

Supplementary Information

A sensitivity workflow for interlayer dwell-time screening in sparse open WAAM data

Journal: Progress in Additive Manufacturing

All primary data are public: AIMEN / Fraunhofer SCAI / EBBAMS, Wire arc Additive Manufacturing Open Repository, Zenodo, doi:10.5281/zenodo.17608626, CC BY 4.0, released within EU PIONEER (GA 101091449). No new experimental data were generated.

Paths quoted in these tables are relative to the root of that dataset. Where a released summary workbook and a primary certificate or report disagree, the primary record is used.

The CSV files accompanying this PDF are the machine-readable, submitted-precision versions; the analysis script regenerates fitting outputs at higher precision. Wide tables are divided into labelled column groups below; repeated identifier columns preserve the row mapping across parts.

Table S1 - Part A

Mapping of every value used in the manuscript to its primary source file.

Values and manuscript use

specimen	alloy	quantity	value_used	manuscript_location
All	both	nominal CAD wall length (mm)	185	Section 2.1, Table S13
All	both	wire feed rate (m/min)	4	Section 2.1, Table S13
All	both	nominal wire diameter (mm)	1.2	Section 2.1, Table S13
All	both	conflicting travel-speed fields (mm/s)	10; 50	Section 2.1, Table S13
M1_0	ER70S-6	wall height (mm)	39.8	Table 1
M1_0	ER70S-6	average layer height (mm)	1.24375	Table 1, Fig. 1
M1_0	ER70S-6	RT penetrated thickness (mm)	9.0	Table 1, Section 4.1
M1_0	ER70S-6	RT indication category	2, 3	Tables 1 and 4, Section 4.3
M1_0	ER70S-6	RT result	Rejected	Tables 1 and 4, Section 4.3
M1_0	ER70S-6	macrograph shape / LoF status	short, bulged, slumped; LoF not classified	Tables 1 and 4; Fig. 2; Sec. 4.3
M1_0	ER70S-6	pooled hardness mean (HV0.3)	191.7	not tabulated (Section 4.4)
M1_0	ER70S-6	cap-region hardness mean (HV0.3)	177.8	Tables 4 and 5, Fig. 3, Section 4.4
M1_30	ER70S-6	wall height (mm)	47.6	Table 1
M1_30	ER70S-6	average layer height (mm)	1.48750	Table 1, Fig. 1
M1_30	ER70S-6	RT penetrated thickness (mm)	7.0	Table 1, Section 4.1
M1_30	ER70S-6	RT indication category	none	Tables 1 and 4, Section 4.3
M1_30	ER70S-6	RT result	Accepted	Tables 1 and 4, Section 4.3
M1_30	ER70S-6	macrograph shape / LoF status	tall, straight; LoF not classified	Tables 1 and 4; Fig. 2; Sec. 4.3
M1_30	ER70S-6	pooled hardness mean (HV0.3)	183.0	not tabulated (Section 4.4)
M1_30	ER70S-6	cap-region hardness mean (HV0.3)	176.0	Tables 4 and 5, Fig. 3, Section 4.4
M1_60	ER70S-6	wall height (mm)	49.0	Table 1
M1_60	ER70S-6	average layer height (mm)	1.53125	Table 1, Fig. 1
M1_60	ER70S-6	RT penetrated thickness (mm)	6.5	Table 1, Section 4.1
M1_60	ER70S-6	RT indication category	2	Tables 1 and 4, Section 4.3
M1_60	ER70S-6	RT result	Accepted	Tables 1 and 4, Section 4.3
M1_60	ER70S-6	macrograph shape / LoF status	tall, straight; LoF not classified	Tables 1 and 4; Fig. 2; Sec. 4.3
M1_60	ER70S-6	pooled hardness mean (HV0.3)	193.7	not tabulated (Section 4.4)
M1_60	ER70S-6	cap-region hardness mean (HV0.3)	175.4	Tables 4 and 5, Fig. 3, Section 4.4
M1_90	ER70S-6	wall height (mm)	49.2	Table 1
M1_90	ER70S-6	average layer height (mm)	1.53750	Table 1, Fig. 1
M1_90	ER70S-6	RT penetrated thickness (mm)	6.5	Table 1, Section 4.1

specimen	alloy	quantity	value_used	manuscript_location
M1_90	ER70S-6	RT indication category	2	Tables 1 and 4, Section 4.3
M1_90	ER70S-6	RT result	Accepted	Tables 1 and 4, Section 4.3
M1_90	ER70S-6	macrograph shape / LoF status	tall, straight; LoF not classified	Tables 1 and 4; Fig. 2; Sec. 4.3
M1_90	ER70S-6	pooled hardness mean (HV0.3)	194.1	not tabulated (Section 4.4)
M1_90	ER70S-6	cap-region hardness mean (HV0.3)	179.3	Tables 4 and 5, Fig. 3, Section 4.4
M1_120	ER70S-6	wall height (mm)	49.8	Table 1
M1_120	ER70S-6	average layer height (mm)	1.55625	Table 1, Fig. 1
M1_120	ER70S-6	RT penetrated thickness (mm)	6.5	Table 1, Section 4.1
M1_120	ER70S-6	RT indication category	2	Tables 1 and 4, Section 4.3
M1_120	ER70S-6	RT result	Accepted	Tables 1 and 4, Section 4.3
M1_120	ER70S-6	macrograph shape / LoF status	tall, straight; LoF not classified	Tables 1 and 4; Fig. 2; Sec. 4.3
M1_120	ER70S-6	pooled hardness mean (HV0.3)	195.8	not tabulated (Section 4.4)
M1_120	ER70S-6	cap-region hardness mean (HV0.3)	180.8	Tables 4 and 5, Fig. 3, Section 4.4
M1_240	ER70S-6	wall height (mm)	50.7	Table 1
M1_240	ER70S-6	average layer height (mm)	1.58438	Table 1, Fig. 1
M1_240	ER70S-6	RT penetrated thickness (mm)	6.5	Table 1, Section 4.1
M1_240	ER70S-6	RT indication category	2, 3	Tables 1 and 4, Section 4.3
M1_240	ER70S-6	RT result	Rejected	Tables 1 and 4, Section 4.3
M1_240	ER70S-6	macrograph shape / LoF status	tall, straight; late-layer instability; LoF not classified	Tables 1 and 4; Fig. 2; Sec. 4.3
M1_240	ER70S-6	pooled hardness mean (HV0.3)	202.5	not tabulated (Section 4.4)
M1_240	ER70S-6	cap-region hardness mean (HV0.3)	187.1	Tables 4 and 5, Fig. 3, Section 4.4
M2_0	ER110S-G	wall height (mm)	38.5	Table 1
M2_0	ER110S-G	average layer height (mm)	1.42593	Table 1, Fig. 1
M2_0	ER110S-G	RT penetrated thickness (mm)	7-9	Table 1, Section 4.1
M2_0	ER110S-G	RT indication category	none	Tables 1 and 4, Section 4.3
M2_0	ER110S-G	RT result	Accepted	Tables 1 and 4, Section 4.3
M2_0	ER110S-G	macrograph shape / LoF status	short, bulged, slumped; LoF not classified	Tables 1 and 4; Fig. 2; Sec. 4.3
M2_30	ER110S-G	wall height (mm)	44.7	Table 1
M2_30	ER110S-G	average layer height (mm)	1.65556	Table 1, Fig. 1
M2_30	ER110S-G	RT penetrated thickness (mm)	7-9	Table 1, Section 4.1
M2_30	ER110S-G	RT indication category	none	Tables 1 and 4, Section 4.3
M2_30	ER110S-G	RT result	Accepted	Tables 1 and 4, Section 4.3
M2_30	ER110S-G	macrograph shape / LoF status	tall, straight; LoF not classified	Tables 1 and 4; Fig. 2; Sec. 4.3
M2_60	ER110S-G	wall height (mm)	46.3	Table 1
M2_60	ER110S-G	average layer height (mm)	1.71481	Table 1, Fig. 1
M2_60	ER110S-G	RT penetrated thickness (mm)	7-9	Table 1, Section 4.1
M2_60	ER110S-G	RT indication category	none	Tables 1 and 4, Section 4.3
M2_60	ER110S-G	RT result	Accepted	Tables 1 and 4, Section 4.3
M2_60	ER110S-G	macrograph shape / LoF status	tall, straight; LoF not classified	Tables 1 and 4; Fig. 2; Sec. 4.3
M2_90	ER110S-G	wall height (mm)	46.0	Table 1
M2_90	ER110S-G	average layer height (mm)	1.70370	Table 1, Fig. 1
M2_90	ER110S-G	RT penetrated thickness (mm)	7-9	Table 1, Section 4.1
M2_90	ER110S-G	RT indication category	2	Tables 1 and 4, Section 4.3
M2_90	ER110S-G	RT result	Accepted	Tables 1 and 4, Section 4.3
M2_90	ER110S-G	macrograph shape / LoF status	tall, straight; LoF not classified	Tables 1 and 4; Fig. 2; Sec. 4.3
M2_120	ER110S-G	wall height (mm)	46.4	Table 1
M2_120	ER110S-G	average layer height (mm)	1.71852	Table 1, Fig. 1
M2_120	ER110S-G	RT penetrated thickness (mm)	7-9	Table 1, Section 4.1
M2_120	ER110S-G	RT indication category	none	Tables 1 and 4, Section 4.3
M2_120	ER110S-G	RT result	Accepted	Tables 1 and 4, Section 4.3
M2_120	ER110S-G	macrograph shape / LoF status	tall, straight; LoF not classified	Tables 1 and 4; Fig. 2; Sec. 4.3
M2_240	ER110S-G	wall height (mm)	46.9	Table 1
M2_240	ER110S-G	average layer height (mm)	1.73704	Table 1, Fig. 1
M2_240	ER110S-G	RT penetrated thickness (mm)	7-9	Table 1, Section 4.1
M2_240	ER110S-G	RT indication category	2	Tables 1 and 4, Section 4.3

