Characterization of Fundamental Building Blocks for Cold Spray Additive Manufacturing

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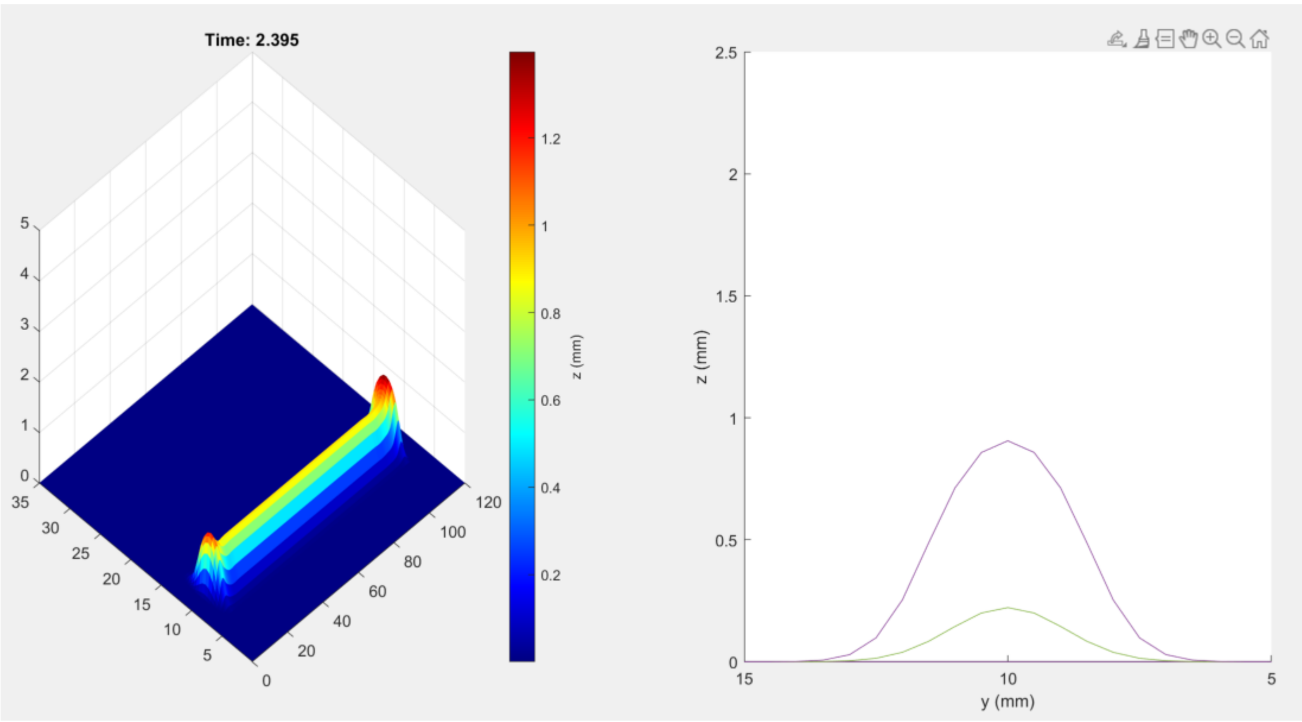
Goal

- Create high volume additive cold-spray forms with robotic planning and control
- Derive triangular tessellation model [1] for formation of fundamental building blocks (FBB)

