ESA STUDY CONTRACT REPORT –

Deliverable D 3.2
Mechanical tests and NDT evaluation

ESA Contract No:	SUBJECT:	CONTRACTOR:
400114452/15/ NL/NDe	**Milestone Fina;, D 3.2 Specimen manufacturing and NDT evaluation**	**Riga Technical University, Institute of Materials and Structures**
* ESA CR( )No:	No. of Volumes:1 This is Volume No:1	CONTRACTOR'S REFERENCE: **62518 (bidder code)**

ABSTRACT:

The current deliverable suymmarise evaluation of non-destructive testing results of mechanically tested specimens. This involves assessment of composite plate and CFRP/Al-honeycomb sandwich panel manufacturing and prototyping practice as well as bearly visible damage introduction to testing panels. Initially or as a first step NDE is applied as ultrasound inspection to assure that CFRP face plates are produced with relatively small scatter for thickness distribution, this involves histogram production. Each panel undergone a self-frequency nature test and assessment by Modal Assurance Criteri, therefore robustly assessing the whole panel maturity/robustness before the mechanical testing. A panel assemblies composed of six test specimens were inspected before and just after introduction of bearly visible damage. During the laser scan, NDT the indentation depth has been measured comparing groove depth to the reference plate. This report is essential part of developed software tools in particularly for validation of implemented approaches. For more visualisation of developed tools one can see http://bnm4eks.rtu.lv/tools.html.

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1 Introduction

Final report on non-destructive inspections procedures implemented for assessment of prototyping procedures and introduced damage on CFRP/Al honeycomb sandwich panels. Both manufacturing (quality control) and testing (damage quantification) procedures are assessed by non-destructive techniques for component quality control and measurement of realized material imperfections as well as for introduction of bearly visible identation damage (BVID).

2 Ultrasound quality inspections and thickness measurement

All composite face sheets and panel specimens manufactured were subject of quality control and thickness measurement employing water coupled Ultrasound inspection. Ultrasound inspection of the thin face plates was carried out on modified Hilgus USPC 3010 HF equipment, for quality control and thickness measurement reasons. Due to panel fixture restrictions, only (440 x 200 mm) part of the panel area was covered by NDE scan. Obtained bitmap files for various total thicknesses and lay-up configurations are outlined in Figure 2.1 to Figure 2.90. In house software ColorThick was programmed in order to shorten the analysis time for panel thickness. Obtained tickness and corresponding standard deviation and 95% distribution margins are presend in Table 2.1 by layup [60/0/-60], in Table 2.2 by layup [0/60/-60/0], in Table 2.3 by layup [90/-0] and in Table 2.4 by layup [60/-60/0].

The thickness calibration was performed for each particular panel by measuring thickness of the panel with calliper/micrometer at the one particular point near panel edge (marked on the panel surface). Speed of sound was adjusted to get ultrasound measured thickness value at the same marked point. That is why there is slight variation of speed of sound among the panels.

In-house created software for bitmap digitalization enabled the possibility to implement obtained thickness measurements into numerical finite element models or for statistical analyses of obtained thickness distribution, as well serves as reference measurement for impact damage characterization. Nevertheless, in general terms, this activity serves as lamination quality measure, required before the sandwich assembly or for assement of mechanical response robustness.

2.1 Face sheet lay-up 60/0/-60

Initially the panels made of thee ply lay-up 60/0/-60 was inspected. By summarising all 17 samples the average thickness of 0.260mm and STD is 0.0093 was set for numerical analysis.

Table 2.1. Average measured thickness of full-scale panels by layup [60/0/-60]

	Panel ID	Face ID	AVE	STD	Min	Max	Histogram max		δ–2σ	δ	δ+2σ
[60/0/-60]	ESA_001	11	0.26	0.019	0.192	0.311	0.264	Ok	0.241	0.260	0.279
		12	0.27	0.020	0.191	0.337	0.279	Ok			
	ESA_002	13	0.27	0.020	0.180	0.328	0.269	Ok			
		14	0.26	0.018	0.180	0.314	0.260	Ok			
	ESA_003	15	0.26	0.020	0.180	0.320	0.264	Ok			
		16	0.25	0.020	0.180	0.300	0.264	Ok			
	ESA_004	17	0.25	0.020	0.188	0.296	0.263	Ok			
		18	0.25	0.019	0.188	0.292	0.261	Ok			
	ESA_005	19	0.25	0.019	0.185	0.304	0.268	Ok			
		20	**0.24**	**0.019**	**0.180**	**0.285**	**0.243**	**Poor**			
	ESA_006	21	0.25	0.015	0.180	0.309	0.257	Ok			
		22	0.25	0.016	0.180	0.304	0.255	Ok			
	ESA_007	23	0.26	0.023	0.180	0.314	0.273	Ok			
		24	0.26	0.021	0.190	0.307	0.284	Ok			
	ESA_008	25	0.25	0.018	0.190	0.294	0.263	Ok			
		26	0.26	0.016	0.180	0.320	0.250	Ok			
	ESA_009	27	0.25	0.019	0.180	0.310	0.271	Ok			
		28	0.25	0.019	0.180	0.310	0.271	Ok			
	ESA_010	29	0.25	0.020	0.180	0.310	0.271	Ok			
		30	0.26	0.020	0.190	0.320	0.281	Ok			
	ESA_011	31	0.27	0.018	0.190	0.320	0.281	Ok			
		32	0.28	0.017	0.190	0.340	0.280	Ok			
	ESA_012	33	0.27	0.015	0.190	0.330	0.288	Ok			
		34	0.26	0.019	0.180	0.320	0.278	Ok			
	ESA_013	35	0.27	0.020	0.190	0.325	0.285	Ok			
		36	0.27	0.016	0.190	0.325	0.285	Ok			
	ESA_014	37	0.28	0.010	0.190	0.340	0.280	Ok			
	ESA_015	39	0.26	0.015	0.200	0.317	0.270	Ok			
		40	0.26	0.027	0.200	0.321	0.285	Ok			
	ESA_024	57	0.27	0.027	0.200	0.331	0.292	Ok			
		58	0.27	0.026	0.200	0.336	0.295	Ok			
	ESA_025	59	0.27	0.027	0.200	0.336	0.295	Ok			