specimen	alloy	quantity	value_used	manuscript_location
M2_240	ER110S-G	RT result	Accepted	Tables 1 and 4, Section 4.3
M2_240	ER110S-G	macrograph shape / LoF status	tall, straight; LoF not classified	Tables 1 and 4; Fig. 2; Sec. 4.3

Table S1 - Part B

Primary-record provenance and source notes

specimen	alloy	primary_source_path	located_in	note
All	both	1. INITIAL REQUIREMENTS/CAD/WALLSpec.STEP	wall solid dimensions	nominal design length; the executed robot path is not released
All	both	1. INITIAL REQUIREMENTS/MANUFACTURING PROCEDURE/WALLSpecimensAML.xlsx	sheet WALL_Specimens, Wire Feed Rate column	constant in the released manufacturing table
All	both	1. INITIAL REQUIREMENTS/MANUFACTURING PROCEDURE/WALLSpecimensAML.xlsx	sheet WALL_Specimens, Wire width column	used as circular feedstock diameter in the coarse volume balance
All	both	1. INITIAL REQUIREMENTS/MANUFACTURING PROCEDURE/WALLSpecimensAML.xlsx	sheet WALL_Specimens, Velocity and Travel Velocity columns	the two fields conflict; the coarse balance disfavors 50 mm/s but does not identify a unique speed
M1_0	ER70S-6	5. METROLOGY/WALLSpecimensMeasurements.xlsx	sheet WALL_Specimens, row M1_0	column labelled "Manually measurements"; quoted to 0.1 mm
M1_0	ER70S-6	5. METROLOGY/WALLSpecimensMeasurements.xlsx	sheet WALL_Specimens, row M1_0	computed in the released sheet as wall height / 32 layers; derived quantity
M1_0	ER70S-6	6. QUALITY_ASSURANCE/M1/RT_M1_0_M1_30.pdf	certificate, penetrated-thickness field	exposure-planning field, quoted to 0.5 mm; ER110S-G given only as a range
M1_0	ER70S-6	6. QUALITY_ASSURANCE/M1/RT_M1_0_M1_30.pdf	certificate, results table	2 = porosity, 3 = clustered porosity; see S9
M1_0	ER70S-6	6. QUALITY_ASSURANCE/M1/RT_M1_0_M1_30.pdf	certificate, results table	
M1_0	ER70S-6	M1/[Macros/M1-0.JPG; Micros/1164109_informe.docx]	macrograph / metallographic report	Shape assigned from macrograph; wall-level LoF verdict absent; section images not re-read
M1_0	ER70S-6	7. DESTRUCTIVE TESTING/M1/Hardness/1164109_informe_DUREZA_VICKERS.docx	results table, all indentations	recomputed from individual values (S8) for the regional-sampling argument of Section 4.4; no pooled wall mean is tabulated in the manuscript
M1_0	ER70S-6	7. DESTRUCTIVE TESTING/M1/Hardness/1164109_informe_DUREZA_VICKERS.docx	results table, Sup rows on two indentation tracks	primary hardness result; see S8 for individual values and source-label limitations
M1_30	ER70S-6	5. METROLOGY/WALLSpecimensMeasurements.xlsx	sheet WALL_Specimens, row M1_30	column labelled "Manually measurements"; quoted to 0.1 mm
M1_30	ER70S-6	5. METROLOGY/WALLSpecimensMeasurements.xlsx	sheet WALL_Specimens, row M1_30	computed in the released sheet as wall height / 32 layers; derived quantity
M1_30	ER70S-6	6. QUALITY_ASSURANCE/M1/RT_M1_0_M1_30.pdf	certificate, penetrated-thickness field	exposure-planning field, quoted to 0.5 mm; ER110S-G given only as a range
M1_30	ER70S-6	6. QUALITY_ASSURANCE/M1/RT_M1_0_M1_30.pdf	certificate, results table	2 = porosity, 3 = clustered porosity; see S9
M1_30	ER70S-6	6. QUALITY_ASSURANCE/M1/RT_M1_0_M1_30.pdf	certificate, results table	
M1_30	ER70S-6	M1/[Macros/M1-30.JPG; Micros/1164109_informe.docx]	macrograph / metallographic report	Shape assigned from macrograph; wall-level LoF verdict absent; section images not re-read
M1_30	ER70S-6	7. DESTRUCTIVE TESTING/M1/Hardness/1164109_informe_DUREZA_VICKERS.docx	results table, all indentations	recomputed from individual values (S8) for the regional-sampling argument of Section 4.4; no pooled wall mean is tabulated in the manuscript
M1_30	ER70S-6	7. DESTRUCTIVE TESTING/M1/Hardness/1164109_informe_DUREZA_VICKERS.docx	results table, Sup rows on two indentation tracks	primary hardness result; see S8 for individual values and source-label limitations
M1_60	ER70S-6	5. METROLOGY/WALLSpecimensMeasurements.xlsx	sheet WALL_Specimens, row M1_60	column labelled "Manually measurements"; quoted to 0.1 mm
M1_60	ER70S-6	5. METROLOGY/WALLSpecimensMeasurements.xlsx	sheet WALL_Specimens, row M1_60	computed in the released sheet as wall height / 32 layers; derived quantity
M1_60	ER70S-6	6. QUALITY_ASSURANCE/M1/RT_M1_240_M1_60.pdf	certificate, penetrated-thickness field	exposure-planning field, quoted to 0.5 mm; ER110S-G given only as a range
M1_60	ER70S-6	6. QUALITY_ASSURANCE/M1/RT_M1_240_M1_60.pdf	certificate, results table	2 = porosity, 3 = clustered porosity; see S9
M1_60	ER70S-6	6. QUALITY_ASSURANCE/M1/RT_M1_240_M1_60.pdf	certificate, results table	
M1_60	ER70S-6	M1/[Macros/M1-60.JPG; Micros/1164109_informe.docx]	macrograph / metallographic report	Shape assigned from macrograph; wall-level LoF verdict absent; section images not re-read
M1_60	ER70S-6	7. DESTRUCTIVE TESTING/M1/Hardness/1164109_informe_DUREZA_VICKERS.docx	results table, all indentations	recomputed from individual values (S8) for the regional-sampling argument of Section 4.4; no pooled wall mean is tabulated in the manuscript
M1_60	ER70S-6	7. DESTRUCTIVE TESTING/M1/Hardness/1164109_informe_DUREZA_VICKERS.docx	results table, Sup rows on two indentation tracks	primary hardness result; see S8 for individual values and source-label limitations

