

Data-Efficient Neural Network for Track Profile Modelling in Cold Spray Additive Manufacturing

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The Design Matrix of Experimental Process Parameters for the Training Dataset

Table S1 shows the design matrix of experimental process parameters in the training dataset for data-driven models presented in the main text of this study. The dataset was defined by input parameter selection and prepared using a full factorial approach, requiring the fabrication of 36 sample single-track profiles with a mixture of four-level spray angle (45°, 60°, 75°, 90°), three-level traverse speed (25 mm/s, 100 mm/s and 200 mm/s) and three-level standoff distances (30 mm, 40 mm and 50 mm) [1]. The run order indicates the order of fabrication, which was randomly selected as discussed in the main text.

Table S1. Experimental process parameters that were used to fabricate each single-track profile in cold spray additive manufacturing for the training dataset in this study.

Sample ID	Run Order	Spray Angle (°)	Traverse Speed (mm/s)	Standoff Distance (mm)
1	6	45	25	30
2	48	60	25	30
3	1	75	25	30
4	35	90	25	30
5	38	45	100	30
6	40	60	100	30
7	4	75	100	30
8	24	90	100	30
9	18	45	200	30
10	37	60	200	30
11	28	75	200	30
12	44	90	200	30
13	13	45	25	40
14	19	60	25	40
15	12	75	25	40
16	10	90	25	40
17	41	45	100	40
18	33	60	100	40
19	32	75	100	40
20	11	90	100	40
21	39	45	200	40
22	34	60	200	40
23	21	75	200	40
24	31	90	200	40
25	25	45	25	50

26	3	60	25	50
27	15	75	25	50
28	8	90	25	50
29	14	45	100	50
30	16	60	100	50
31	27	75	100	50
32	2	90	100	50
33	43	45	200	50
34	46	60	200	50
35	30	75	200	50
36	29	90	200	50

The Design Matrix of Experimental Process Parameters for the Testing Dataset

Table S2 shows the design matrix of experimental process parameters in the testing dataset for data-driven models presented in the main body. The dataset was defined by the 75–25 data division rule, requiring the fabrication of 12 sample single-track profiles with randomly selected process parameters values between their minimum and maximum: spray angle (45° and 90°), traverse speed (25 mm/s and 200 mm/s) and standoff distance (30 mm and 50 mm) with the aid of MATLAB version R2018a [1].

Table S2. Experimental process parameters that were used to fabricate each single-track profile in cold spray additive manufacturing for the testing dataset in this study.

Sample ID	Run Order	Spray Angle (°)	Traverse Speed (mm/s)	Standoff Distance (mm)
37	20	86	75	45
38	42	79	92	41
39	22	48	34	41
40	7	80	188	33
41	36	71	107	30
42	23	60	53	46
43	17	59	117	33
44	26	72	71	43
45	5	76	156	39
46	9	49	65	48
47	45	52	170	41
48	47	90	39	39

The Coefficients of Mathematical Gaussian Function Models for Sample S1–S36 Profiles

In this study, a mathematical Gaussian function model framework, proposed by Chen et al. [2], was adopted as an example of the existing model at hand that acted as domain knowledge to leverage into the development and learning of the proposed data-efficient ANN model. As described in the main body, the coefficients of the mathematical Gaussian function models, σ and A , were found in Equation 1 through the curve-fitting method in MATLAB version R2018a. These optimal coefficients are summarised in Table S3, resulting in the best fit of Equation 1 to each single-track profile in the training dataset.

$$y = \frac{A}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x}{\sigma}\right)^2} \quad (1)$$

Table S3. The list of curve-fitted coefficients of mathematical Gaussian function models for Sample S1–S36 single-track profiles that were used for the training dataset for data-driven models.