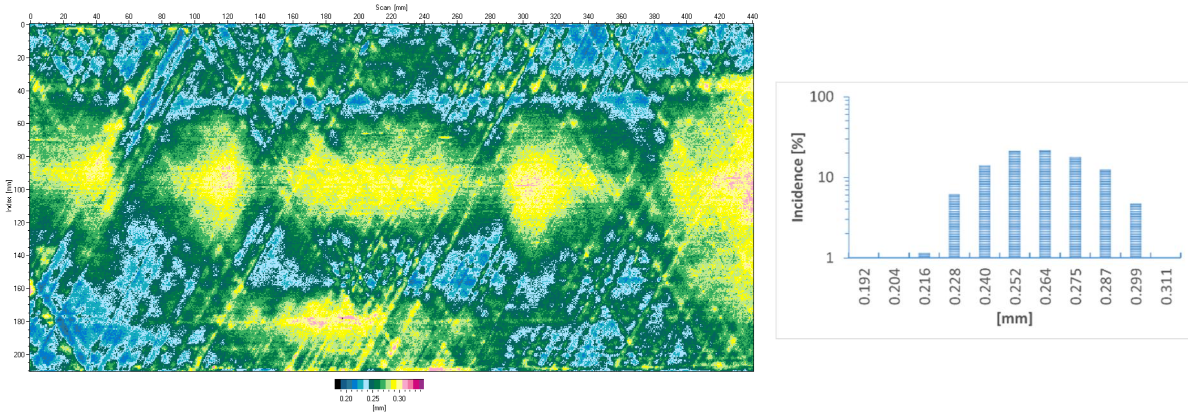


Figure 2.1. Panel Face ID **11** (60/0/-60) 100g/m^2

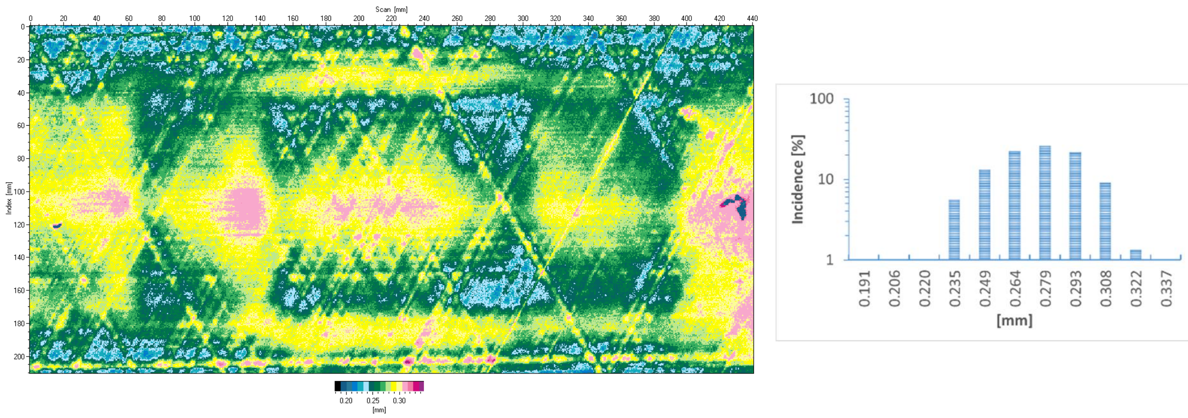


Figure 2.2. Panel Face ID **12** (60/0/-60) 100g/m^2

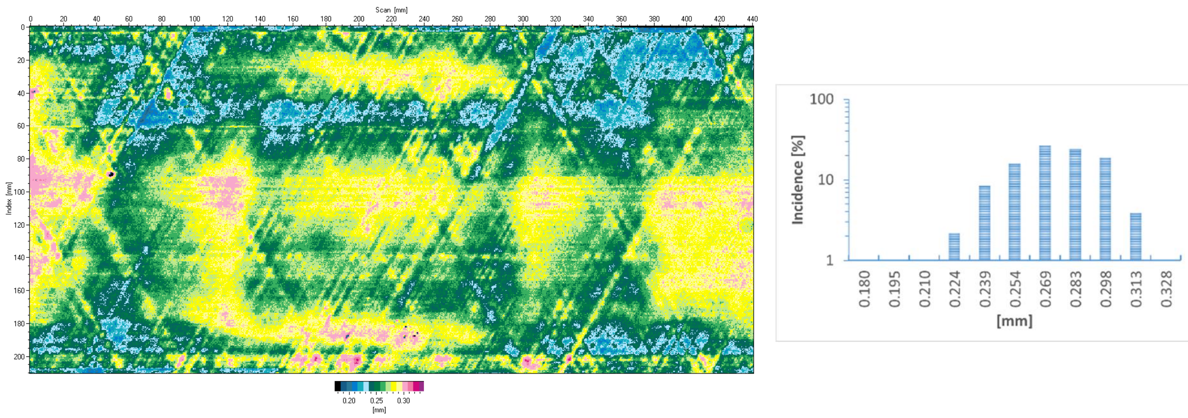


Figure 2.3. Panel Face ID **13** (60/0/-60) 100g/m^2

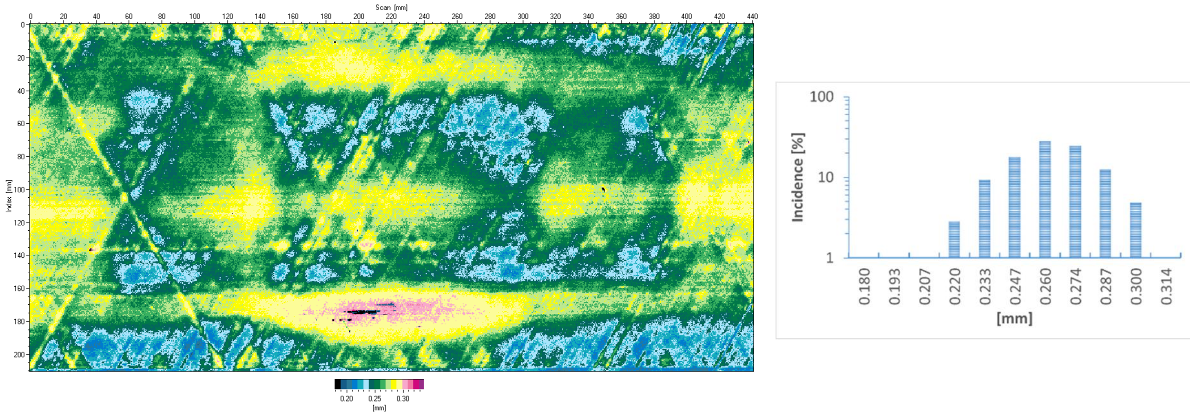
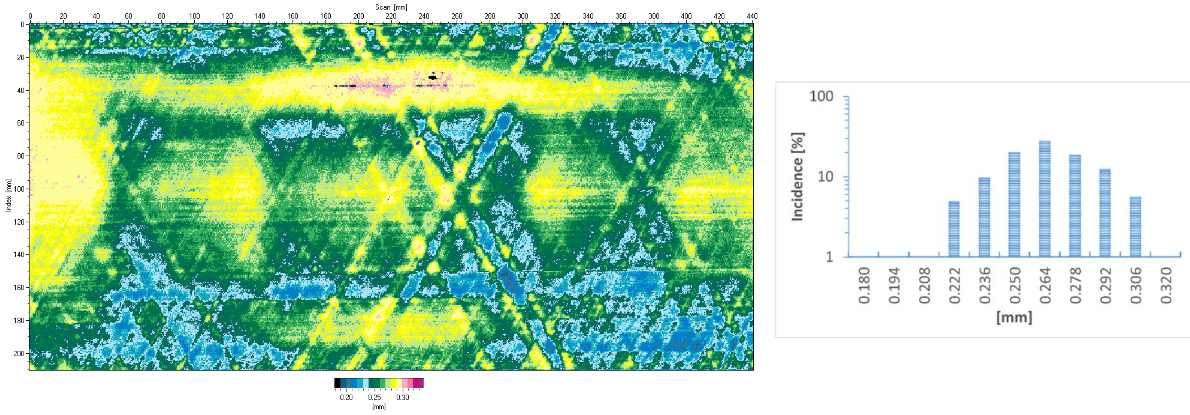


Figure 2.4. Panel Face ID **14** (60/0/-60) 100g/m^2



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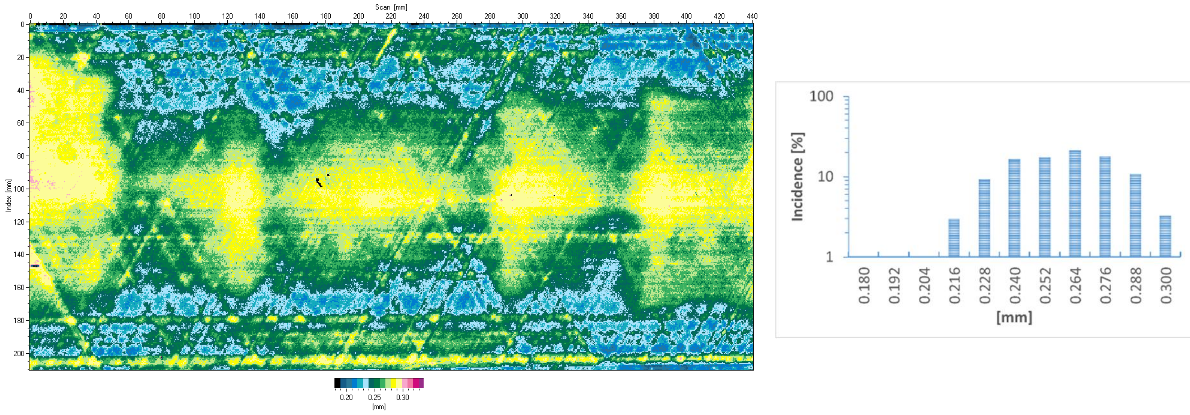


