SEM images of shot-peened cross-section. Image A represents sample 6. Image B represents sample 8. Image C represents sample 10. Image D represents sample 12, which has been etched

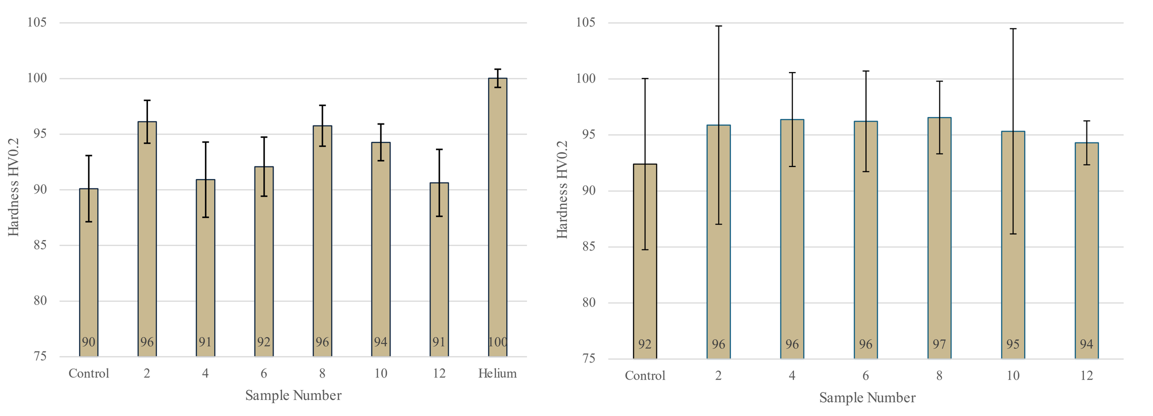
Hardness

Vickers Hardness:

- Samples were indented 50 times in a 10x5 grid across the entire cross section to investigate if any gradients were present in the hardness from the surface to the substrate
- All testing was done using a load of 200 gf and a dwell time of 15 seconds and followed the requirement for indent spacing outlined in ASTM E384 [3]

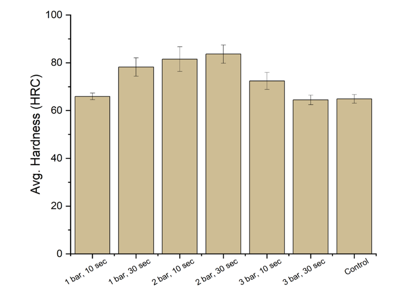


An Example of the grid layout used on Sample 4, the top of the image is the peened surface

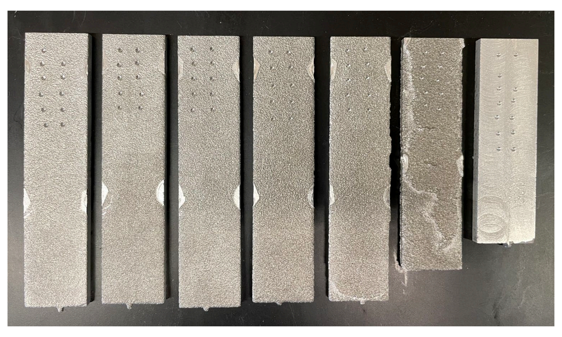


Resulting hardness values graphed with 95% confidence intervals. In Graph A all hardness values from the grid were averaged together to create a "bulk" hardness value compared to the value of a helium-sprayed sample. In Graph B hardness values from only the row closest to the peened surface were averaged to create a value for the "densified zone".

Rockwell Hardness:



Average hardness (HRC) of post shot peen nitrogen surface



Nitrogen Cold Sprayed samples with Rockwell Hardness indents on post-peen surface

Conclusion & Recommendations

Conclusion:
Based on our observations, using shot peening to densify nitrogen cold-sprayed 6061 Aluminum has the potential for industry application. Shot-peening influences the microstructure by densifying the aluminum in a thin layer at the surface. However, the samples shot-peened at 2 bar for 30 seconds and above experienced increasing particle delamination. The sample shot-peened at 3 bar for 30 seconds began to experience separation of cold spray layers.

Recommendations:
Given that the depth of densification due to shot peening only reached about 450 μm, it might be worth looking into the feasibility of shot peening by layer (cold spray, shot peen, cold spray...). If future research is going to be conducted, we recommend determining the "best" shot peen pressure or time and keeping it constant while varying the other parameter. For example, keep 2 bar pressure the same and change the peen time by a specified interval and observe the effect of peen time versus depth of densification. Using different shot media, material and size, may also be worth looking into, as peen media may affect densification.

Acknowledgments

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[1] Karthikeyan, J. & Industries, & Inc,. Development of Oxidation Resistant Coatings on GRCop-84 Substrates by Cold Spray Process.
[2] Jibin Boban, P M Abhilash, Afzaal Ahmed, M Azizur Rahman, 10.11 - An overview on post-processing of metal additive manufactured components, Comprehensive Materials Processing (Second Edition), Elsevier, 2024.
[3] ASTM International. (2022). *E384-22, Standard Test Method for Knoop and Vickers Hardness of Materials.* https://doi.org/10.1520/E0384-22