Sample ID	σ	A	Sample ID	σ	A
1	1.174	4.922	19	1.237	1.241
2	1.266	4.838	20	1.255	1.148
3	1.245	4.976	21	0.8697	0.3488
4	1.252	4.926	22	1.082	0.5323
5	1.008	0.9787	23	1.075	0.4984
6	1.181	1.154	24	1.174	0.5355
7	1.156	1.185	25	1.234	4.485
8	1.227	1.241	26	1.336	4.707
9	0.9051	0.3811	27	1.365	4.772
10	0.9122	0.4710	28	1.379	5.019
11	0.9829	0.4706	29	1.096	1.036
12	1.025	0.4857	30	1.146	1.062
13	1.213	4.508	31	1.287	1.142
14	1.344	5.052	32	1.273	1.181
15	1.287	4.945	33	0.09970	0.4374
16	1.344	5.169	34	1.082	0.4990
17	1.039	0.9953	35	1.216	0.5390
18	1.189	1.187	36	1.216	0.5579

The Coefficients of Mathematical Gaussian Function Models for Sample S37–S48 Profiles

Table S4 summarises the optimal coefficients of the mathematical Gaussian function model for the single-track profiles in the testing dataset.

Table S4. The list of curve-fitted coefficients of mathematical Gaussian function models for Sample S37–S48 single-track profiles that were used for the testing dataset for data-driven models.

Sample ID	σ	A	Sample ID	σ	A
37	1.414	1.894	43	1.152	1.066
38	1.414	1.213	44	1.329	1.754
39	1.301	3.699	45	1.081	0.6460
40	1.082	0.5614	46	1.237	1.809
41	1.169	1.062	47	1.110	0.5315
42	1.294	2.196	48	1.474	3.644

Sample Single-Track Profiles S1–S36 in the Training Dataset

Figure S1–S3 show the experimental sample profile of each single-track at the experimental conditions specified in Table S1 and as prepared following the procedures detailed in Section 2.1 in the main text.