specimen	alloy	primary_source_path	located_in	note
M1_90	ER70S-6	5. METROLOGY/WALLSpecimensMeasurements.xlsx	sheet WALL_Specimens, row M1_90	column labelled "Manually measurements"; quoted to 0.1 mm
M1_90	ER70S-6	5. METROLOGY/WALLSpecimensMeasurements.xlsx	sheet WALL_Specimens, row M1_90	computed in the released sheet as wall height / 32 layers; derived quantity
M1_90	ER70S-6	6. QUALITY_ASSURANCE/M1/RT_M1_90_M1_120.pdf	certificate, penetrated-thickness field	exposure-planning field, quoted to 0.5 mm; ER110S-G given only as a range
M1_90	ER70S-6	6. QUALITY_ASSURANCE/M1/RT_M1_90_M1_120.pdf	certificate, results table	2 = porosity, 3 = clustered porosity; see S9
M1_90	ER70S-6	6. QUALITY_ASSURANCE/M1/RT_M1_90_M1_120.pdf	certificate, results table	
M1_90	ER70S-6	M1/[Macros/M1-90.JPG; Micros/1164109_informe.docx]	macrograph / metallographic report	Shape assigned from macrograph; wall-level LoF verdict absent; section images not re-read
M1_90	ER70S-6	7. DESTRUCTIVE TESTING/M1/Hardness/1164109_informe_DUREZA_VICKERS.docx	results table, all indentations	recomputed from individual values (S8) for the regional-sampling argument of Section 4.4; no pooled wall mean is tabulated in the manuscript
M1_90	ER70S-6	7. DESTRUCTIVE TESTING/M1/Hardness/1164109_informe_DUREZA_VICKERS.docx	results table, Sup rows on two indentation tracks	primary hardness result; see S8 for individual values and source-label limitations
M1_120	ER70S-6	5. METROLOGY/WALLSpecimensMeasurements.xlsx	sheet WALL_Specimens, row M1_120	column labelled "Manually measurements"; quoted to 0.1 mm
M1_120	ER70S-6	5. METROLOGY/WALLSpecimensMeasurements.xlsx	sheet WALL_Specimens, row M1_120	computed in the released sheet as wall height / 32 layers; derived quantity
M1_120	ER70S-6	6. QUALITY_ASSURANCE/M1/RT_M1_90_M1_120.pdf	certificate, penetrated-thickness field	exposure-planning field, quoted to 0.5 mm; ER110S-G given only as a range
M1_120	ER70S-6	6. QUALITY_ASSURANCE/M1/RT_M1_90_M1_120.pdf	certificate, results table	2 = porosity, 3 = clustered porosity; see S9
M1_120	ER70S-6	6. QUALITY_ASSURANCE/M1/RT_M1_90_M1_120.pdf	certificate, results table	
M1_120	ER70S-6	M1/[Macros/M1-120.JPG; Micros/1164109_informe.docx]	macrograph / metallographic report	Shape assigned from macrograph; wall-level LoF verdict absent; section images not re-read
M1_120	ER70S-6	7. DESTRUCTIVE TESTING/M1/Hardness/1164109_informe_DUREZA_VICKERS.docx	results table, all indentations	recomputed from individual values (S8) for the regional-sampling argument of Section 4.4; no pooled wall mean is tabulated in the manuscript
M1_120	ER70S-6	7. DESTRUCTIVE TESTING/M1/Hardness/1164109_informe_DUREZA_VICKERS.docx	results table, Sup rows on two indentation tracks	primary hardness result; see S8 for individual values and source-label limitations
M1_240	ER70S-6	5. METROLOGY/WALLSpecimensMeasurements.xlsx	sheet WALL_Specimens, row M1_240	column labelled "Manually measurements"; quoted to 0.1 mm
M1_240	ER70S-6	5. METROLOGY/WALLSpecimensMeasurements.xlsx	sheet WALL_Specimens, row M1_240	computed in the released sheet as wall height / 32 layers; derived quantity
M1_240	ER70S-6	6. QUALITY_ASSURANCE/M1/RT_M1_240_M1_60.pdf	certificate, penetrated-thickness field	exposure-planning field, quoted to 0.5 mm; ER110S-G given only as a range
M1_240	ER70S-6	6. QUALITY_ASSURANCE/M1/RT_M1_240_M1_60.pdf	certificate, results table	2 = porosity, 3 = clustered porosity; see S9
M1_240	ER70S-6	6. QUALITY_ASSURANCE/M1/RT_M1_240_M1_60.pdf	certificate, results table	
M1_240	ER70S-6	M1/[Macros/M1-240.JPG; Micros/1164109_informe.docx]	macrograph / metallographic report	Shape assigned from macrograph; wall-level LoF verdict absent; section images not re-read
M1_240	ER70S-6	7. DESTRUCTIVE TESTING/M1/Hardness/1164109_informe_DUREZA_VICKERS.docx	results table, all indentations	recomputed from individual values (S8) for the regional-sampling argument of Section 4.4; no pooled wall mean is tabulated in the manuscript
M1_240	ER70S-6	7. DESTRUCTIVE TESTING/M1/Hardness/1164109_informe_DUREZA_VICKERS.docx	results table, Sup rows on two indentation tracks	primary hardness result; see S8 for individual values and source-label limitations
M2_0	ER110S-G	5. METROLOGY/WALLSpecimensMeasurements.xlsx	sheet WALL_Specimens, row M2_0	column labelled "Manually measurements"; quoted to 0.1 mm
M2_0	ER110S-G	5. METROLOGY/WALLSpecimensMeasurements.xlsx	sheet WALL_Specimens, row M2_0	computed in the released sheet as wall height / 27 layers; derived quantity
M2_0	ER110S-G	6. QUALITY_ASSURANCE/M2/RT_M2_0.pdf	certificate, penetrated-thickness field	exposure-planning field, quoted to 0.5 mm; ER110S-G given only as a range
M2_0	ER110S-G	6. QUALITY_ASSURANCE/M2/RT_M2_0.pdf	certificate, results table	2 = porosity, 3 = clustered porosity; see S9
M2_0	ER110S-G	6. QUALITY_ASSURANCE/M2/RT_M2_0.pdf	certificate, results table	
M2_0	ER110S-G	M2/[Macros/M2_0.jpg; Micros/1164200_informe.docx]	macrograph / metallographic report	Shape assigned from macrograph; wall-level LoF verdict absent; section images not re-read
M2_30	ER110S-G	5. METROLOGY/WALLSpecimensMeasurements.xlsx	sheet WALL_Specimens, row M2_30	column labelled "Manually measurements"; quoted to 0.1 mm
M2_30	ER110S-G	5. METROLOGY/WALLSpecimensMeasurements.xlsx	sheet WALL_Specimens, row M2_30	computed in the released sheet as wall height / 27 layers; derived quantity
M2_30	ER110S-G	6. QUALITY_ASSURANCE/M2/RT_M2_30.pdf	certificate, penetrated-thickness field	exposure-planning field, quoted to 0.5 mm; ER110S-G given only as a range
M2_30	ER110S-G	6. QUALITY_ASSURANCE/M2/RT_M2_30.pdf	certificate, results table	2 = porosity, 3 = clustered porosity; see S9

specimen	alloy	primary_source_path	located_in	note
M2_30	ER110S-G	6. QUALITY_ASSURANCE/M2/RT_M2_30.pdf	certificate, results table	
M2_30	ER110S-G	M2/[Macros/M2_30.jpg; Micros/1164200_informe.docx]	macrograph / metallographic report	Shape assigned from macrograph; wall-level LoF verdict absent; section images not re-read
M2_60	ER110S-G	5. METROLOGY/WALLSpecimensMeasurements.xlsx	sheet WALL_Specimens, row M2_60	column labelled "Manually measurements"; quoted to 0.1 mm
M2_60	ER110S-G	5. METROLOGY/WALLSpecimensMeasurements.xlsx	sheet WALL_Specimens, row M2_60	computed in the released sheet as wall height / 27 layers; derived quantity
M2_60	ER110S-G	6. QUALITY_ASSURANCE/M2/RT_M2_60.pdf	certificate, penetrated-thickness field	exposure-planning field, quoted to 0.5 mm; ER110S-G given only as a range
M2_60	ER110S-G	6. QUALITY_ASSURANCE/M2/RT_M2_60.pdf	certificate, results table	2 = porosity, 3 = clustered porosity; see S9
M2_60	ER110S-G	6. QUALITY_ASSURANCE/M2/RT_M2_60.pdf	certificate, results table	CERTIFICATE USED: the destructive-testing summary workbook disagrees for this specimen
M2_60	ER110S-G	M2/[Macros/M2_60.jpg; Micros/1164200_informe.docx]	macrograph / metallographic report	Shape assigned from macrograph; wall-level LoF verdict absent; section images not re-read
M2_90	ER110S-G	5. METROLOGY/WALLSpecimensMeasurements.xlsx	sheet WALL_Specimens, row M2_90	column labelled "Manually measurements"; quoted to 0.1 mm
M2_90	ER110S-G	5. METROLOGY/WALLSpecimensMeasurements.xlsx	sheet WALL_Specimens, row M2_90	computed in the released sheet as wall height / 27 layers; derived quantity
M2_90	ER110S-G	6. QUALITY_ASSURANCE/M2/RT_M2_90.pdf	certificate, penetrated-thickness field	exposure-planning field, quoted to 0.5 mm; ER110S-G given only as a range
M2_90	ER110S-G	6. QUALITY_ASSURANCE/M2/RT_M2_90.pdf	certificate, results table	2 = porosity, 3 = clustered porosity; see S9
M2_90	ER110S-G	6. QUALITY_ASSURANCE/M2/RT_M2_90.pdf	certificate, results table	CERTIFICATE USED: the destructive-testing summary workbook disagrees for this specimen
M2_90	ER110S-G	M2/[Macros/M2_90.jpg; Micros/1164200_informe.docx]	macrograph / metallographic report	Shape assigned from macrograph; wall-level LoF verdict absent; section images not re-read
M2_120	ER110S-G	5. METROLOGY/WALLSpecimensMeasurements.xlsx	sheet WALL_Specimens, row M2_120	column labelled "Manually measurements"; quoted to 0.1 mm
M2_120	ER110S-G	5. METROLOGY/WALLSpecimensMeasurements.xlsx	sheet WALL_Specimens, row M2_120	computed in the released sheet as wall height / 27 layers; derived quantity
M2_120	ER110S-G	6. QUALITY_ASSURANCE/M2/RT_M2_120.pdf	certificate, penetrated-thickness field	exposure-planning field, quoted to 0.5 mm; ER110S-G given only as a range
M2_120	ER110S-G	6. QUALITY_ASSURANCE/M2/RT_M2_120.pdf	certificate, results table	2 = porosity, 3 = clustered porosity; see S9
M2_120	ER110S-G	6. QUALITY_ASSURANCE/M2/RT_M2_120.pdf	certificate, results table	CERTIFICATE USED: the destructive-testing summary workbook disagrees for this specimen
M2_120	ER110S-G	M2/[Macros/M2_120.jpg; Micros/1164200_informe.docx]	macrograph / metallographic report	Shape assigned from macrograph; wall-level LoF verdict absent; section images not re-read
M2_240	ER110S-G	5. METROLOGY/WALLSpecimensMeasurements.xlsx	sheet WALL_Specimens, row M2_240	column labelled "Manually measurements"; quoted to 0.1 mm
M2_240	ER110S-G	5. METROLOGY/WALLSpecimensMeasurements.xlsx	sheet WALL_Specimens, row M2_240	computed in the released sheet as wall height / 27 layers; derived quantity
M2_240	ER110S-G	6. QUALITY_ASSURANCE/M2/RT_M2_240.pdf	certificate, penetrated-thickness field	exposure-planning field, quoted to 0.5 mm; ER110S-G given only as a range
M2_240	ER110S-G	6. QUALITY_ASSURANCE/M2/RT_M2_240.pdf	certificate, results table	2 = porosity, 3 = clustered porosity; see S9
M2_240	ER110S-G	6. QUALITY_ASSURANCE/M2/RT_M2_240.pdf	certificate, results table	CERTIFICATE USED: the destructive-testing summary workbook disagrees for this specimen
M2_240	ER110S-G	M2/[Macros/M2_240.jpg; Micros/1164200_informe.docx]	macrograph / metallographic report	Shape assigned from macrograph; wall-level LoF verdict absent; section images not re-read