Figure 2.6. Panel Face ID **16** (60/0/-60) 100g/m^2

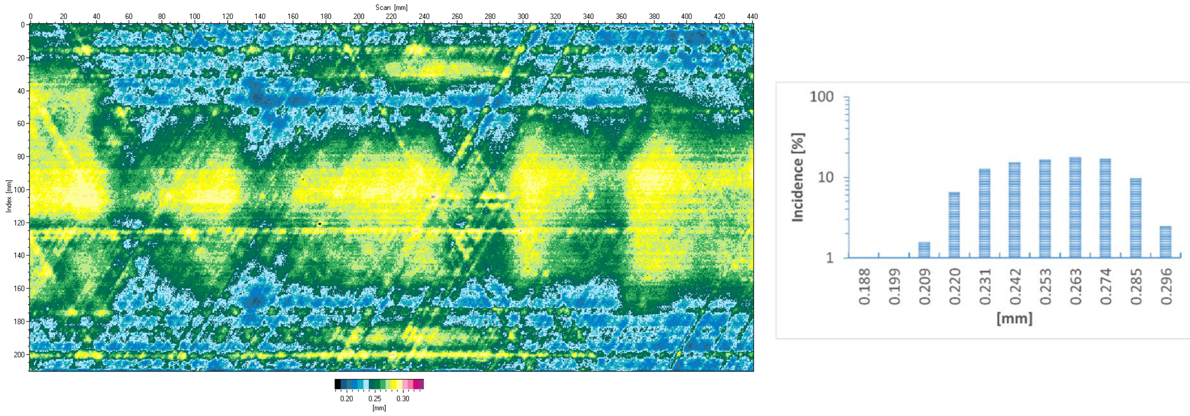


Figure 2.7. Panel Face ID **17** (60/0/-60) 100g/m^2

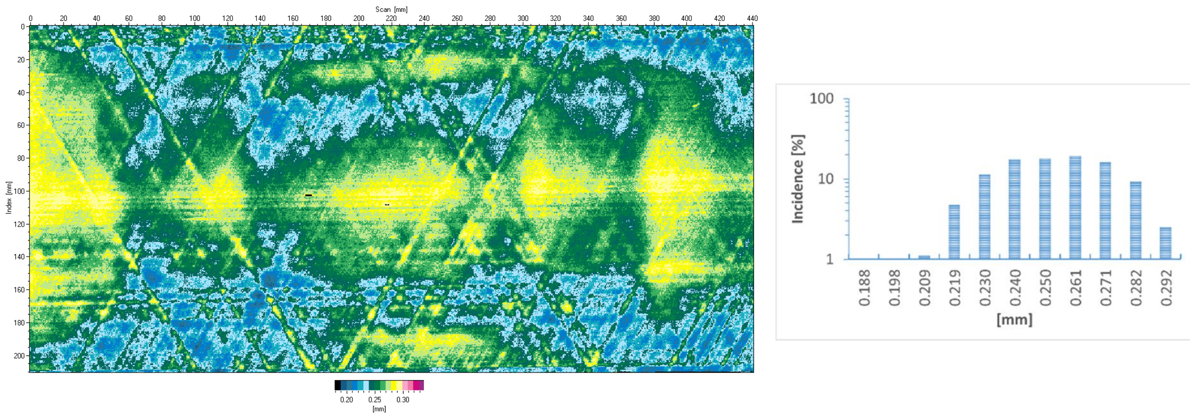


Figure 2.8. Panel Face ID **18** (60/0/-60) 100g/m^2

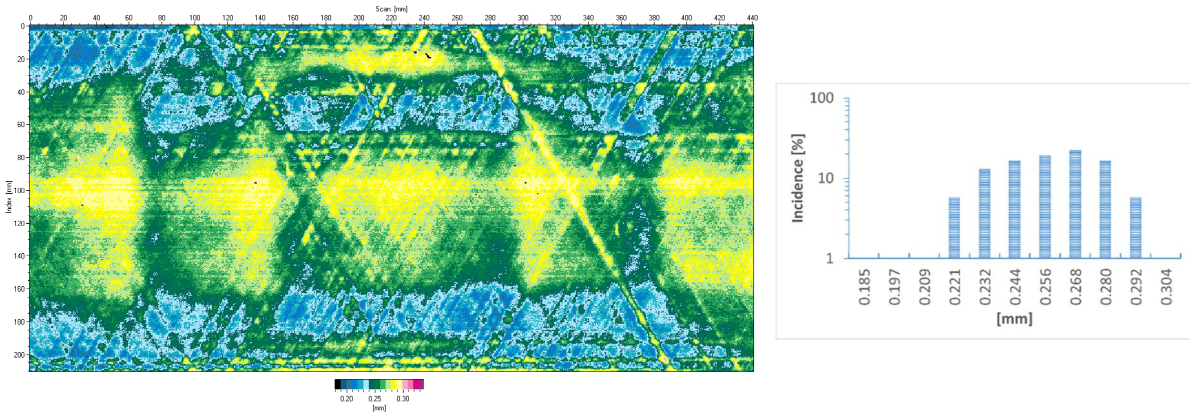


Figure 2.9. Panel Face ID **19** (60/0/-60) 100g/m^2

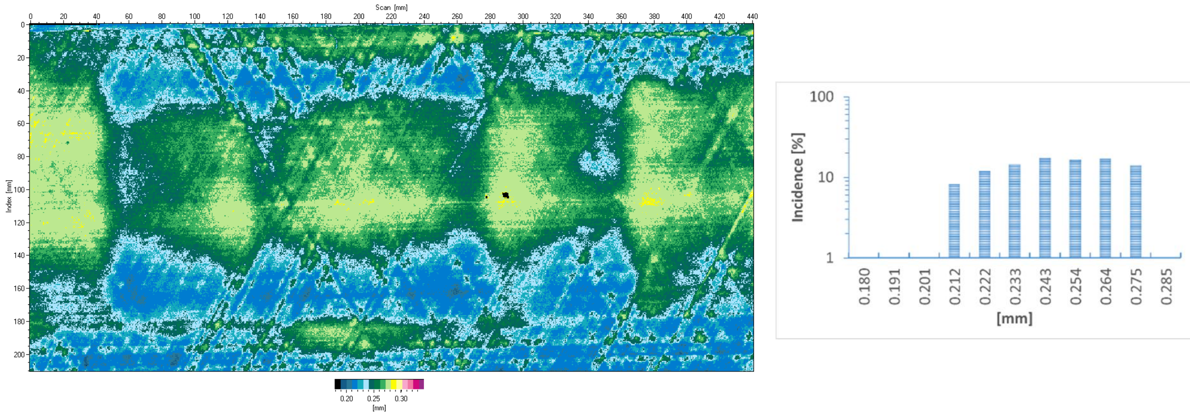


Figure 2.10. Panel Face ID **20** (60/0/-60) 100g/m^2

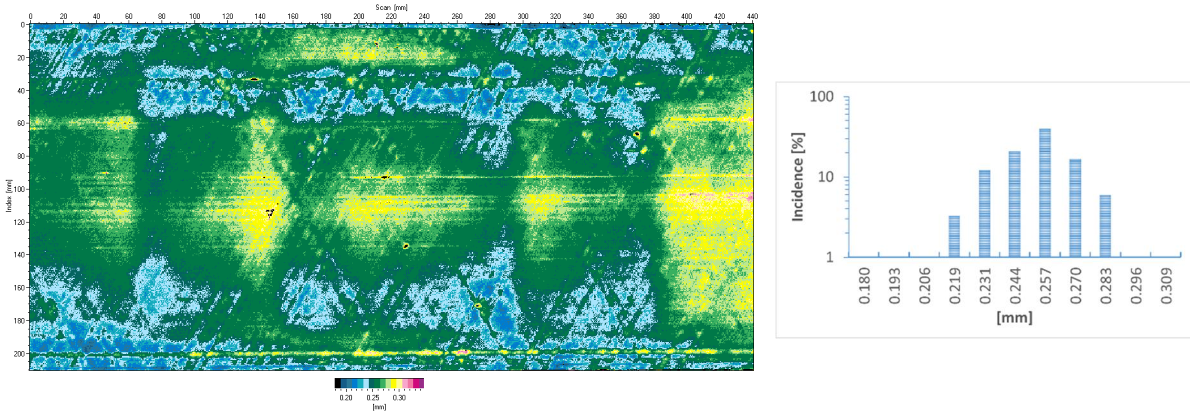


Figure 2.11. Panel Face ID **21** (60/0/-60) 100g/m^2

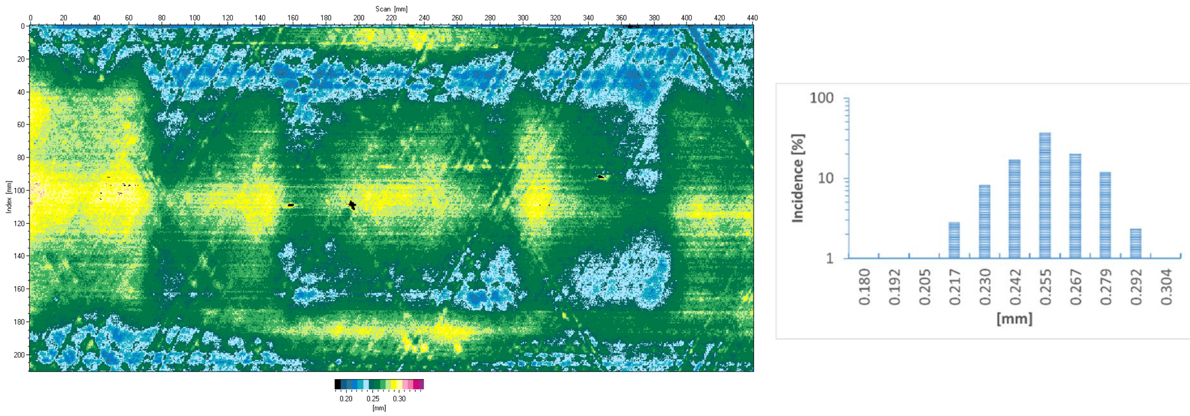


Figure 2.12. Panel Face ID **22** (60/0/-60) 100g/m^2

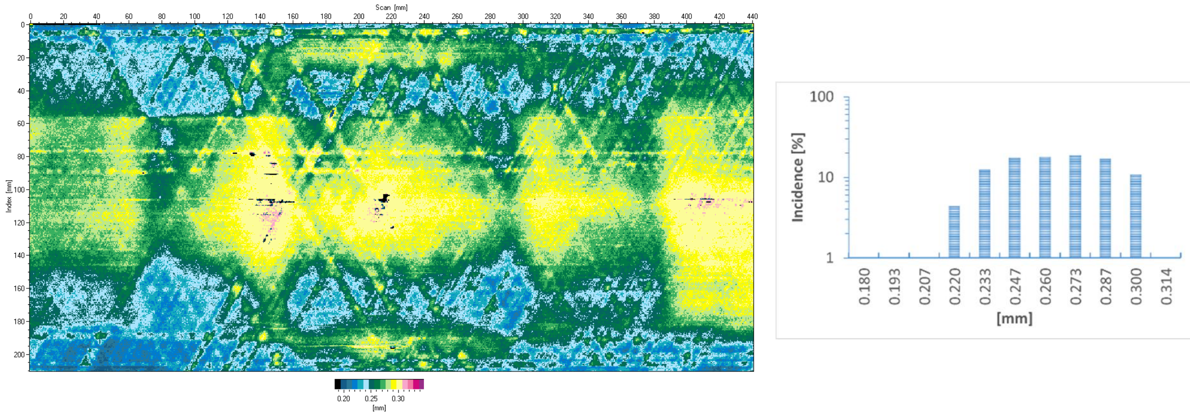


Figure 2.13. Panel Face ID **23** (60/0/-60) 100g/m^2

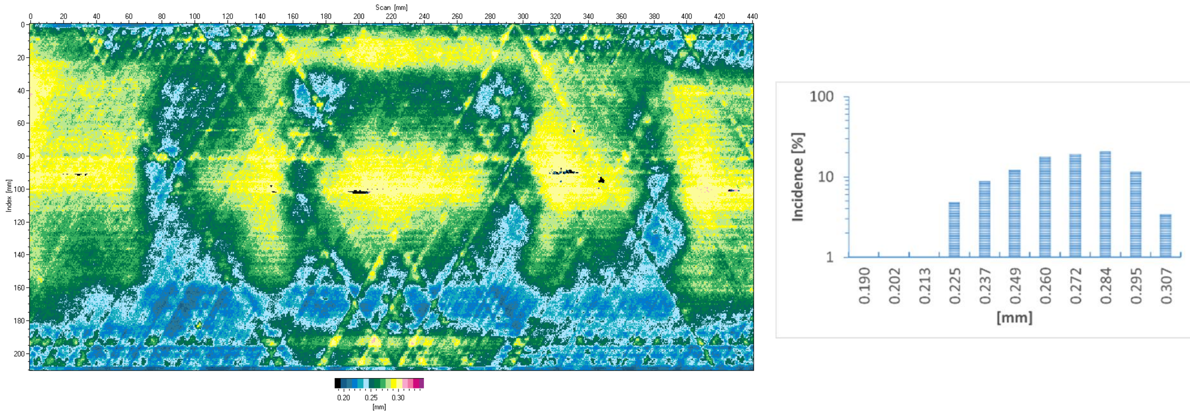
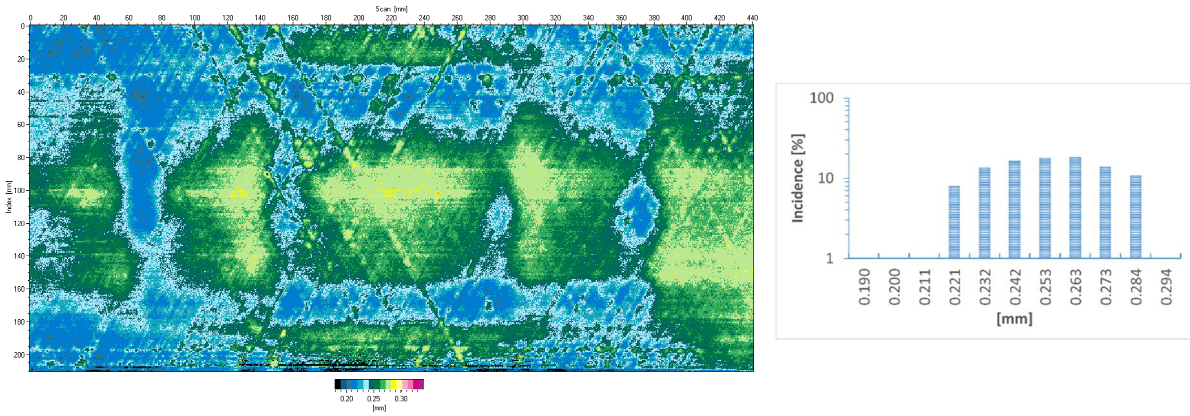


Figure 2.14. Panel Face ID **24** (60/0/-60) 100g/m^2



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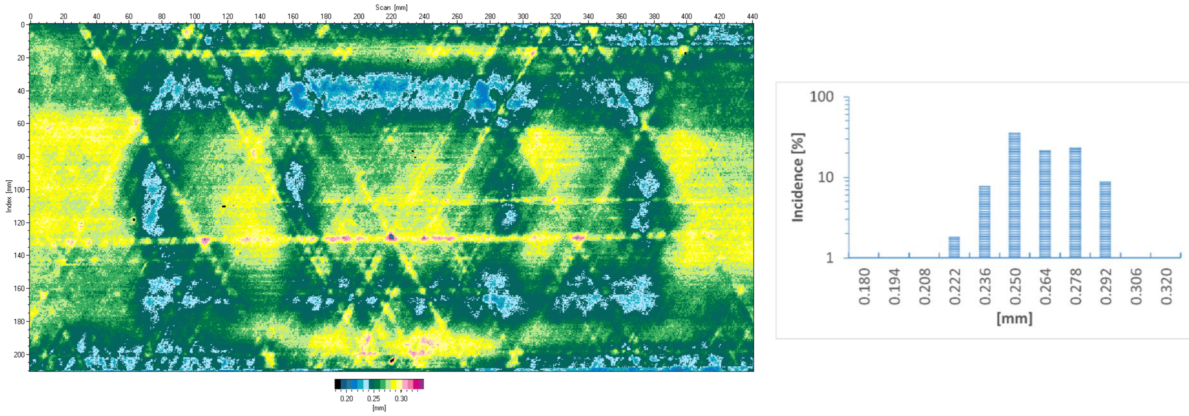