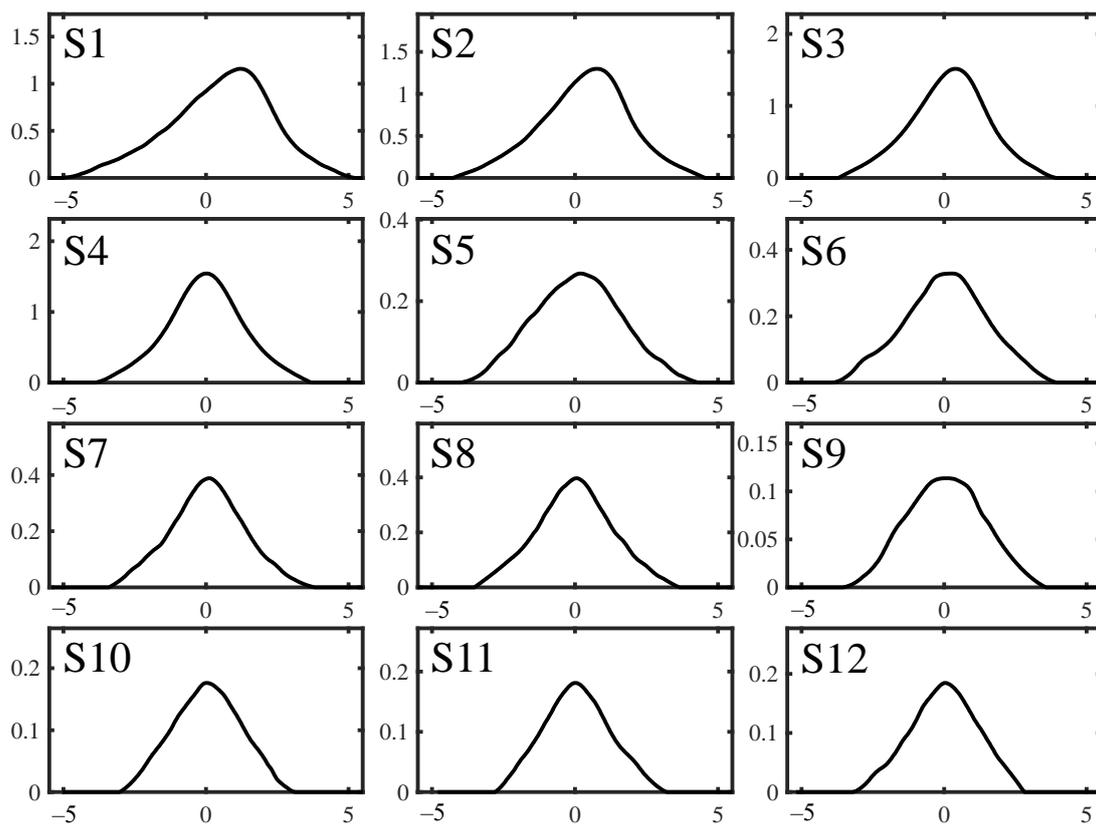


Figure S1. The measured track profiles of Samples 1–12. The vertical axis is Deposit height (mm), while the horizontal axis is the Horizontal location on substrate (mm).

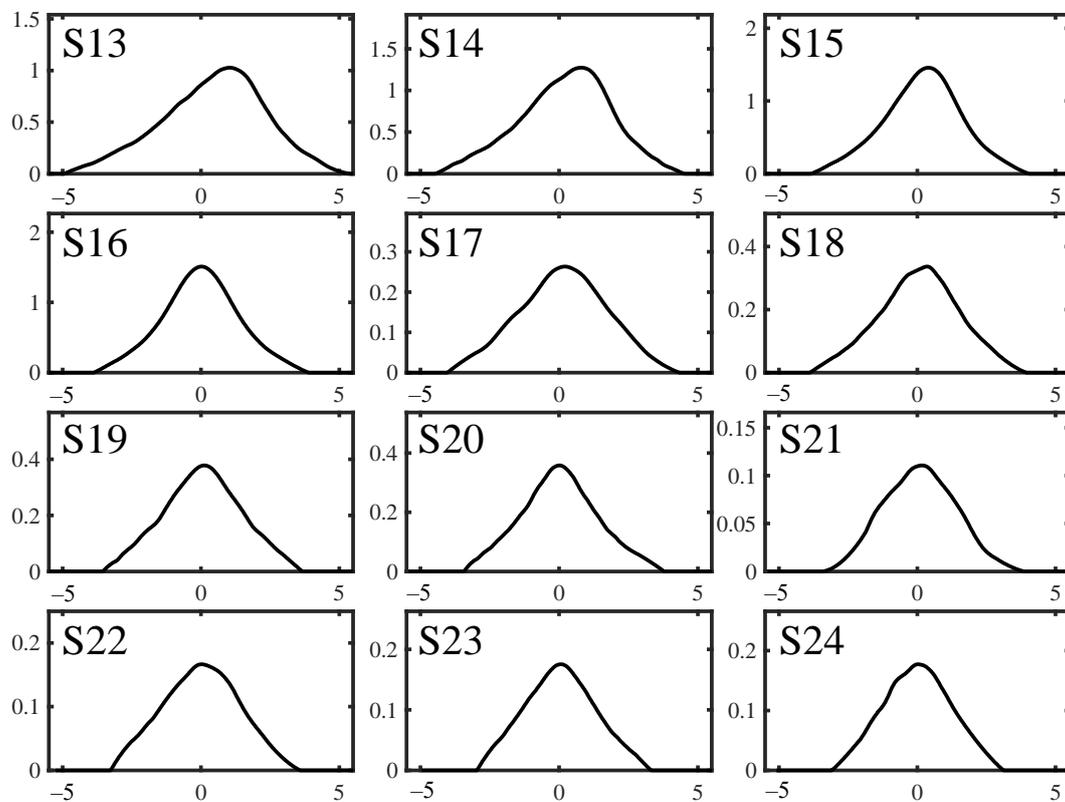


Figure S2. The measured track profiles of Samples 13–24. The vertical axis is Deposit height (mm), while the horizontal axis is the Horizontal location on substrate (mm).