Formulation

MATLAB Cold Spray Deposition Modeling

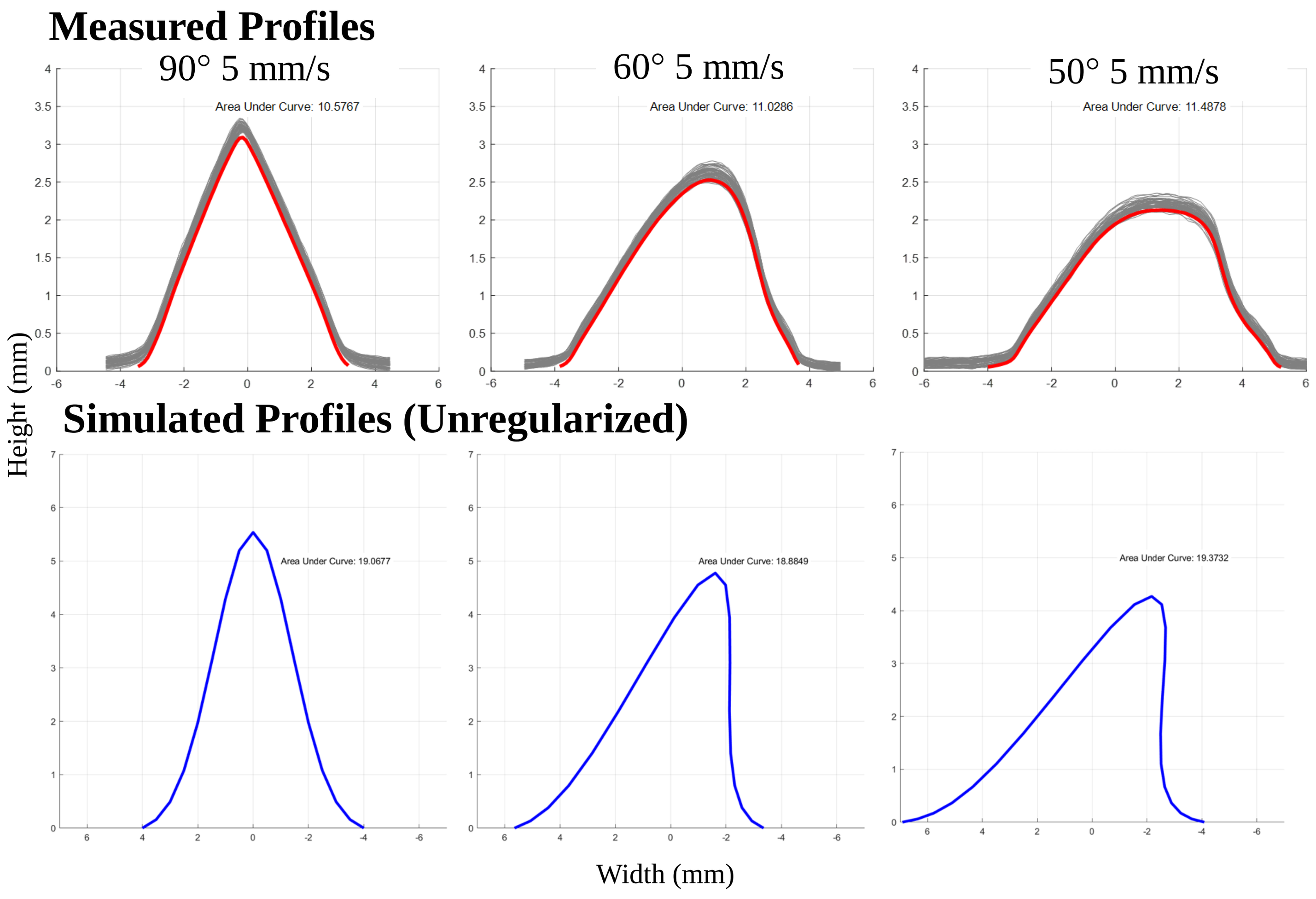


- Considers spray angle, mass flux, and nozzle traverse speed to generate 3D deposition profiles and cross sections for raster paths
- Models discrete depositions as bivariate Gaussian Distribution
- Allows for the variation of standoff distance, time steps, spray angles, and nozzle speed in creation of simulated profiles
- Assumes continuous material flow and unchanging mass flux per limitations of the spray system architecture
- Deposition efficiency functions are taken from [2] and incorporate nozzle standoff, traverse speed, and normal angle to substrate