Figure 2.16. Panel Face ID **26** (60/0/-60) 100g/m^2

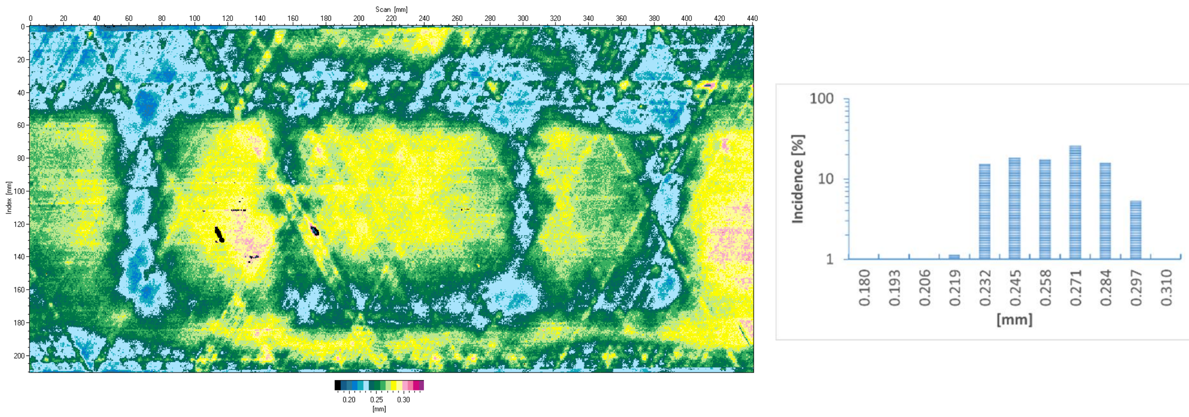


Figure 2.17. Panel Face ID **27** (60/0/-60) 100g/m^2

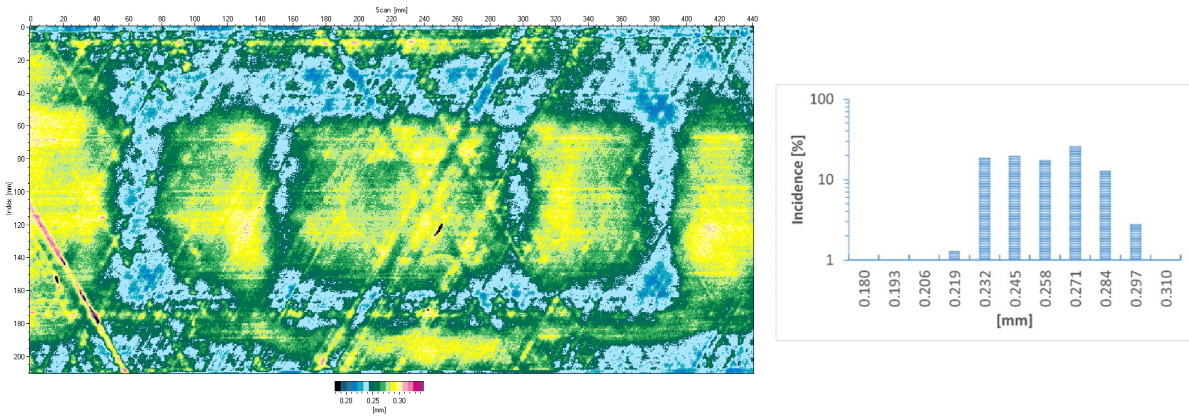


Figure 2.18. Panel Face ID **28** (60/0/-60) 100g/m^2

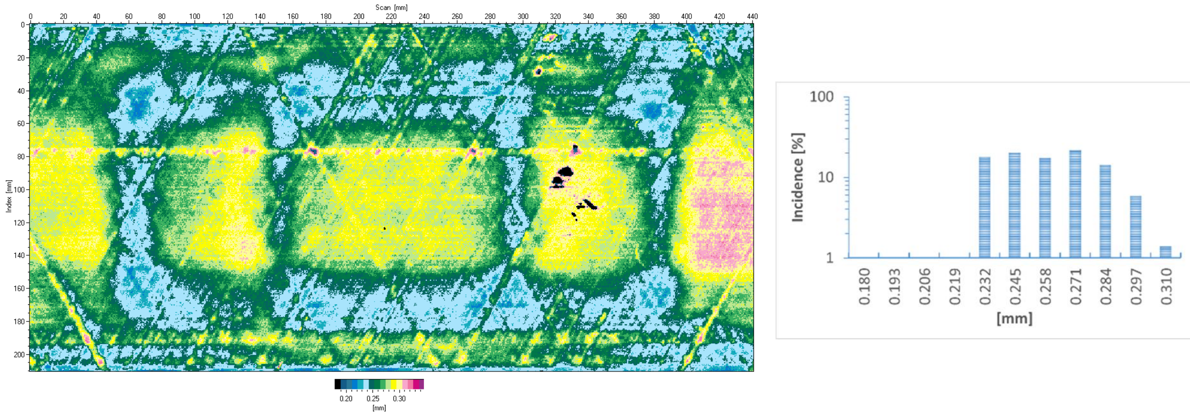


Figure 2.19. Panel Face ID **29** (60/0/-60) 100g/m^2

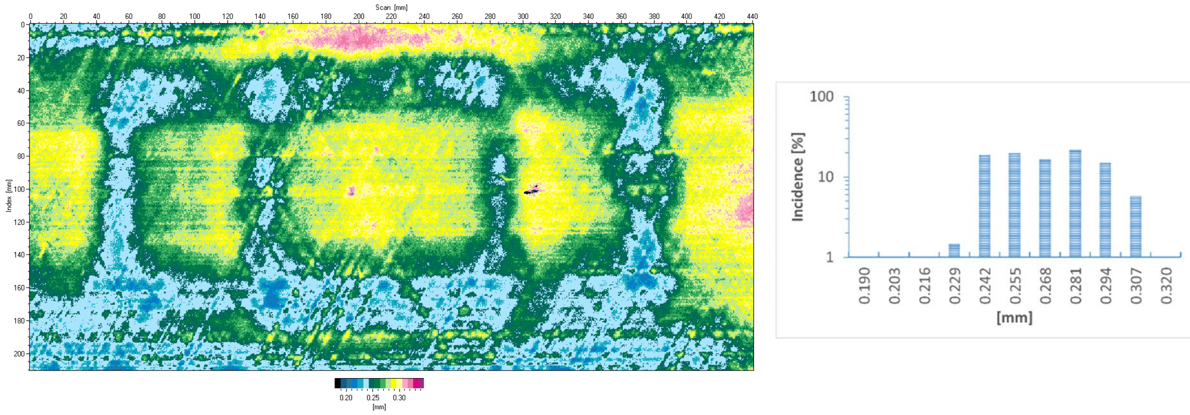


Figure 2.20. Panel Face ID **30** (60/0/-60) 100g/m^2

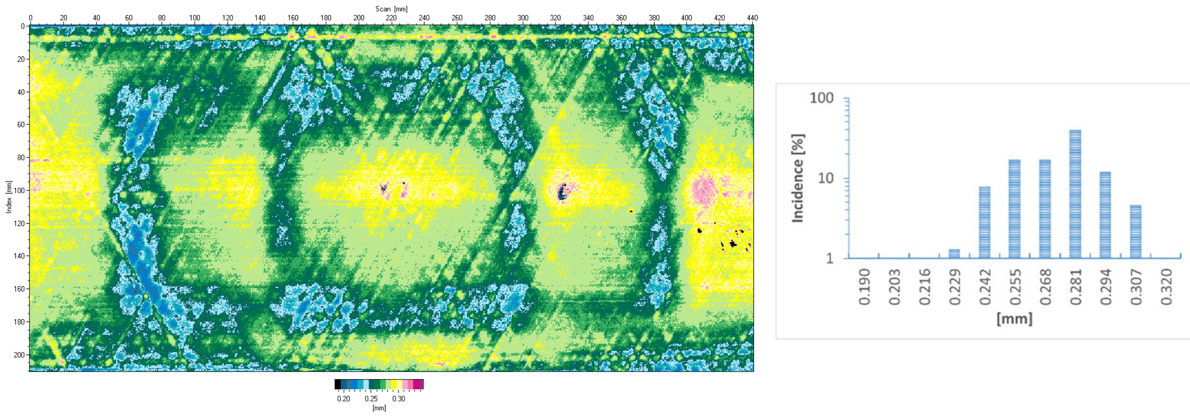


Figure 2.21. Panel Face ID **31** (60/0/-60) 100g/m^2

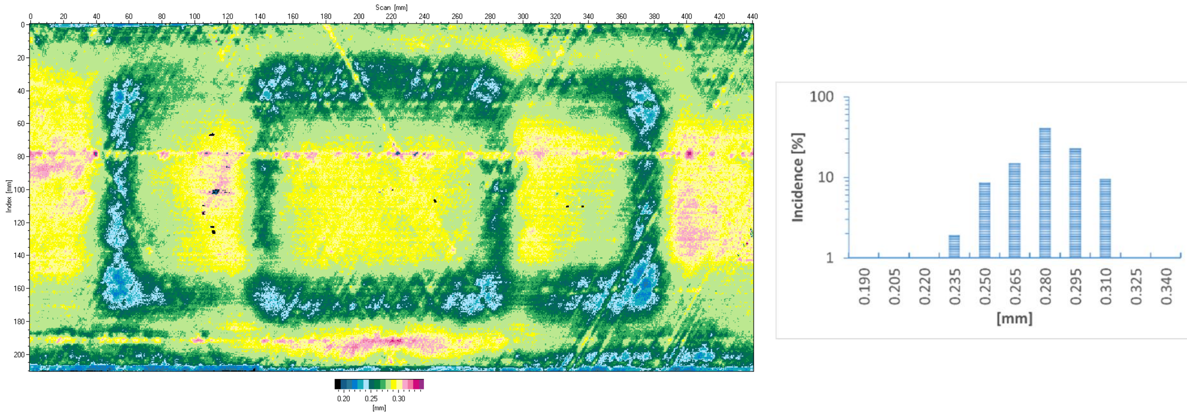


Figure 2.22. Panel Face ID **32** (60/0/-60) 100g/m^2

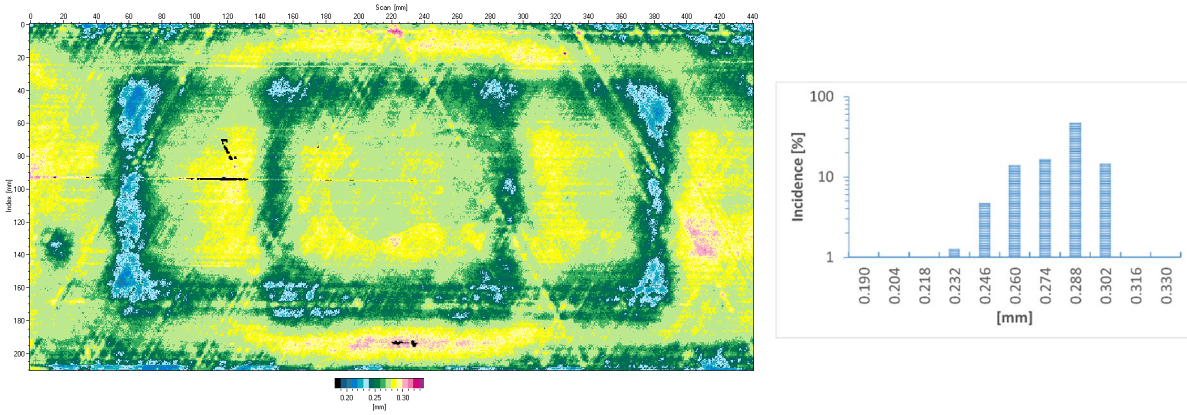


Figure 2.23. Panel Face ID **33** (60/0/-60) 100g/m^2

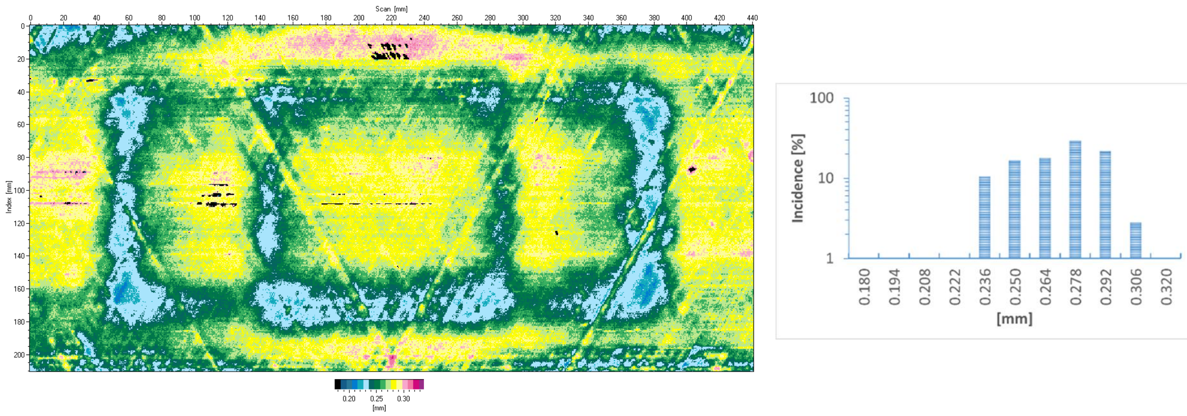


Figure 2.24. Panel Face ID **34** (60/0/-60) 100g/m^2

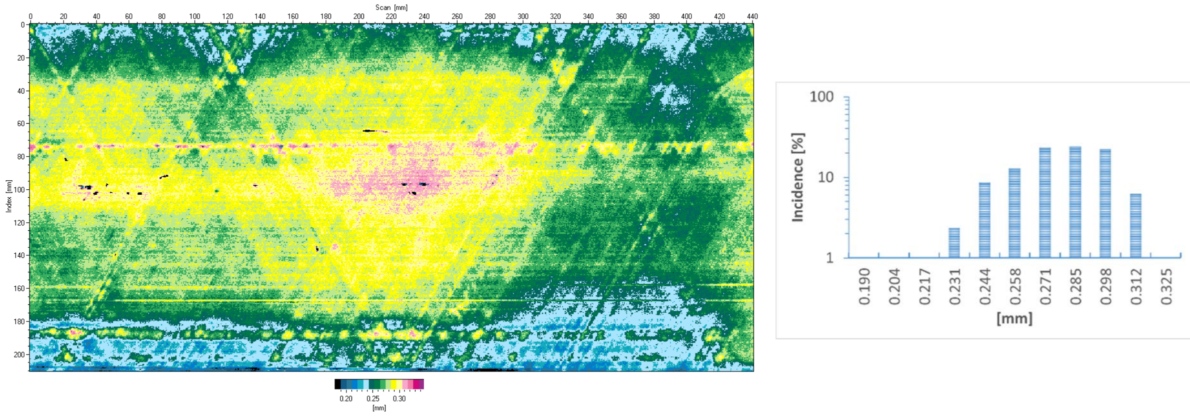


Figure 2.25. Panel Face ID **35** (60/0/-60) 100g/m^2

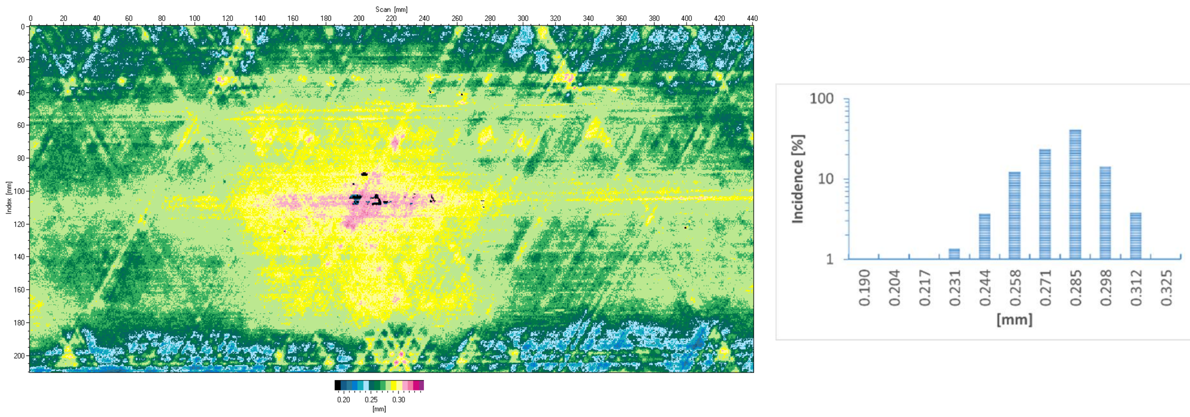


Figure 2.26. Panel Face ID **36** (60/0/-60) 100g/m^2

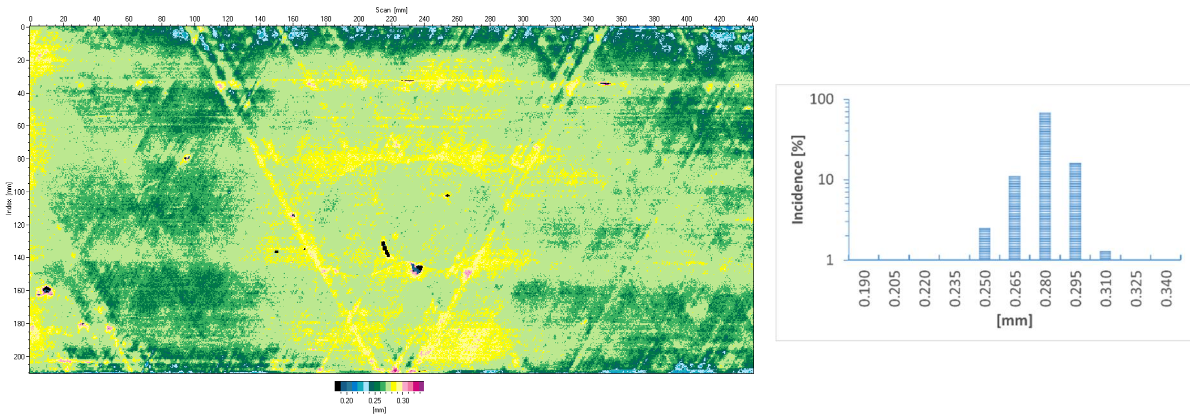