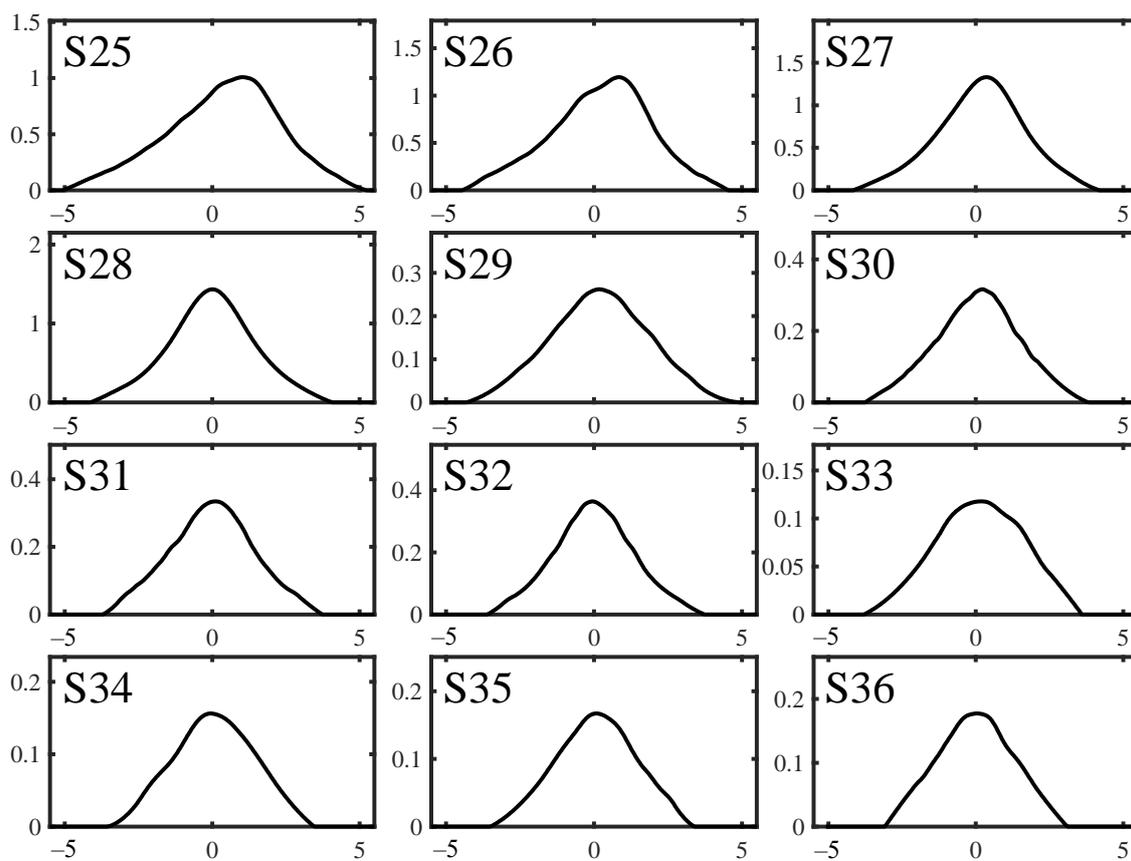


Figure S3. The measured track profiles of Samples 25–36. The vertical axis is Deposit height (mm), while the horizontal axis is the Horizontal location on substrate (mm).

Sample Single-Track Profiles S37–S48 in the Testing Dataset

Figure S4 shows the experimental sample profile of each single-track at the experimental conditions specified in Table S2 (black) and as prepared following the procedures detailed in Section 2.1 in the main text, plotted along with the corresponding prediction results of: the curve-fitted Gaussian function models with the coefficients listed in Table S4 (blue), the purely data-driven ANN model (green) and the proposed data-efficient ANN model with Technique 1 and 2 (red).