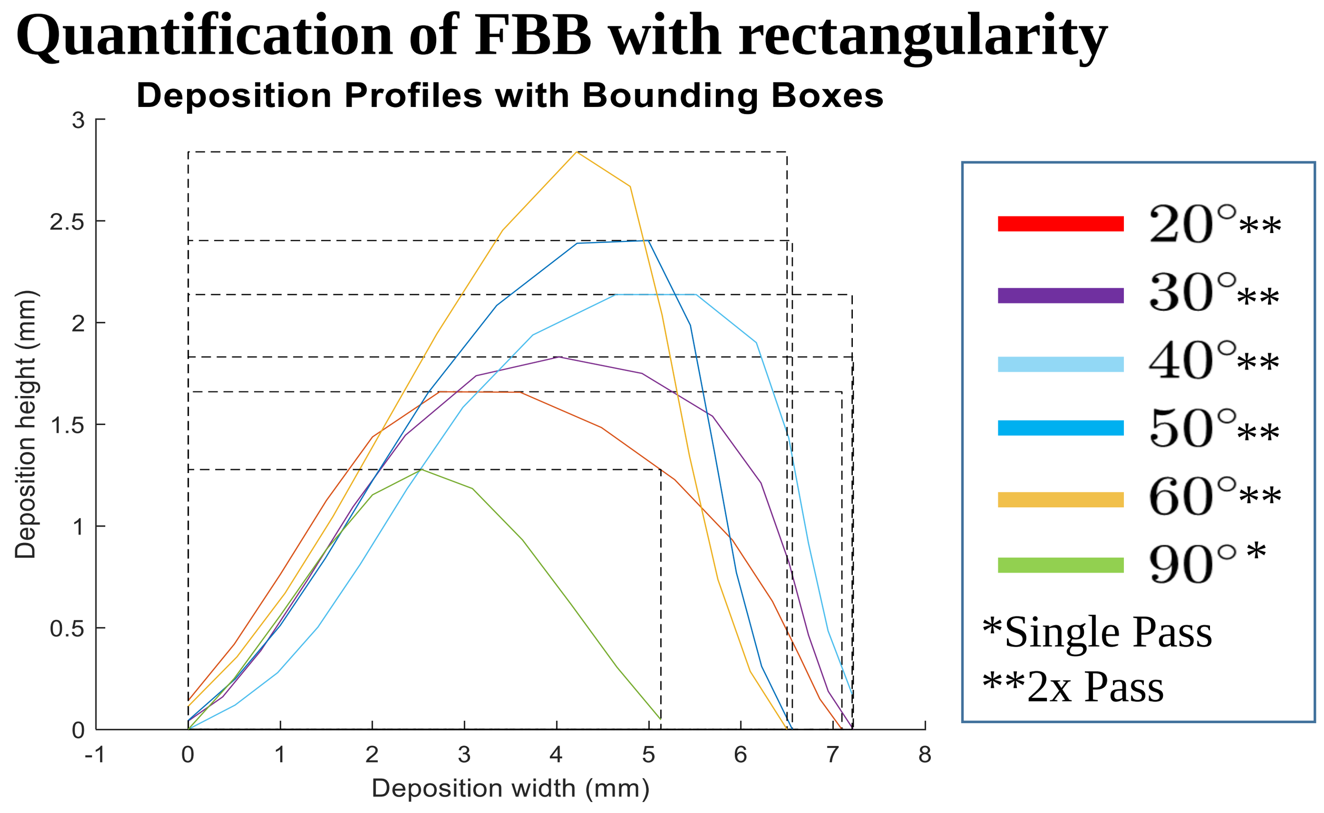
$$\phi = \eta\zeta(\theta)\zeta(s)\int_0^T\left(\int \frac{A\zeta(v)}{\sigma\sqrt{2\pi}} e^{-\left(\frac{(x-\mu_x)^2}{2\sigma^2}+\frac{(y-\mu_y)^2}{2\sigma^2}\right)} dxdy\right)dt)$$

- Model was scaled using constant coefficient to properly match deposition height values from previously run experiments (η)
- Simulations were conducted to explore effects of changing angle with respect to most promising rectangular shape formation