Figure 2.27. Panel Face ID **37** (60/0/-60) 100g/m^2

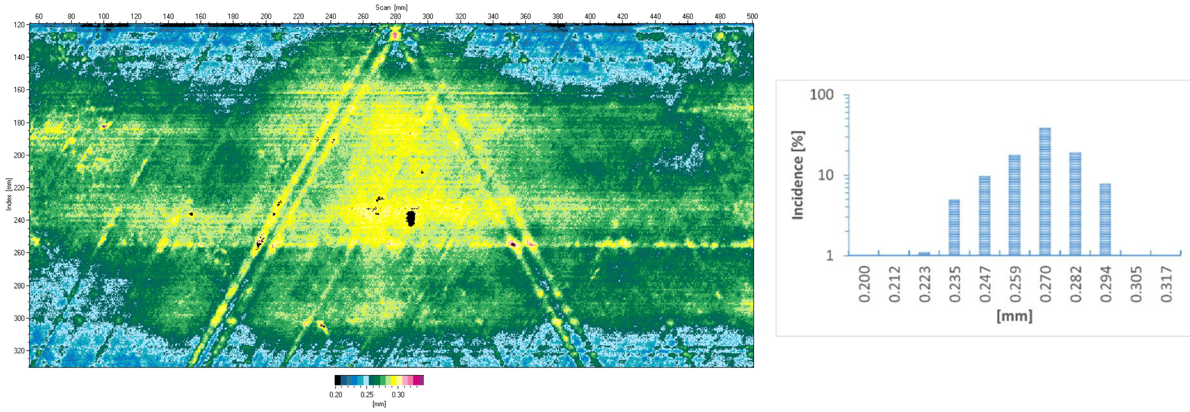


Figure 2.28. Panel Face ID **39** (60/0/-60) 100g/m^2

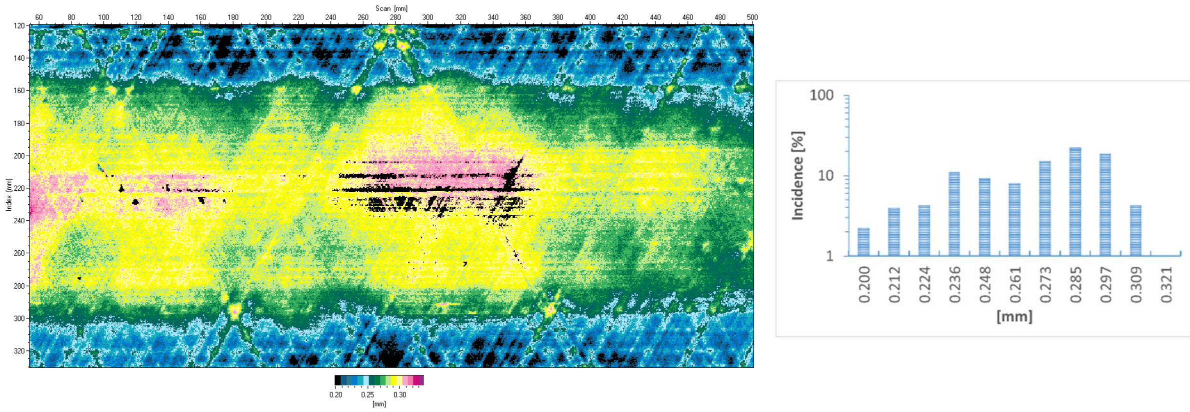


Figure 2.29. Panel Face ID 40 (60/0/-60) 100g/m^2

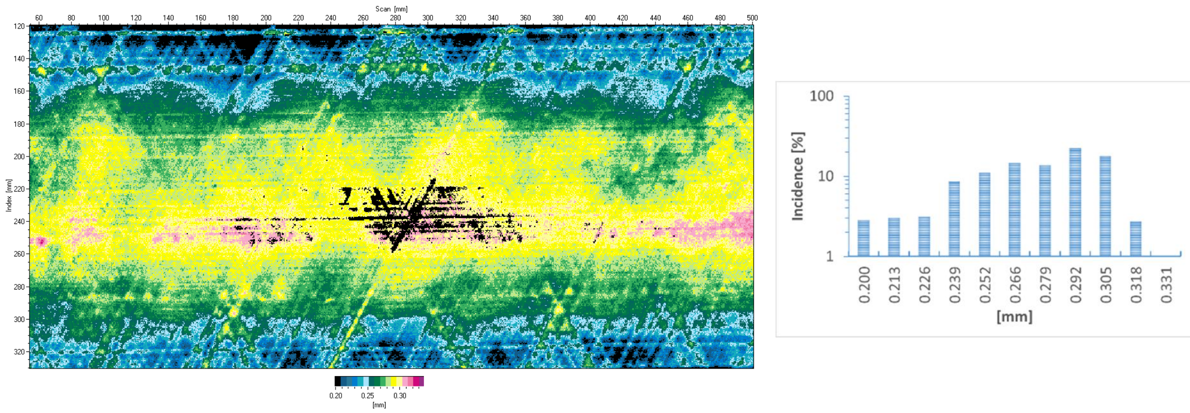


Figure 2.30. Panel Face ID 57 (60/0/-60) 100g/m^2

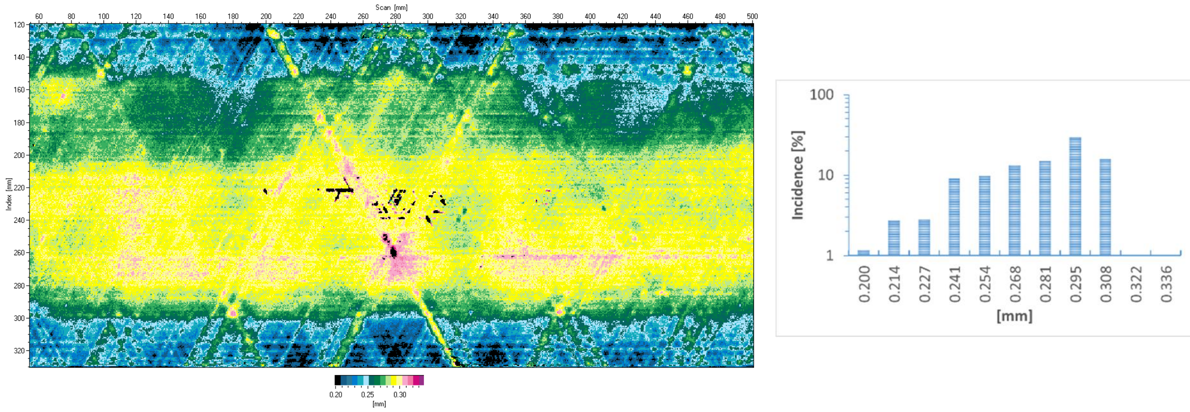


Figure 2.31. Panel Face ID 58 (60/0/-60) 100g/m^2

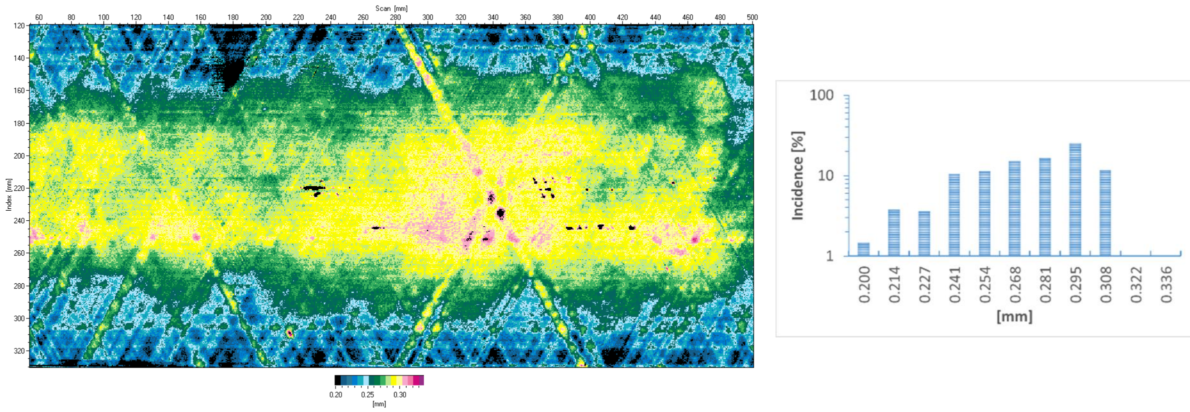


Figure 2.32. Panel Face ID 59 (60/0/-60) 100g/m^2

2.2 Face sheet lay-up 0/60/-60/0

Panels made of four-ply lay-up 0/60/-60/0 was inspected. By summarising all 13 samples the average thickness of 0.353mm and STD is 0.0175 was set for numerical analysis.

Table 2.2. Average measured thickness of full-scale panels by layup [0/60/-60/0]

	Panel ID	Face ID	AVE	STD	Min	Max	Histogram max		δ–2σ	δ	δ+2σ
[0/60/-60/0]	ESA_016	41	0.34	0.027	0.260	0.420	0.34	Ok	0.318	0.353	0.388
		42	0.37	0.026	0.290	0.460	0.375	Ok			
	ESA_017	43	0.36	0.023	0.290	0.460	0.375	Ok			