Notes. Primary records override conflicting summary entries. Paths are dataset-relative. ER110S-G hardness is absent; the 10 mm/s field is retained in the rank-only thermal calculation. The wire-volume check disfavors 50 mm/s but does not select uniquely between 8.2 and 10 mm/s. To keep the portrait PDF compact, each wall's macrograph shape and LoF-reporting status share one display row; the submitted CSV retains the two source-mapped records. In those combined display rows, paired M1/M2 paths are relative to 7. DESTRUCTIVE TESTING/.

Table S2 - Part A

Thermophysical-property assumptions of the reduced ranking model.

Property values and units

property	ER70S-6 L2 value	ER110S-G L2 value	unit
material card name	ER70S6_BOEHLER_QG3_DEPOSIT_V1	ER110SG_UNIONX85_DEPOSIT_V1	text
density rho	7.85e-6 (7850)	7.85e-6 (7850)	kg/mm ³ (kg/m ³)
thermal conductivity k at 20 C	0.053334 (53.334)	0.0480 (48.0)	W/(mm K) (W/(m K))
specific heat cp at 20 C	439.8	450	J/(kg K)
solidus temperature	1439	1430	C
liquidus temperature	1493	1485	C

property	ER70S-6 L2 value	ER110S-G L2 value	unit
latent heat of fusion	270000	270000	J/kg
initial/reference temperature T0	20	20	C
ambient temperature Tinf	20	20	C
convection coefficient h	10	10	W/(m^2 K)
source efficiency eta	0.8	0.8	dimensionless
electrical input	131 A / 13.4 V	137 A / 14.1 V	A / V

Table S2 - Part B

Source or basis and status

property	source_or_basis	status_note
material card name	_CONSOLIDATED/01_material_cards/ER70S-6_card.md; _CONSOLIDATED/01_material_cards/ER110S-G_card.md	ER110S-G card is an alloy-class estimate because measured k(T)/cp(T) for the wire was not available
density rho	material-card archive	constant density used in reduced L2 ranking configuration
thermal conductivity k at 20 C	material-card archive	ER110S-G is approximately 10 percent lower than ER70S-6 in the alloy-class estimate
specific heat cp at 20 C	material-card archive	values reproduce the card assumptions rather than calibrated calorimetry
solidus temperature	material-card archive	reported for transparency; remelting depth is not reported in the manuscript
liquidus temperature	material-card archive	reported for transparency; remelting depth is not reported in the manuscript
latent heat of fusion	material-card archive	listed for material-card reproducibility but not used to claim quantitative remelting depth
initial/reference temperature T0	stage2_dwll_configs YAML	normalization reference for the relative interpass-temperature index
ambient temperature Tinf	submitted reduced-model runtime configuration	convective boundary reference; identical to the initial and reference temperatures in Table S5 and the submitted YAML files
convection coefficient h	manuscript Methods / L2 configuration	reduced ranking configuration
source efficiency eta	stage2_dwll_configs YAML	applied to AML electrical inputs in the reduced configuration
electrical input	stage2_dwll_configs YAML	AML as-built values used for the reduced L2 ranking cases

Table S3 - Part A

Relative interpass-temperature index computed from the corrected heat-source configuration.

Pre-activation probe temperatures

dwll_s	probe_L8_pre_activation_C	probe_L16_pre_activation_C	probe_L24_pre_activation_C	probe_L32_pre_activation_C
30	362.199409	431.274916	512.014862	585.494839
60	309.961029	364.033884	410.416273	456.318439
90	274.893402	319.133637	341.511811	357.705684
120	246.721410	280.557413	297.239766	303.893064
240	171.743657	181.503739	183.653666	181.243830

Table S3 - Part B

Mean excess temperature and relative index

dwll_s	mean_minus_T0_K	I_T	power_scale
30	452.746006	1.000000	1.0
60	365.182406	0.806594	1.0
90	303.311133	0.669937	1.0
120	262.102913	0.578918	1.0
240	159.536223	0.352375	1.0

Notes. I_T is the mean last pre-activation temperature at layers 8, 16, 24 and 32 above T0 = 20 C, normalised to the 30 s case. It is an ordering index, not a process bound.

Table S4 - Part A

Audit of the released CAE thermal workbook channels.

Channel identity

specimen	alloy_folder	series_type	scenario
M1_240	M1	experimental_thermocouple	Thermocouple3
M1_240	M1	cae_probe	eff0.6_h30 0.5 dt
M1_30	M1	experimental_thermocouple	Thermocouple3
M1_30	M1	cae_probe	eff0.6_h10
M1_30	M1	cae_probe	eff0.6_h30 0.1 dt

specimen	alloy_folder	series_type	scenario
M1_30	M1	cae_probe	eff0.6_h30 0.5 dt
M1_30	M1	cae_probe	eff0.7_h30_deltaT0.5
M1_60	M1	experimental_thermocouple	Thermocouple3
M1_60	M1	cae_probe	eff0.6_h30 0.5 dt
M1_90	M1	experimental_thermocouple	Thermocouple3
M1_90	M1	cae_probe	eff0.6_h30 0.5 dt
M2_120	M2	experimental_thermocouple	Thermocouple3
M2_120	M2	cae_probe	eff0.6_h30 0.5 dt
M2_240	M2	experimental_thermocouple	Thermocouple3
M2_240	M2	cae_probe	eff0.6_h30 0.5 dt
M2_30	M2	experimental_thermocouple	Thermocouple3
M2_30	M2	cae_probe	eff0.6_h30 0.5 dt
M2_60	M2	experimental_thermocouple	Thermocouple3
M2_60	M2	cae_probe	eff0.6_h30 0.5 dt
M2_90	M2	experimental_thermocouple	Thermocouple3
M2_90	M2	cae_probe	eff0.6_h30 0.5 dt