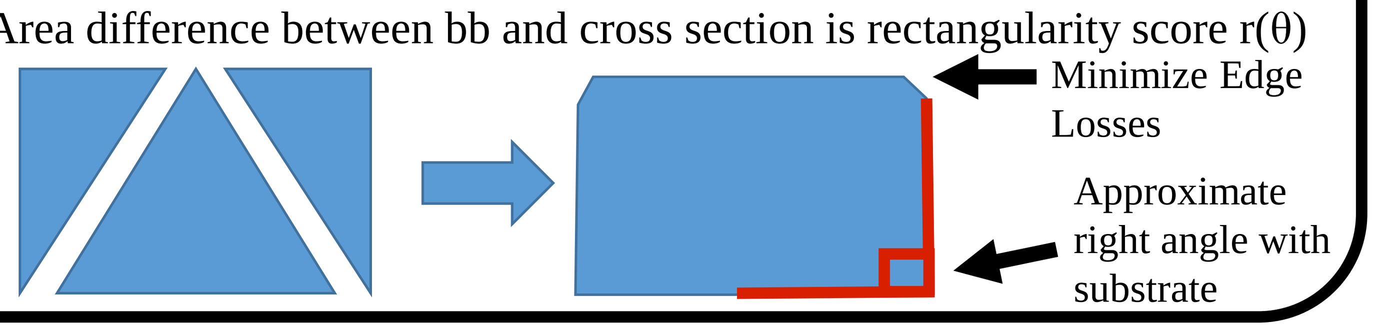
Measured Profiles



Quantification of FBB with rectangularity



- Define fundamental building block as a rectangular prism with minimal edge losses and vertical sides perpendicular to the base
- Select minimal bounding box (bb), encapsulating deposition such that:
  - $\varphi \geq 0.1$ mm (minimally measurable deposition height)
- Area difference between bb and cross section is rectangularity score r(θ)



Trials

Most promising candidate trials from simulation

- Shape building procedures consist of raster paths with nozzle traversing x axis at $\theta\epsilon\{90,60,50,40\}°$
- Traverse speed (P#-V) is mm/s, P#-θ is in degrees
- Attempt to build right-angle triangular form using minimal passes
- Nozzle controlled via 7 DoF Fanuc® M-710iC industrial robot

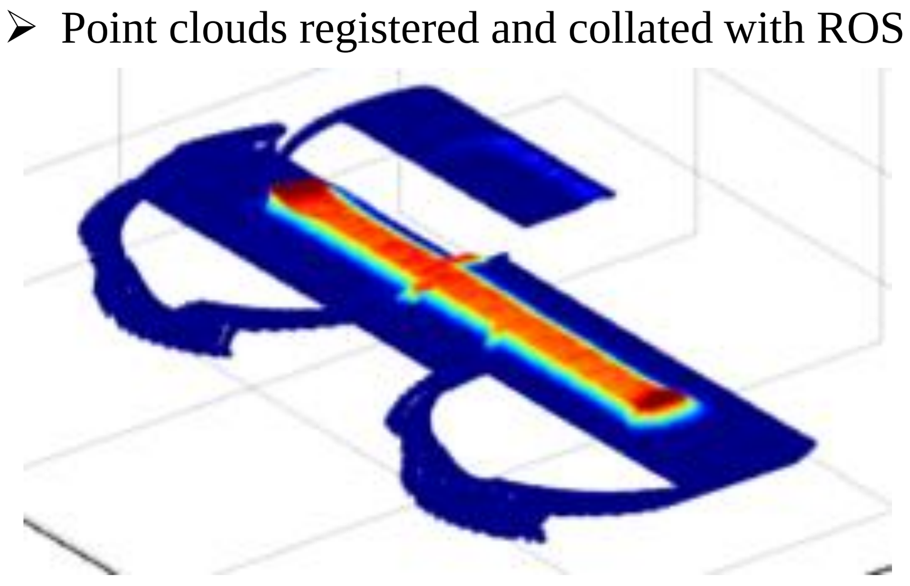
P1-V	P1-θ	P2-V	P2-θ	P3-V	P3-θ	P4-V	P4-θ
5	90	5	60	5	60	-	-
5	90	5	90	5	60	-	-
5	90	5	90	5	60	5	60
5	90	5	60	5	60	10	60
5	90	5	60	5	60	15	60