		44	0.35	0.028	0.250	0.470	0.36	Ok			
	ESA_027	63	0.38	0.037	0.300	0.473	0.421	Ok			
		64	0.36	0.023	0.300	0.500	0.38	Ok			
	ESA_028	65	0.35	0.027	0.260	0.420	0.372	Ok			
		66	0.36	0.020	0.270	0.398	0.372	Ok			
	ESA_029	67	0.35	0.024	0.270	0.419	0.374	Ok			
		68	0.35	0.021	0.270	0.430	0.366	Ok			
	ESA_030	69	0.34	0.020	0.265	0.389	0.364	Ok			
		70	0.36	0.020	0.280	0.430	0.37	Ok			
	ESA_031	71	0.34	0.022	0.280	0.435	0.373	Ok			
		72	0.34	0.021	0.280	0.435	0.342	Ok			
	ESA_032	73	0.36	0.021	0.280	0.438	0.375	Ok			
		74	0.36	0.027	0.280	0.495	0.366	Ok			
	ESA_033	**75**	**0.39**	**0.026**	**0.300**	**0.520**	**0.388**	**Poor**			
		76	0.36	0.026	0.270	0.470	0.39	Ok			
	ESA_034	**77**	**0.39**	**0.031**	**0.300**	**0.480**	**0.408**	**Poor**			
		78	0.34	0.020	0.280	0.430	0.37	Ok			
	ESA_035	79	0.34	0.021	0.280	0.420	0.364	Ok			
		80	0.34	0.021	0.280	0.415	0.361	Ok			
	ESA_049	107	0.34	0.018	0.280	0.425	0.353	Ok			
		108	**0.31**	**0.018**	**0.260**	**0.362**	**0.311**	**Poor**			
	ESA_050	109	0.34	0.016	0.280	0.414	0.36	Ok			
		110	0.35	0.017	0.290	0.435	0.377	Ok			