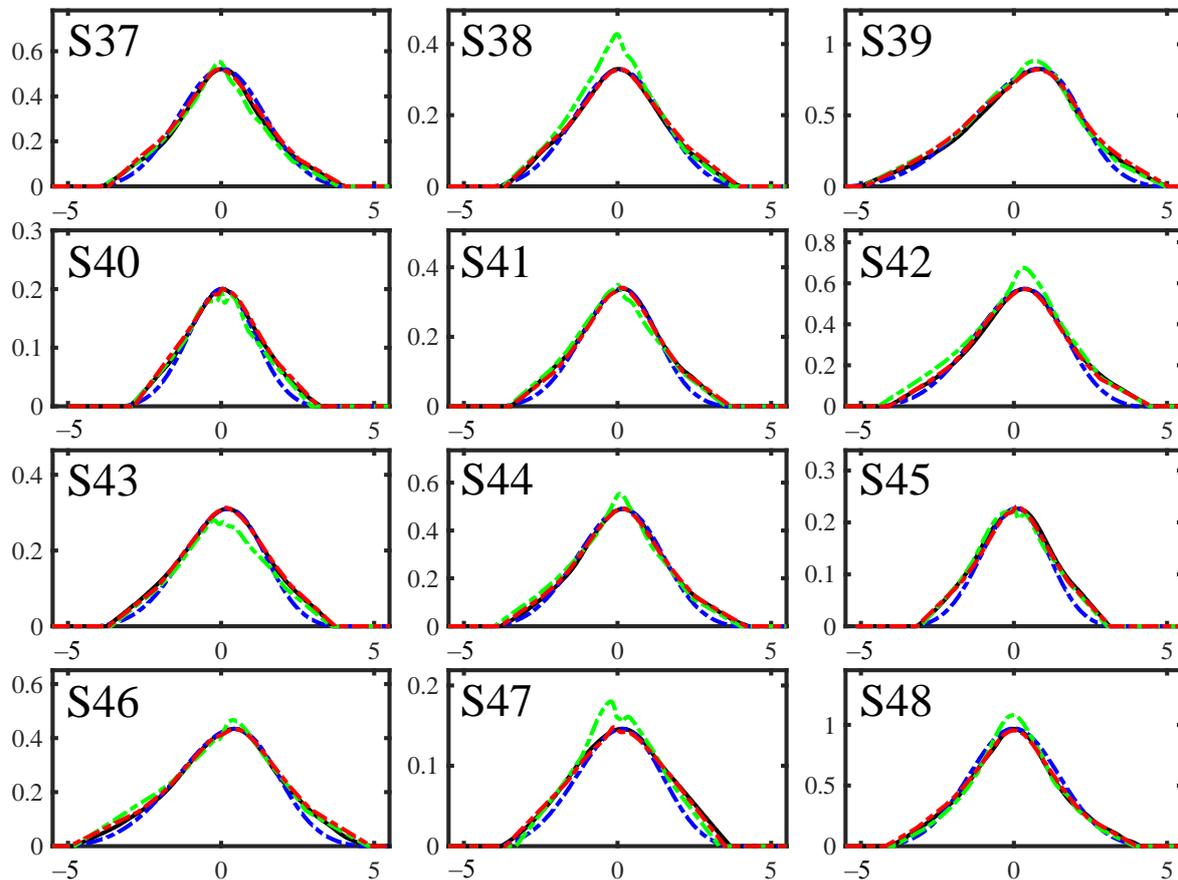


Figure S4. The measured track profiles of Samples 37–48 with the corresponding prediction results. The vertical axis is Deposit height (mm), while the horizontal axis is the Horizontal location on substrate (mm).

References

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2. Chen, C.; Xie, Y.; Verdy, C.; Liao, H.; Deng, S. Modelling of coating thickness distribution and its application in offline programming software. *Surf. Coat. Technol.* 2017, 318, 315–325.



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