Table S4 - Part B

Workbook columns and headers

specimen	scenario	time_column	value_column	header_time	header_value
M1_240	Thermocouple3	2	3	Time	Thermocouple3
M1_240	eff0.6_h30 0.5 dt	5	6	Time (s)	probe_T_basePlate_T3
M1_30	Thermocouple3	2	3	Time (s)	Thermocouple3 (K)
M1_30	eff0.6_h10	5	6	Time (s)	probe_T_basePlate_T3
M1_30	eff0.6_h30 0.1 dt	8	9	Time (s)	probe_T_basePlate_T3
M1_30	eff0.6_h30 0.5 dt	12	13	Time (s)	probe_T_basePlate_T3
M1_30	eff0.7_h30_deltaT0.5	15	16	Time (s)	probe_T_basePlate_T3
M1_60	Thermocouple3	2	3	Time	Thermocouple3
M1_60	eff0.6_h30 0.5 dt	5	6	Time (s)	probe_T_basePlate_T3
M1_90	Thermocouple3	2	3	Time	Thermocouple3
M1_90	eff0.6_h30 0.5 dt	5	6	Time (s)	probe_T_basePlate_T3
M2_120	Thermocouple3	2	3	Time	Thermocouple3
M2_120	eff0.6_h30 0.5 dt	5	6	Time (s)	probe_T_basePlate_T3
M2_240	Thermocouple3	2	3	Time	Thermocouple3
M2_240	eff0.6_h30 0.5 dt	5	6	Time (s)	probe_T_basePlate_T3
M2_30	Thermocouple3	2	3	Time	Thermocouple3
M2_30	eff0.6_h30 0.5 dt	5	6	Time (s)	probe_T_basePlate_T3
M2_60	Thermocouple3	2	3	Time	Thermocouple3
M2_60	eff0.6_h30 0.5 dt	5	6	Time (s)	probe_T_basePlate_T3
M2_90	Thermocouple3	2	3	Time	Thermocouple3
M2_90	eff0.6_h30 0.5 dt	5	6	Time (s)	probe_T_basePlate_T3

Table S4 - Part C

Sampling coverage

specimen	scenario	sample_limit_rows	n_points_in_sample	median_dt_s
M1_240	Thermocouple3	50000	50000	0.002999883145093918
M1_240	eff0.6_h30 0.5 dt	50000	18000	0.5
M1_30	Thermocouple3	50000	50000	0.002999883145093918
M1_30	eff0.6_h10	50000	30000	0.10000000000000853
M1_30	eff0.6_h30 0.1 dt	50000	10000	0.10000000000002274
M1_30	eff0.6_h30 0.5 dt	50000	6000	0.5
M1_30	eff0.7_h30_deltaT0.5	50000	6000	0.5
M1_60	Thermocouple3	50000	50000	0.002999883145093918
M1_60	eff0.6_h30 0.5 dt	50000	6400	0.5
M1_90	Thermocouple3	50000	50000	0.002999883145093918
M1_90	eff0.6_h30 0.5 dt	50000	8600	0.5
M2_120	Thermocouple3	50000	50000	0.0030401162803173065
M2_120	eff0.6_h30 0.5 dt	50000	8400	0.5
M2_240	Thermocouple3	50000	50000	0.0030501745641231537

specimen	scenario	sample_limit_rows	n_points_in_sample	median_dt_s
M2_240	eff0.6_h30 0.5 dt	50000	8400	0.5
M2_30	Thermocouple3	50000	50000	0.003060232847929001
M2_30	eff0.6_h30 0.5 dt	50000	5000	0.5
M2_60	Thermocouple3	50000	50000	0.0030495459213852882
M2_60	eff0.6_h30 0.5 dt	50000	7200	0.5
M2_90	Thermocouple3	50000	50000	0.003039487637579441
M2_90	eff0.6_h30 0.5 dt	50000	7000	0.5

Table S4 - Part D

Time coverage

specimen	scenario	time_min_s	time_max_s
M1_240	Thermocouple3	0.0	151.04205063544214
M1_240	eff0.6_h30 0.5 dt	0.5	9000.0
M1_30	Thermocouple3	0.0	151.1390803847462
M1_30	eff0.6_h10	0.1	3000.0
M1_30	eff0.6_h30 0.1 dt	0.1	1000.0
M1_30	eff0.6_h30 0.5 dt	0.5	3000.0
M1_30	eff0.7_h30_deltaT0.5	0.5	3000.0
M1_60	Thermocouple3	0.0	151.13897037226707
M1_60	eff0.6_h30 0.5 dt	0.5	3200.0
M1_90	Thermocouple3	0.0	150.98803010769188
M1_90	eff0.6_h30 0.5 dt	0.5	4300.0
M2_120	Thermocouple3	0.0	181.8079796154052
M2_120	eff0.6_h30 0.5 dt	0.5	4200.0
M2_240	Thermocouple3	0.0	181.89091959502548
M2_240	eff0.6_h30 0.5 dt	0.5	4200.0
M2_30	Thermocouple3	0.0	184.164360165596
M2_30	eff0.6_h30 0.5 dt	0.5	2500.0
M2_60	Thermocouple3	0.0	181.5415105316788
M2_60	eff0.6_h30 0.5 dt	0.5	3600.0
M2_90	Thermocouple3	0.0	181.34397023823112
M2_90	eff0.6_h30 0.5 dt	0.5	3500.0

Table S4 - Part E

Raw and converted temperature ranges

specimen	scenario	raw_temperature_min	raw_temperature_max	temperature_c_min	temperature_c_max
M1_240	Thermocouple3	284.2500003814697	464.15	11.100000381469727	191.0
M1_240	eff0.6_h30 0.5 dt	300.07017	377.63202	26.92017000000004	104.48202000000003
M1_30	Thermocouple3	284.4500001907348	479.65	11.300000190734806	206.5
M1_30	eff0.6_h10	300.00006	574.501	26.850060000000042	301.351
M1_30	eff0.6_h30 0.1 dt	300.00006	461.39652	26.850060000000042	188.24652000000003
M1_30	eff0.6_h30 0.5 dt	300.0428	456.39911	26.892800000000022	183.24911000000003
M1_30	eff0.7_h30_deltaT0.5	300.04993	481.53826	26.89993000000004	208.38826
M1_60	Thermocouple3	308.0500015258789	455.049993896484	34.900001525878906	181.89999389648403
M1_60	eff0.6_h30 0.5 dt	300.07017	429.62981	26.92017000000004	156.47981000000004
M1_90	Thermocouple3	311.24999847412096	516.750006103515	38.09999847412098	243.60000610351506
M1_90	eff0.6_h30 0.5 dt	300.07017	411.64529	26.92017000000004	138.49529
M2_120	Thermocouple3	293.75	408.95	20.600000000000023	135.8
M2_120	eff0.6_h30 0.5 dt	300.0356	395.62125	26.885600000000001	122.47125
M2_240	Thermocouple3	303.95	429.45	30.800000000000001	156.3
M2_240	eff0.6_h30 0.5 dt	300.0356	395.62125	26.885600000000001	122.47125
M2_30	Thermocouple3	308.25	478.04999999999995	35.100000000000002	204.89999999999998
M2_30	eff0.6_h30 0.5 dt	300.03755	452.44525	26.887550000000033	179.29525
M2_60	Thermocouple3	302.04999999999995	424.34999999999997	28.899999999999977	151.2
M2_60	eff0.6_h30 0.5 dt	300.0356	426.74815	26.885600000000001	153.59815000000003
M2_90	Thermocouple3	292.65	410.04999999999995	19.5	136.89999999999998
M2_90	eff0.6_h30 0.5 dt	300.0356	408.34478	26.885600000000001	135.19478000000004

Table S4 - Part F**Workbook path and manuscript role**

specimen	scenario	workbook_relative_path	manuscript_role
M1_240	Thermocouple3	M1\M1_240\M1_240Combined.xlsx	first-50000-row sample; high-frequency experimental T3/baseplate channel, not wall interpass-temperature ground truth
M1_240	eff0.6_h30 0.5 dt	M1\M1_240\M1_240Combined.xlsx	released consortium FEM/CAE basePlate_T3 probe channel; context only, not calibration of present L2 wall interpass index
M1_30	Thermocouple3	M1\M1_30\M1_30Combined.xlsx	first-50000-row sample; high-frequency experimental T3/baseplate channel, not wall interpass-temperature ground truth
M1_30	eff0.6_h10	M1\M1_30\M1_30Combined.xlsx	released consortium FEM/CAE basePlate_T3 probe channel; context only, not calibration of present L2 wall interpass index
M1_30	eff0.6_h30 0.1 dt	M1\M1_30\M1_30Combined.xlsx	released consortium FEM/CAE basePlate_T3 probe channel; context only, not calibration of present L2 wall interpass index
M1_30	eff0.6_h30 0.5 dt	M1\M1_30\M1_30Combined.xlsx	released consortium FEM/CAE basePlate_T3 probe channel; context only, not calibration of present L2 wall interpass index
M1_30	eff0.7_h30_deltaT0.5	M1\M1_30\M1_30Combined.xlsx	released consortium FEM/CAE basePlate_T3 probe channel; context only, not calibration of present L2 wall interpass index
M1_60	Thermocouple3	M1\M1_60\M1_60Combined.xlsx	first-50000-row sample; high-frequency experimental T3/baseplate channel, not wall interpass-temperature ground truth
M1_60	eff0.6_h30 0.5 dt	M1\M1_60\M1_60Combined.xlsx	released consortium FEM/CAE basePlate_T3 probe channel; context only, not calibration of present L2 wall interpass index
M1_90	Thermocouple3	M1\M1_90\M1_90Combined.xlsx	first-50000-row sample; high-frequency experimental T3/baseplate channel, not wall interpass-temperature ground truth
M1_90	eff0.6_h30 0.5 dt	M1\M1_90\M1_90Combined.xlsx	released consortium FEM/CAE basePlate_T3 probe channel; context only, not calibration of present L2 wall interpass index
M2_120	Thermocouple3	M2\M2_120\M2_120Combined.xlsx	first-50000-row sample; high-frequency experimental T3/baseplate channel, not wall interpass-temperature ground truth
M2_120	eff0.6_h30 0.5 dt	M2\M2_120\M2_120Combined.xlsx	released consortium FEM/CAE basePlate_T3 probe channel; context only, not calibration of present L2 wall interpass index
M2_240	Thermocouple3	M2\M2_240\M2_240Combined.xlsx	first-50000-row sample; high-frequency experimental T3/baseplate channel, not wall interpass-temperature ground truth
M2_240	eff0.6_h30 0.5 dt	M2\M2_240\M2_240Combined.xlsx	released consortium FEM/CAE basePlate_T3 probe channel; context only, not calibration of present L2 wall interpass index
M2_30	Thermocouple3	M2\M2_30\M2_30Combined.xlsx	first-50000-row sample; high-frequency experimental T3/baseplate channel, not wall interpass-temperature ground truth
M2_30	eff0.6_h30 0.5 dt	M2\M2_30\M2_30Combined.xlsx	released consortium FEM/CAE basePlate_T3 probe channel; context only, not calibration of present L2 wall interpass index
M2_60	Thermocouple3	M2\M2_60\M2_60Combined.xlsx	first-50000-row sample; high-frequency experimental T3/baseplate channel, not wall interpass-temperature ground truth
M2_60	eff0.6_h30 0.5 dt	M2\M2_60\M2_60Combined.xlsx	released consortium FEM/CAE basePlate_T3 probe channel; context only, not calibration of present L2 wall interpass index
M2_90	Thermocouple3	M2\M2_90\M2_90Combined.xlsx	first-50000-row sample; high-frequency experimental T3/baseplate channel, not wall interpass-temperature ground truth
M2_90	eff0.6_h30 0.5 dt	M2\M2_90\M2_90Combined.xlsx	released consortium FEM/CAE basePlate_T3 probe channel; context only, not calibration of present L2 wall interpass index