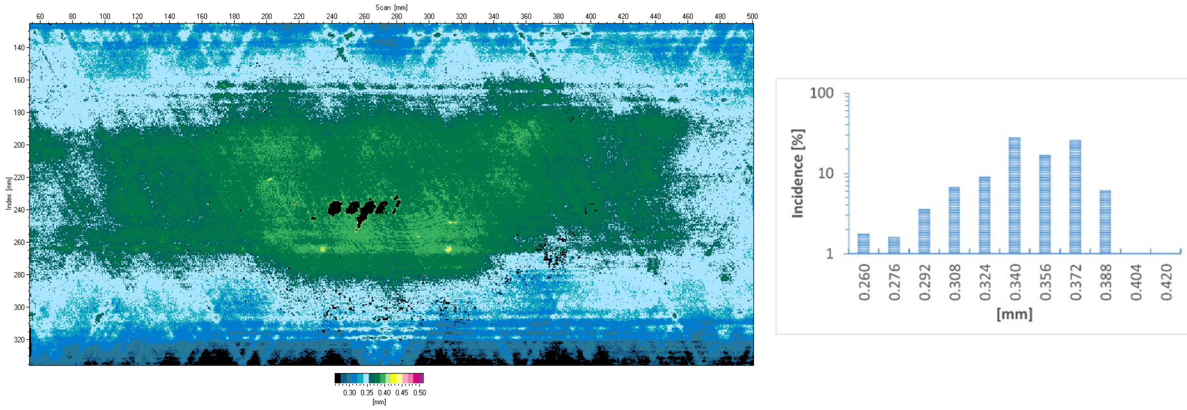


Figure 2.33. Panel Face ID 41 (0/60/-60/0) 100g/m^2

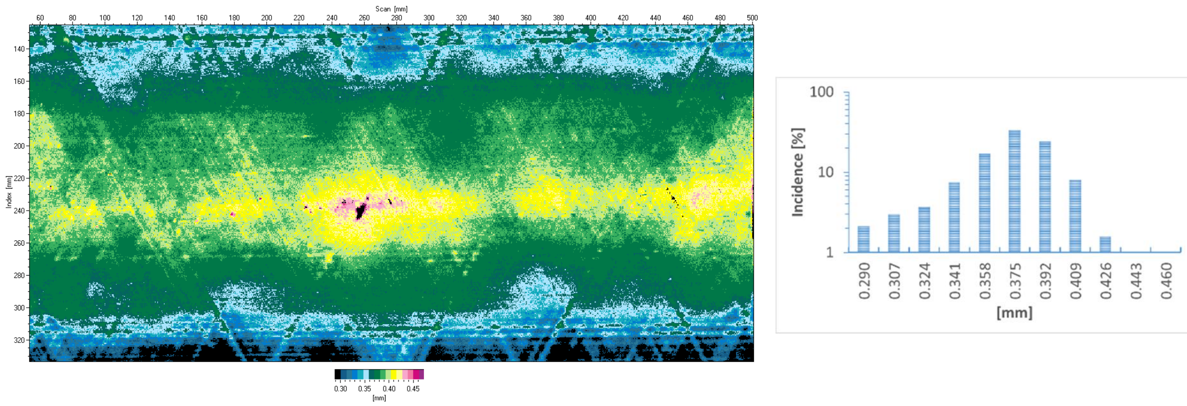


Figure 2.34. Panel Face ID 42 (0/60/-60/0) 100g/m^2

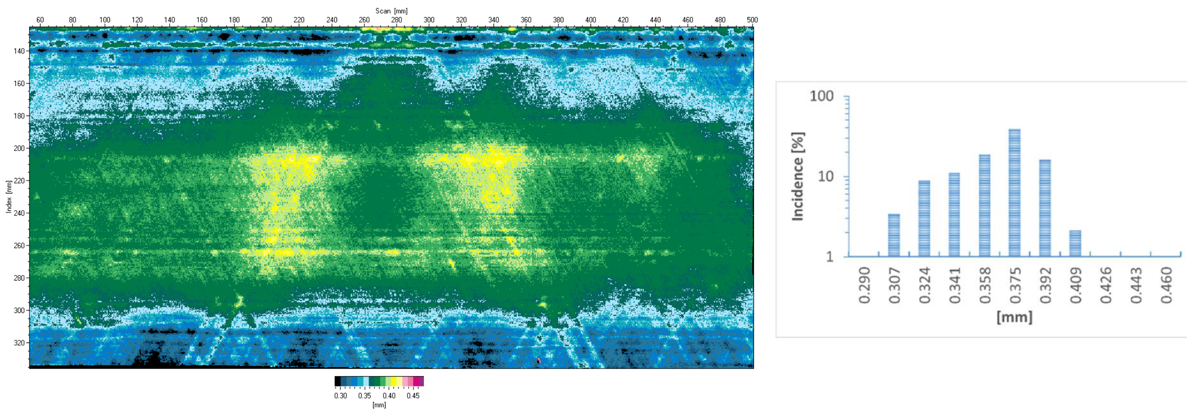


Figure 2.35. Panel Face ID 43 (0/60/-60/0) 100g/m^2

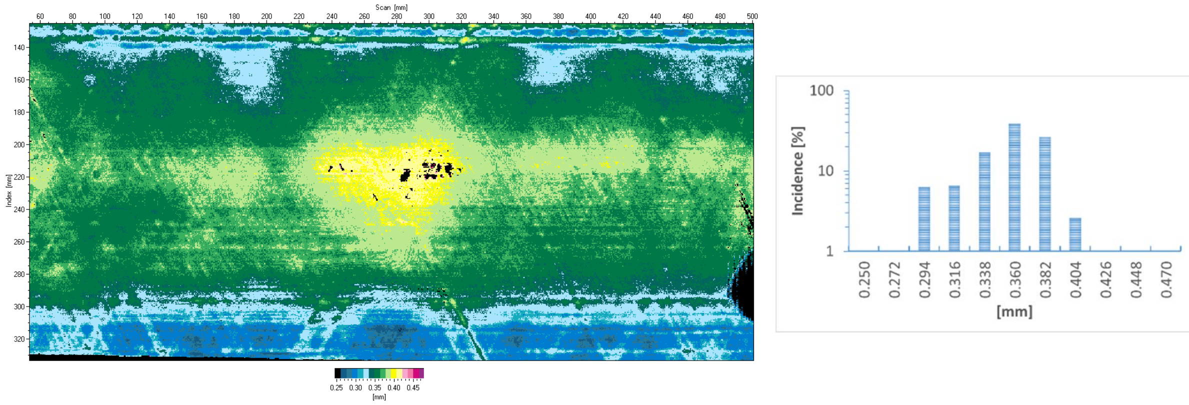


Figure 2.36. Panel Face ID 44 (0/60/-60/0) 100g/m^2

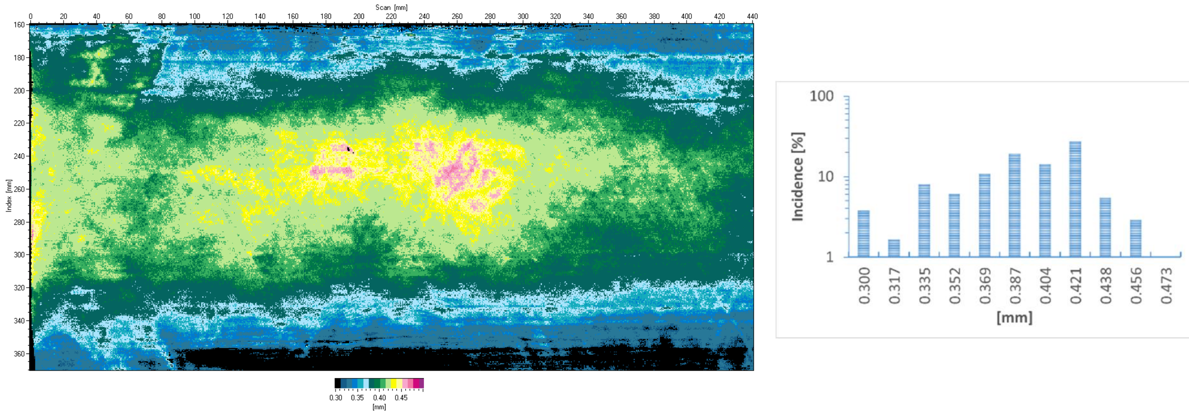


Figure 2.37. Panel Face ID 63 (0/60/-60/0) 100g/m^2

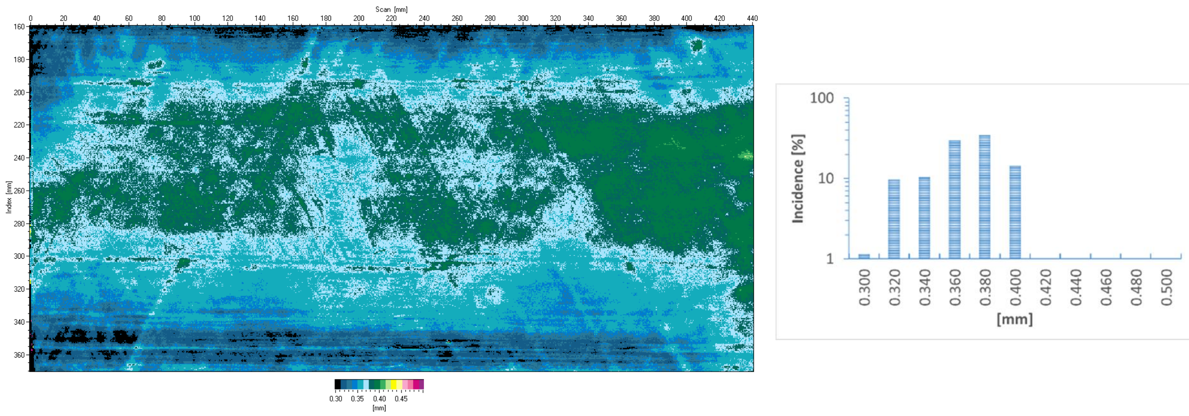


Figure 2.38. Panel Face ID 64 (0/60/-60/0) 100g/m^2

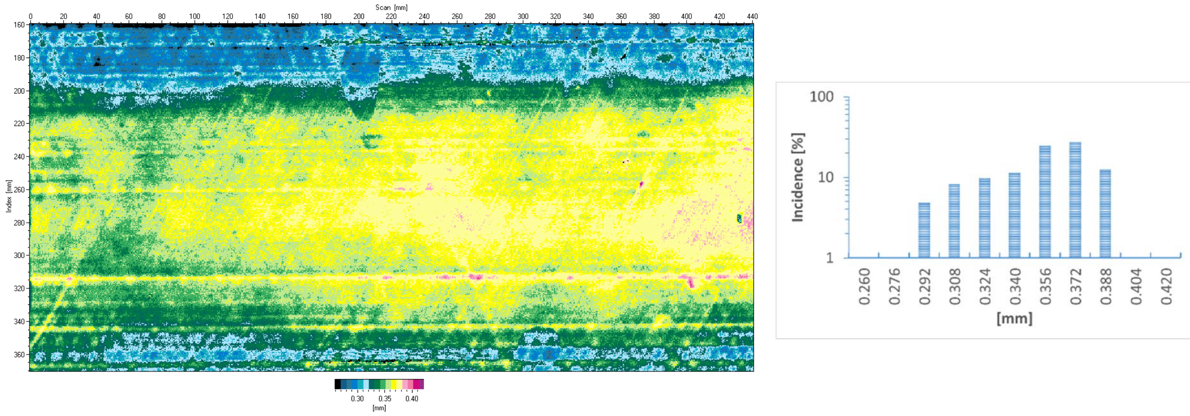


Figure 2.39. Panel Face ID 65 (0/60/-60/0) 100g/m^2