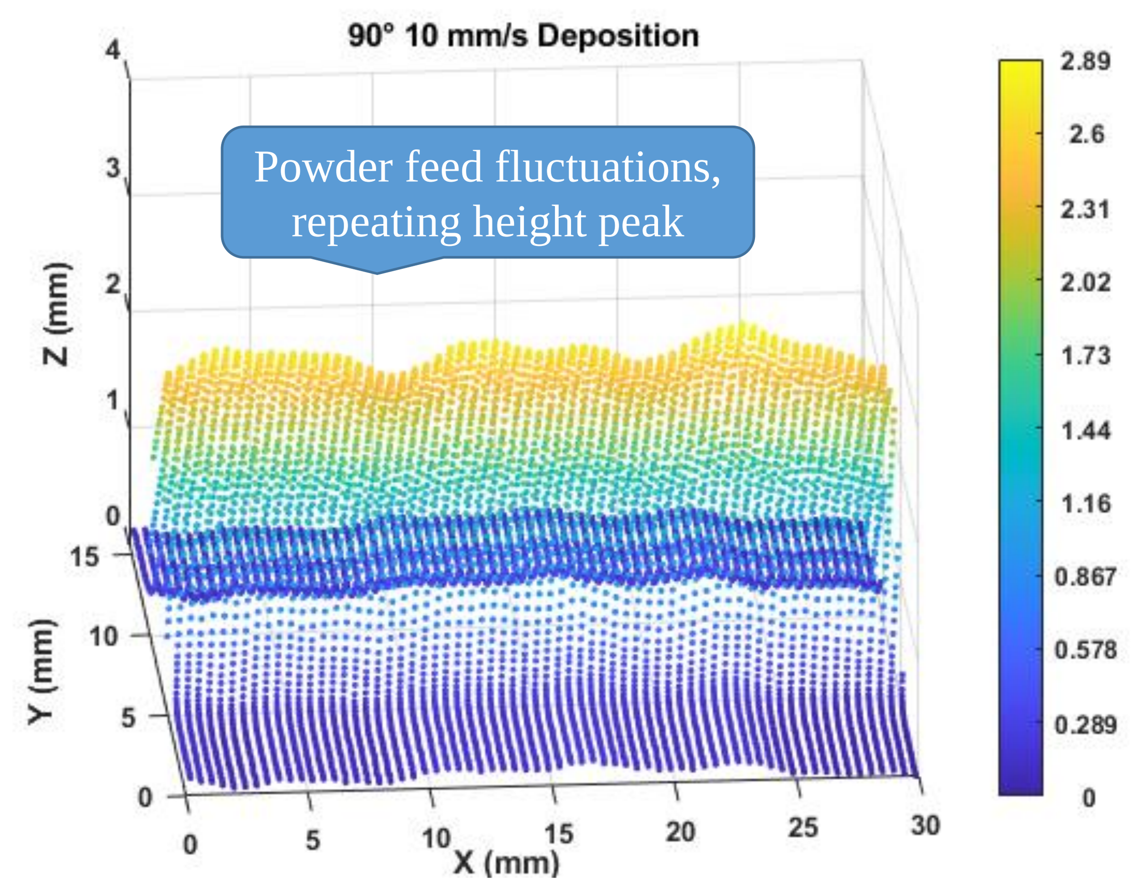
Parameter	Value
Spraying System	VRC® Gen III
Nozzle	VRC® Nozzle 0058
Powder Material	Cu-159-3
Gas	Nitrogen
Pressure	870 psi
Substrate	Aluminum
Powder Feed Rate	33.56 g/min
Standoff	25 mm