Table S5*Runtime configuration of the reduced thermal calculation (corrected runs).*

parameter	value	unit	note
mesh_cells	4x2x32	-	reduced ranking scaffold; see S6 for source-to-cell resolution
n_layers	32	-	ER70S-6 reference geometry
thermal_only	True	-	no mechanical solve; the mechanical proxy of the runner is not exercised
current	131.0	A	AML as-built value
voltage	13.4	V	AML as-built value
arc_power	1755.4	W	current x voltage
efficiency	0.8	-	consistent with S2
effective_power	1404.32	W	arc power x efficiency; the target of the source rescaling in S12
power_scale	1.0	-	no calibration factor applied to the source
travel_speed	10.0	mm/s	the released 10 mm/s field; see manuscript Section 2.1
layer_scan_time	2.0	s	
source_dt	0.2	s	
interpass_dt	5.0	s	time step during the dwell
interpass_time	30 / 60 / 90 / 120 / 240	s	the varied parameter
goldak_af_ar_b_c	2.25 / 4.5 / 2.25 / 0.72	mm	frozen M1-30 source dimensions
goldak_ff_fr	0.6 / 1.4	-	front and rear power fractions

parameter	value	unit	note
convection_h	10.0	W/(m ² K)	one global external-boundary term
ambient_T_inf	20.0	C	
initial_temperature	20.0	C	T0 of the index definition
radiation	False	-	not enabled
material	ER70S6_BOEHLER_QG3_DEPOSIT_V1	-	see S2 and the material card in the reproducibility package

Notes. Corrected runs use power_scale = 1.0 and differ only in interpass_time_s; this supersedes the pre-correction value of 3.0. The retained NO_GO flag precludes a validated-temperature claim.

Table S6 - Part A

Heat-source dimensions against cell size.

Source and cell dimensions

source	mesh_cells	cell_size_dx_dy_dz_mm	goldak_af_ar_b_c_mm
nominal_stage2_scaffold	4x2x32	6/3/3	2/4/1.8/1.2
nominal_stage2_scaffold	8x4x64	3/1.5/1.5	2/4/1.8/1.2
runtime_audit_refined_summary	8x4x64	3/1.5/1.5	2.25/4.5/2.25/0.72

Table S6 - Part B

Source-to-cell resolution ratios

source	mesh_cells	af_over_dx	ar_over_dx	b_over_dy	c_over_dz
nominal_stage2_scaffold	4x2x32	0.333	0.667	0.600	0.400
nominal_stage2_scaffold	8x4x64	0.667	1.333	1.200	0.800
runtime_audit_refined_summary	8x4x64	0.750	1.500	1.500	0.480

Table S6 - Part C

Interpretation

source	mesh_cells	interpretation
nominal_stage2_scaffold	4x2x32	source support is weakly resolved; rank-level only, not convergence
nominal_stage2_scaffold	8x4x64	source support is weakly resolved; rank-level only, not convergence
runtime_audit_refined_summary	8x4x64	source support is weakly resolved; rank-level only, not convergence

Table S7 - Part A

Experimental baseplate thermocouple ordering check.

Records and status

specimen	alloy	dwelt_s	status
M1_240	ER70S-6	240	usable_unregistered_peak_intervals
M1_30	ER70S-6	30	usable_unregistered_peak_intervals
M1_60	ER70S-6	60	usable_unregistered_peak_intervals
M1_90	ER70S-6	90	usable_unregistered_peak_intervals
M2_120	ER110S-G	120	insufficient_detected_peak_intervals
M2_240	ER110S-G	240	usable_unregistered_peak_intervals
M2_30	ER110S-G	30	usable_unregistered_peak_intervals
M2_60	ER110S-G	60	insufficient_detected_peak_intervals
M2_90	ER110S-G	90	usable_unregistered_peak_intervals

Table S7 - Part B

Acquisition coverage and source file

specimen	dwelt_s	n_raw	time_start_s	time_end_s	source_file
M1_240	240	1043727	0.0	3151.662100176327	M1/M1_240/M1_240Combined.xlsx
M1_30	30	1042961	0.0	3150.0657505821437	M1/M1_30/M1_30Combined.xlsx
M1_60	60	1042669	0.0	3149.831600021571	M1/M1_60/M1_60Combined.xlsx
M1_90	90	1042650	0.0	3150.3011502558365	M1/M1_90/M1_90Combined.xlsx
M2_120	120	1046066	0.0	3796.174149471335	M2/M2_120/M2_120Combined.xlsx
M2_240	240	1046066	0.0	3801.298109558411	M2/M2_240/M2_240Combined.xlsx
M2_30	30	1046017	0.0	3832.2839402826503	M2/M2_30/M2_30Combined.xlsx
M2_60	60	1046116	0.0	3818.518300051801	M2/M2_60/M2_60Combined.xlsx

specimen	dwel_l_s	n_raw	time_start_s	time_end_s	source_file
M2_90	90	1045930	0.0	3821.596079575829	M2/M2_90/M2_90Combined.xlsx

Table S7 - Part C

Temperature range and mean

specimen	dwel_l_s	t3_min_c	t3_max_c	t3_mean_c
M1_240	240	11.100000381469727	225.89999389648403	67.6597778605078
M1_30	30	11.300000190734806	216.19999694824196	143.1810805121356
M1_60	60	34.900001525878906	183.80000305175702	141.54453640462796
M1_90	90	38.09999847412098	248.10000610351506	124.6298889178482
M2_120	120	20.600000000000023	149.8	104.86623778996737
M2_240	240	21.800000000000001	211.0	76.70232547468324
M2_30	30	35.100000000000002	226.10000000000002	112.34251269338834
M2_60	60	28.899999999999977	188.8	126.17627270780679
M2_90	90	19.5	161.10000000000002	112.09119128431158

Table S7 - Part D

Detected intervals, conventional median and layer registration

specimen	dwel_l_s	detected_peak_count	between_peak_interval_count	between_peak_minimum_median_c	layer_registered
M1_240	240	8	7	57.59999847412098	no
M1_30	30	5	4	136.64999771118102	no
M1_60	60	5	4	109.85000228881750	no
M1_90	90	10	9	85.0999984741211	no
M2_120	120	4	3	92.10000000000002	no
M2_240	240	9	8	61.400000000000006	no
M2_30	30	11	10	155.0	no
M2_60	60	1	0		no
M2_90	90	8	7	111.30000000000001	no

Notes. Rows marked insufficient_detected_peak_intervals were excluded. M1_0 and M1_120 lack a usable T3 channel. Detected intervals were not registered to deposited layers; mean and last-interval minima remain in the CSV. Exact p-values are two-sided permutations over the 24 distinct four-condition arrangements.