Results

Measurement of depositions with in-situ profilometry system

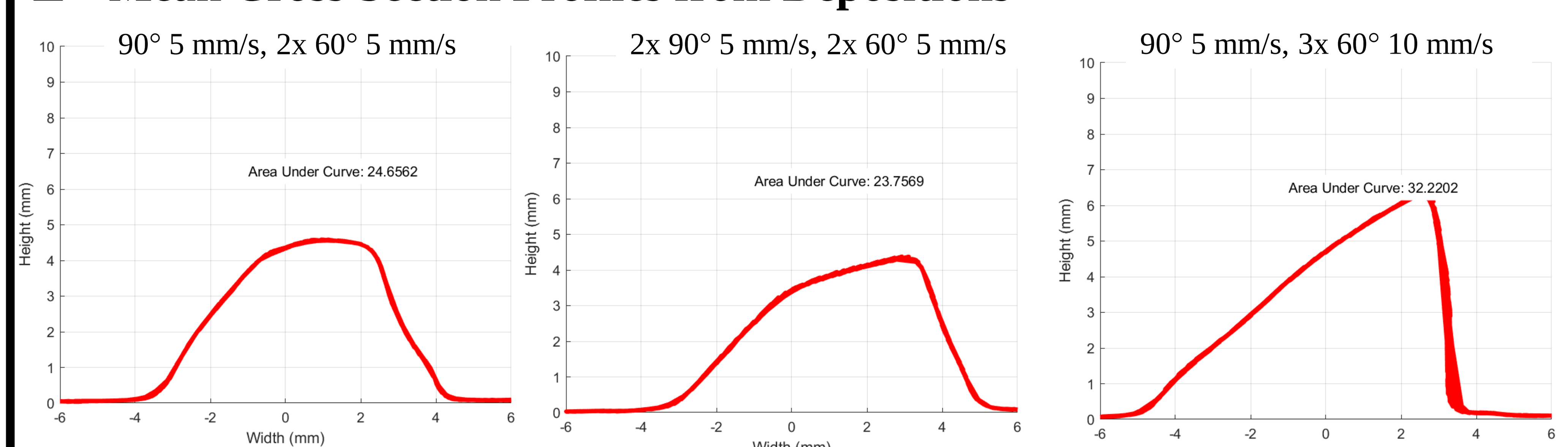
- Laser profilometer rotates to follow the spray nozzle ensuring new depositions are always acquired by the scanner
- Resolution < 0.1 mm, revealing fine perturbation by powder feed fluctuations
- Point clouds registered and collated with ROS

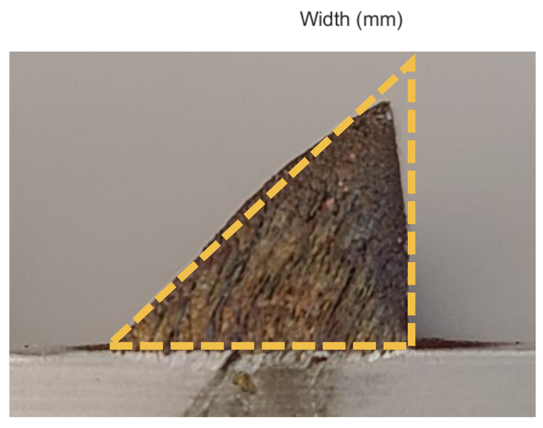




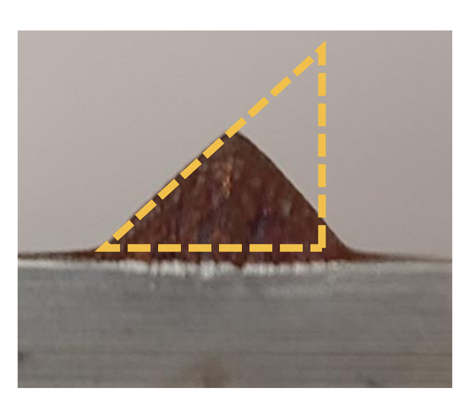
Profilometry enables real-time analysis of cross sections and assembly of point cloud slices into 3D model

Mean Cross Section Profiles from Depositions





Macro Image, Best Match Triangle
90° 5 mm/s, 3x 60° 10 mm/s
$\frac{Triangle_{fit}}{Triangle_{ideal}} = 0.94$



Macro Image, Single Pass 90° 5 mm/s
$\frac{Triangle_{fit}}{Triagnle_{ideal}} = 0.62$

Conclusions

- Cold Spray can be used to create simple, prismatic shapes as precursor finite elements to larger 3D models
- Varying the spray angle normal to previously deposited surfaces and nozzle traverse speed is sufficient to build shapes with sharp angles
- Future Work: Converting 3D CAD model slicing software to decompose layer slices into raster plans incorporating FBB approach

Three raster passes is sufficient to create regular triangular forms; rectangles are a simple extension

References

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