Table S7 - Part E

Conditions and observed values

alloy	metric	n_cases	dwel_l_s	values_c
ER70S-6	between_peak_minimum_median_c	4	240;30;60;90	57.600;136.650;109.850;85.100
ER70S-6	between_peak_minimum_mean_c	4	240;30;60;90	52.943;134.900;112.050;83.311
ER70S-6	t3_max_c	4	240;30;60;90	225.900;216.200;183.800;248.100

Table S7 - Part F

Ordering statistics

alloy	metric	spearman_rho_dwel_l_vs_metric	exact_two_sided_p	distinct_arrangements	rank_descending_temperature
ER70S-6	between_peak_minimum_median_c	-1.000	0.083	24	4;1;2;3
ER70S-6	between_peak_minimum_mean_c	-1.000	0.083	24	4;1;2;3
ER70S-6	t3_max_c	0.600	0.417	24	2;3;4;1

Table S7 - Part G

Interpretation of the ordering check

alloy	metric	interpretation
ER70S-6	between_peak_minimum_median_c	unregistered baseplate-channel diagnostic only; not layer-wise or wall interpass ground truth
ER70S-6	between_peak_minimum_mean_c	unregistered baseplate-channel diagnostic only; not layer-wise or wall interpass ground truth
ER70S-6	t3_max_c	unregistered baseplate-channel diagnostic only; not layer-wise or wall interpass ground truth

Table S8

Individual HV0.3 indentation values (324 rows; summarised here, full data and track labels in the CSV).

dwel_s	track	region	used_in_analysis	n	mean_HV0_3	minimum_HV0_3	maximum_HV0_3
0	1	cap	yes	16	176.1	161	210
0	1	root	yes	6	222.0	190	249
0	2	cap	yes	14	179.7	159	218
0	2	root	yes	6	231.3	207	252
30	1	cap	yes	21	173.9	159	210
30	1	root	no	7	184.6	164	210
30	2	cap	yes	21	178.2	166	220
30	2	root	yes	7	224.7	189	274
60	1	cap	yes	21	175.0	162	212
60	1	root	yes	9	232.8	202	277
60	2	cap	yes	21	175.7	163	202
60	2	root	yes	9	239.8	198	290
90	1	cap	yes	22	180.3	166	220
90	1	root	yes	7	244.6	193	277
90	2	cap	yes	22	178.4	169	225
90	2	root	yes	7	236.4	196	260
120	1	cap	yes	17	182.7	161	246
120	1	root	yes	6	241.8	187	296
120	2	cap	yes	17	178.8	161	202
120	2	root	yes	6	235.2	195	276
240	1	cap	yes	21	188.0	169	208
240	1	root	yes	10	233.2	195	290
240	2	cap	yes	21	186.1	170	213
240	2	root	yes	10	236.3	185	280

Notes. Source: AIMEN order 1164109. Expanded uncertainty is 6.7% ($k = 2$). Source rows labelled Inf and Sup are designated root and cap here only as shorthand; no metric coordinates or indentation spacing are reported. The source describes one transverse section per wall and two indentation tracks (1 and 2) on that section. Each indentation appears once; seven M1_30 track-1 root values are excluded as a probable transcription duplicate. ER110S-G hardness is absent. The CSV retains all 324 records.

Table S9 - Part A

Radiographic technique and exposure parameters transcribed from the twelve certificates.

Specimen, report and penetrated thickness

specimen	alloy	report_no	thickness_mm	penetrated_thickness_mm
M1_0	ER70S-6	1162926.2.0	9	9
M1_30	ER70S-6	1162926.2.0	7	7
M1_60	ER70S-6	1162926.1.0	6.5	6.5
M1_90	ER70S-6	1162926.2.0	6.5	6.5
M1_120	ER70S-6	1162926.2.0	6.5	6.5
M1_240	ER70S-6	1162926.1.0	6.5	6.5
M2_0	ER110S-G	not stated	7-9	7-9
M2_30	ER110S-G	not stated	7-9	7-9
M2_60	ER110S-G	not stated	7-9	7-9
M2_90	ER110S-G	not stated	7-9	7-9
M2_120	ER110S-G	not stated	7-9	7-9
M2_240	ER110S-G	not stated	7-9	7-9

Table S9 - Part B**Geometry and exposure**

specimen	report_no	distance_F_O_mm	distance_O_P_mm	distance_F_P_mm	exposure_time
M1_0	1162926.2.0	941	9	950	1'47"
M1_30	1162926.2.0	943	7	950	1'47"
M1_60	1162926.1.0	943.5	6.5	950	1'47"
M1_90	1162926.2.0	943.5	6.5	950	1'48"
M1_120	1162926.2.0	943.5	6.5	950	1'48"
M1_240	1162926.1.0	943.5	6.5	950	1'47"
M2_0	not stated	n.s.	n.s.	950	2'41"
M2_30	not stated	n.s.	n.s.	950	2'21"
M2_60	not stated	n.s.	n.s.	950	2'41"
M2_90	not stated	n.s.	n.s.	950	2'41"
M2_120	not stated	n.s.	n.s.	950	2'41"
M2_240	not stated	n.s.	n.s.	950	2'41"

Table S9 - Part C**Image quality, indication and result**

specimen	report_no	iqi_wire_required	iqi_wire_achieved	film_density	indication_category	result
M1_0	1162926.2.0	14	16	2.5	2, 3	Rejected
M1_30	1162926.2.0	15	16	2.5	none	Accepted
M1_60	1162926.1.0	15	16	3.1	2	Accepted
M1_90	1162926.2.0	15	16	3.3	2	Accepted
M1_120	1162926.2.0	15	16	3.3	2	Accepted
M1_240	1162926.1.0	15	16	3.1	2, 3	Rejected
M2_0	not stated	15	16	2.2	none	Accepted
M2_30	not stated	15	17	2.2	none	Accepted
M2_60	not stated	15	17	3.0	none	Accepted
M2_90	not stated	15	17	3.1	2	Accepted
M2_120	not stated	15	17	3.4	none	Accepted
M2_240	not stated	15	17	3.2	2	Accepted

Notes. Certificates used UNE-EN ISO 17636-1:2023 test level B, acceptance level 1 and UNE-EN ISO 5817:2023 quality level B; exposures were single-wall/single-image at 120 kV, 7.5 mA and 950 mm on C3 film. Category 11 denotes lack of fusion (not recorded); n.s. means not stated. Certificates override conflicting summary entries.

Table S10

Full-data rank summaries and the 240 s endpoint deletions; all condition deletions are retained in the accompanying CSV.

variable_x	variable_y	range	n	spearman_rho	exact_two_sided_p	distinct_arrangements
Dwell time	Average layer height (ER70S-6)	30-240 s	5	+1.000	0.017	120
Dwell time	Cap-region hardness (ER70S-6)	30-240 s	5	+0.900	0.083	120
Dwell time	Root-region hardness (ER70S-6)	30-240 s	5	+0.300	0.683	120
Average layer height	Cap-region hardness (ER70S-6)	30-240 s	5	+0.900	0.083	120
Relative interpass index	Average layer height (ER70S-6)	30-240 s	5	-1.000	0.017	120
Relative interpass index	Cap-region hardness (ER70S-6)	30-240 s	5	-0.900	0.083	120
Dwell time	Penetrated thickness (ER70S-6)	0-240 s	6	-0.845	0.067	30
Wall height	Penetrated thickness (ER70S-6)	0-240 s	6	-0.845	0.067	30
Dwell time	Radiographic ordinal score (ER70S-6)	0-240 s	6	-0.185	0.733	60
Dwell time	Radiographic ordinal score (ER110S-G)	0-240 s	6	-0.621	0.267	15
Dwell time	Cap-region hardness LOO (ER70S-6; omit 240 s)	30-240 s; one condition omitted	4	+0.800	0.333	24
Dwell time	Radiographic ordinal score LOO (ER70S-6; omit 240 s)	0-240 s; one condition omitted	5	+0.224	1.000	20
Dwell time	Radiographic ordinal score LOO (ER110S-G; omit 240 s)	0-240 s; one condition omitted	5	-0.354	0.800	5

Notes. p-values are exact two-sided permutations over distinct response arrangements and describe only the ordering of tested conditions. LOO rows delete one condition-level wall; indentations are not treated as independent observations. The PDF shows the endpoint deletions used in the main interpretation;

the CSV contains all five hardness and twelve radiographic deletions.

Table S11 - Part A

Every leave-one-out refit behind the LOO columns of Table 2.

Refitted parameters and bound status

alloy	model	deleted_dwell_s	h0_mm	dh_inf_mm	tau_s_or_slope	parameter_on_bound
ER70S-6	Exponential	0	1.4454	0.1448	79.7724	no
ER70S-6	Exponential	30	1.2444	0.3282	32.6352	no
ER70S-6	Exponential	60	1.2444	0.3181	21.5497	no
ER70S-6	Exponential	90	1.2449	0.3233	23.1489	no
ER70S-6	Exponential	120	1.2452	0.3180	22.6980	no
ER70S-6	Exponential	240	1.2440	0.3036	18.9190	no
ER70S-6	Hyperbolic	0	1.4158	0.2040	53.3174	no
ER70S-6	Hyperbolic	30	1.2438	0.3593	16.8637	no
ER70S-6	Hyperbolic	60	1.2440	0.3516	14.1425	no
ER70S-6	Hyperbolic	90	1.2439	0.3556	14.0985	no
ER70S-6	Hyperbolic	120	1.2440	0.3533	14.1712	no
ER70S-6	Hyperbolic	240	1.2437	0.3391	11.6424	no
ER70S-6	Linear	0	1.4958		0.0004	no
ER70S-6	Linear	30	1.3714		0.0012	no
ER70S-6	Linear	60	1.3755		0.0011	no
ER70S-6	Linear	90	1.3876		0.0010	no
ER70S-6	Linear	120	1.3931		0.0010	no
ER70S-6	Linear	240	1.3362		0.0023	no
ER110S-G	Exponential	0	1.5308	0.1961	28.7776	no
ER110S-G	Exponential	30	1.4260	0.2967	19.3327	no
ER110S-G	Exponential	60	1.4263	0.2957	20.6042	no
ER110S-G	Exponential	90	1.4259	0.3035	21.0379	no
ER110S-G	Exponential	120	1.4261	0.2992	20.6156	no
ER110S-G	Exponential	240	1.4257	0.2905	18.5718	no
ER110S-G	Hyperbolic	0	0.0000	1.7446	1.5561	yes
ER110S-G	Hyperbolic	30	1.4260	0.3129	6.9997	no
ER110S-G	Hyperbolic	60	1.4260	0.3234	12.6759	no
ER110S-G	Hyperbolic	90	1.4257	0.3278	11.5544	no
ER110S-G	Hyperbolic	120	1.4258	0.3261	11.6322	no
ER110S-G	Hyperbolic	240	1.4258	0.3217	10.9216	no
ER110S-G	Linear	0	1.6739		0.0003	no
ER110S-G	Linear	30	1.5546		0.0010	no
ER110S-G	Linear	60	1.5519		0.0010	no
ER110S-G	Linear	90	1.5679		0.0009	no
ER110S-G	Linear	120	1.5732		0.0009	no
ER110S-G	Linear	240	1.5170		0.0021	no

Table S11 - Part B

Held-out predictions and residuals

alloy	model	deleted_dwell_s	held_out_prediction_mm	held_out_residual_mm
ER70S-6	Exponential	0	1.4454	-0.2016
ER70S-6	Exponential	30	1.4417	+0.0458
ER70S-6	Exponential	60	1.5429	-0.0116
ER70S-6	Exponential	90	1.5616	-0.0241
ER70S-6	Exponential	120	1.5616	-0.0053
ER70S-6	Exponential	240	1.5476	+0.0368
ER70S-6	Hyperbolic	0	1.4158	-0.1721
ER70S-6	Hyperbolic	30	1.4739	+0.0136
ER70S-6	Hyperbolic	60	1.5285	+0.0027
ER70S-6	Hyperbolic	90	1.5513	-0.0138
ER70S-6	Hyperbolic	120	1.5599	-0.0037
ER70S-6	Hyperbolic	240	1.5671	+0.0173
ER70S-6	Linear	0	1.4958	-0.2520
ER70S-6	Linear	30	1.4065	+0.0810

alloy	model	deleted_dwell_s	held_out_prediction_mm	held_out_residual_mm
ER70S-6	Linear	60	1.4420	+0.0893
ER70S-6	Linear	90	1.4806	+0.0569
ER70S-6	Linear	120	1.5128	+0.0435
ER70S-6	Linear	240	1.8763	-0.2919
ER110S-G	Exponential	0	1.5308	-0.1049
ER110S-G	Exponential	30	1.6598	-0.0043
ER110S-G	Exponential	60	1.7059	+0.0089
ER110S-G	Exponential	90	1.7252	-0.0215
ER110S-G	Exponential	120	1.7243	-0.0058
ER110S-G	Exponential	240	1.7162	+0.0208
ER110S-G	Hyperbolic	0	0.0000	+1.4259
ER110S-G	Hyperbolic	30	1.6797	-0.0241
ER110S-G	Hyperbolic	60	1.6930	+0.0218
ER110S-G	Hyperbolic	90	1.7162	-0.0125
ER110S-G	Hyperbolic	120	1.7231	-0.0046
ER110S-G	Hyperbolic	240	1.7334	+0.0036
ER110S-G	Linear	0	1.6739	-0.2479
ER110S-G	Linear	30	1.5856	+0.0699
ER110S-G	Linear	60	1.6121	+0.1027
ER110S-G	Linear	90	1.6504	+0.0533
ER110S-G	Linear	120	1.6792	+0.0393
ER110S-G	Linear	240	2.0237	-0.2867

Notes. Fits used Python 3.13, SciPy 1.17.1 and `scipy.optimize.least_squares` with unweighted residuals and default tolerances. For saturation models, $1e-6 \leq \tau \leq 1e4$ s; the linear slope is stored in `tau_s` or `slope`. For the ER70S-6 exponential refit with 0 s deleted, $x = 0.60, 0.70, 0.80$ and 0.90 give grid-rounded bounds of 90, 120, 240 and 240 s.

Table S11 - Part C

Wall-height rounding interval and fitted time scale

alloy	model	rounding_interval_mm	n_perturbations	nominal_tau_s	tau_min_s	tau_max_s
ER70S-6	Exponential	± 0.05	729	22.2456706620	21.3422689368	23.1940364005
ER70S-6	Hyperbolic	± 0.05	729	13.9584118278	13.1178119881	14.8302868521
ER110S-G	Exponential	± 0.05	729	20.1948431102	19.3099200827	21.1283464540
ER110S-G	Hyperbolic	± 0.05	729	11.3751916627	10.4768513479	12.3127654692

Table S11 - Part D

Distinct grid-rounded bounds across perturbations

alloy	model	x_0_60_bound_s	x_0_70_bound_s	x_0_80_bound_s	x_0_90_bound_s
ER70S-6	Exponential	30	30	60	60
ER70S-6	Hyperbolic	30	60	60	120;240
ER70S-6	Grid-only	30	30	60	120
ER110S-G	Exponential	30	30	60	60
ER110S-G	Hyperbolic	30	30	60	120
ER110S-G	Grid-only	30	30	60	60

Notes. Each reported wall height was perturbed over $-0.05, 0$ and $+0.05$ mm ($3^6 = 729$ combinations per alloy). These are rounding-interval sensitivity envelopes, not confidence intervals. Full crossing ranges are retained in the accompanying CSV.

Table S12 - Part A

Verification of the reduced thermal calculation.

Power deposited by the discretised source

mesh	cells	cell_size_z_mm	deposited_W_unscaled	ratio_to_requested_unscaled	ratio_to_requested_rescaled
4x2x32	256	3.0	0.1	0.0	1.0
8x4x64	2048	1.5	460.6	0.328	1.0
12x6x96	6912	1.0	1771.8	1.262	1.0
16x8x128	16384	0.75	2559.4	1.823	1.0
24x12x192	55296	0.5	2781.4	1.981	1.0

Table S12 - Part B

Mesh study with the rescaled source

mesh	cells	cell_size_z_mm	steps_recorded	simulated_end_time_s	domain_max_temperature_C	refinement_ratio_vs_previous
4x2x32	256	3.0	519	1054.0	2151.1	
8x4x64	2048	1.5	519	1054.0	2226.2	2.00
12x6x96	6912	1.0	519	1054.0	2408.3	1.50

Table S12 - Part C

Dwell sweep with the corrected source

dwell_s	run_summary_maximum_C
30	581.1
60	452.8
90	367.7
120	305.9
240	193.3

Notes. Source rescaling enforces 1404.32 W at every step. Absolute maximum temperature is not mesh-converged. Part C uses the coarse mesh only for dwell ordering and is not comparable in magnitude with the whole-history maxima in Part B.

Table S13

Coarse cross-sectional-area and wire-volume consistency check for ER70S-6.

dwell_s	wall_height_mm	reported_thickness_mm	height_x_thickness_mm2	proxy_per_layer_mm2
0	39.8	9.0	358.2	11.1938
30	47.6	7.0	333.2	10.4125
60	49.0	6.5	318.5	9.9531
90	49.2	6.5	319.8	9.9938
120	49.8	6.5	323.7	10.1156
240	50.7	6.5	329.6	10.2984

Notes. Wall height multiplied by certificate penetrated thickness is a coarse proxy, not a metrology result; the 0 s value uses a local thickness on a bulged section. The nominal CAD wall is 185 mm long; the executed robot path is unavailable. With 1.2 mm wire at 4 m/min, the ideal incoming areas are 9.195, 7.540 and 1.508 mm² at 8.2, 10 and 50 mm/s. Bead shape and transfer efficiency prevent a unique 8.2-versus-10 mm/s choice, whereas 50 mm/s is strongly inconsistent with the observed proxy.