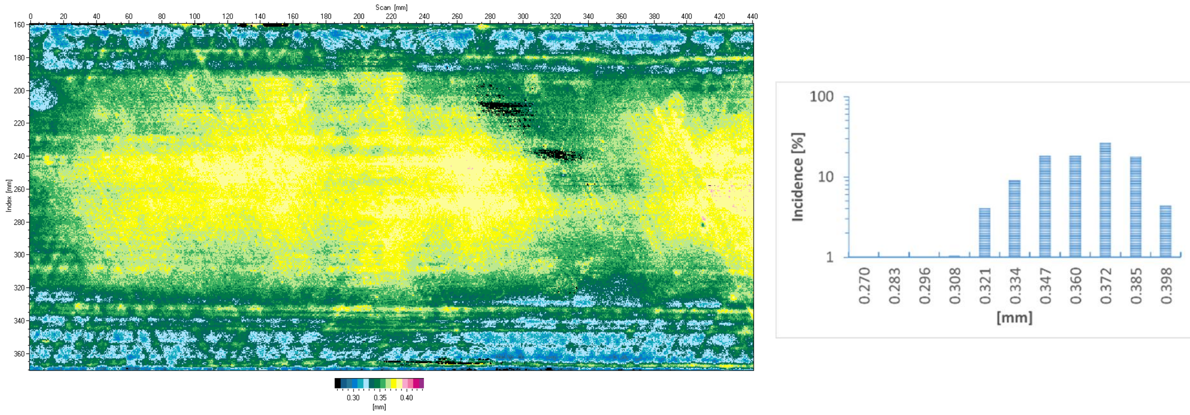


Figure 2.40. Panel Face ID 66 (0/60/-60/0) 100g/m^2

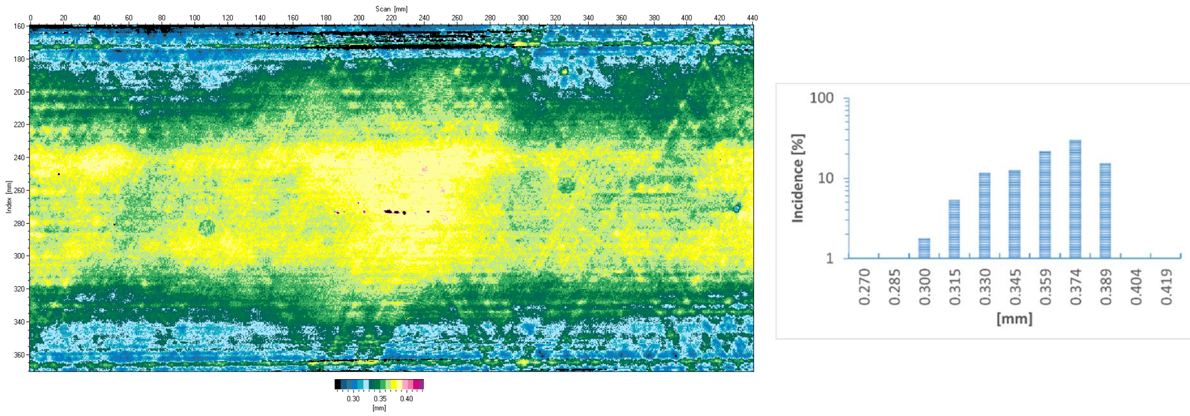


Figure 2.41. Panel Face ID 67 (0/60/-60/0) 100g/m^2

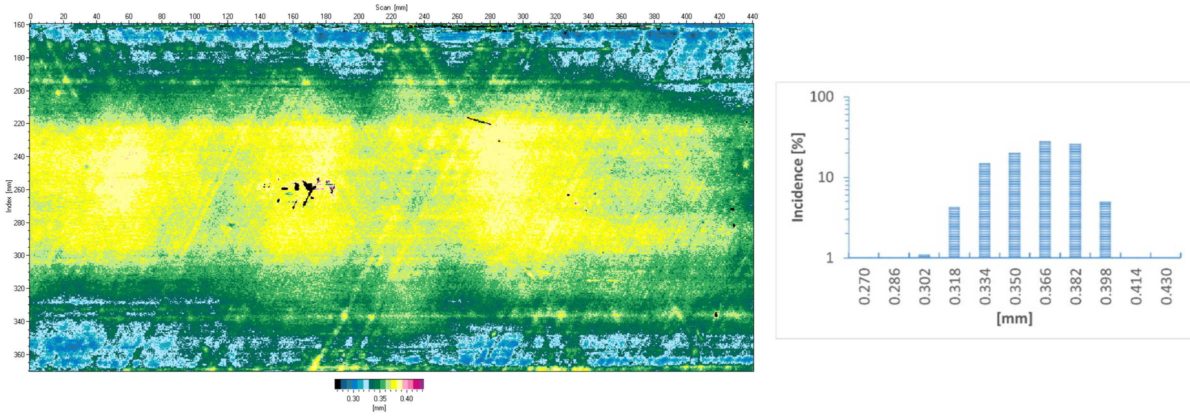


Figure 2.42. Panel Face ID 68 (0/60/-60/0) 100g/m^2

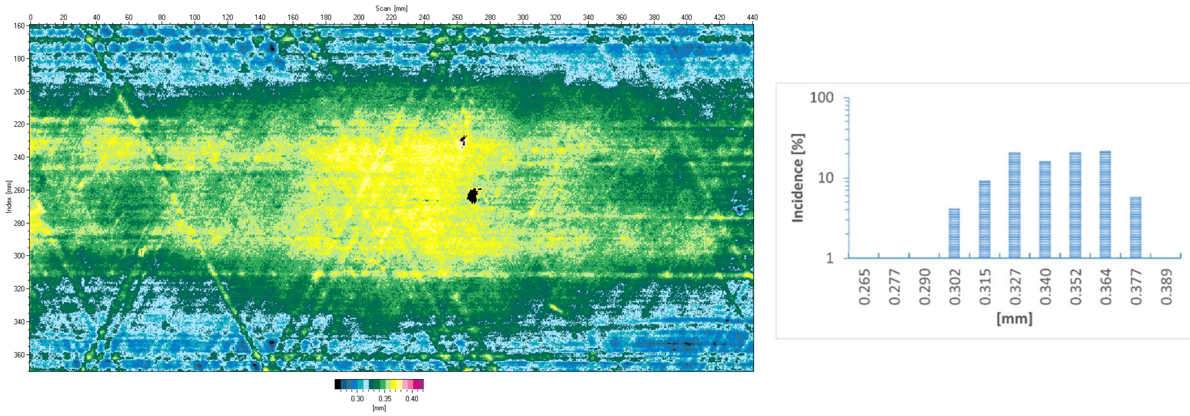


Figure 2.43. Panel Face ID 69 (0/60/-60/0) 100g/m^2

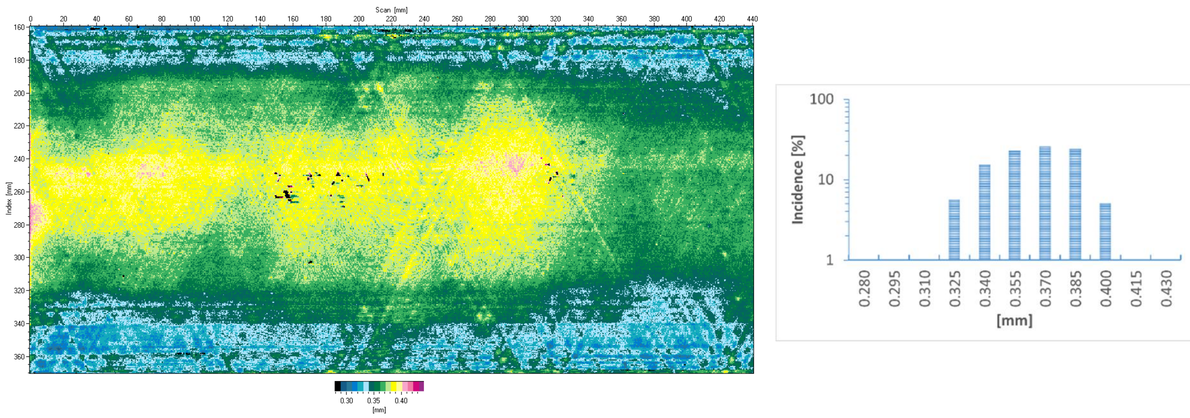


Figure 2.44. Panel Face ID 70 (0/60/-60/0) 100g/m^2

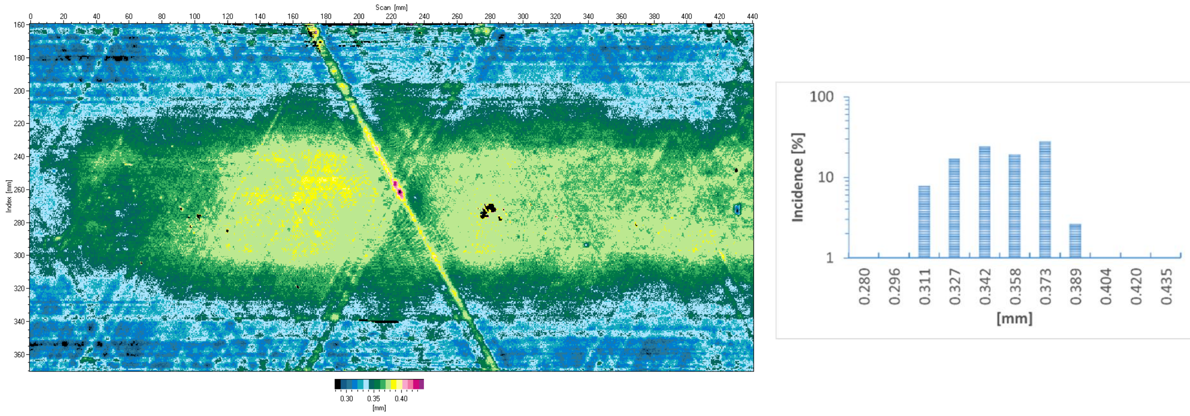


Figure 2.45. Panel Face ID 71 (0/60/-60/0) 100g/m^2

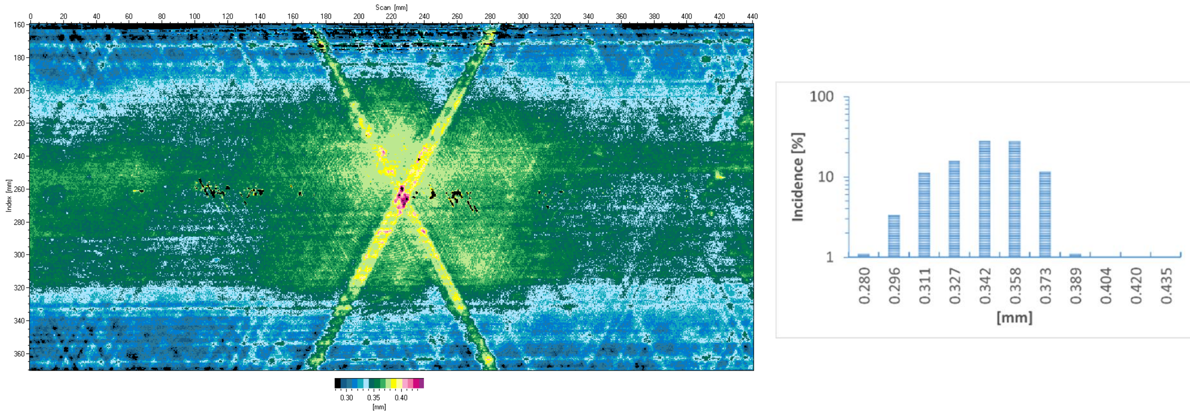


Figure 2.46. Panel Face ID 72 (0/60/-60/0) 100g/m^2

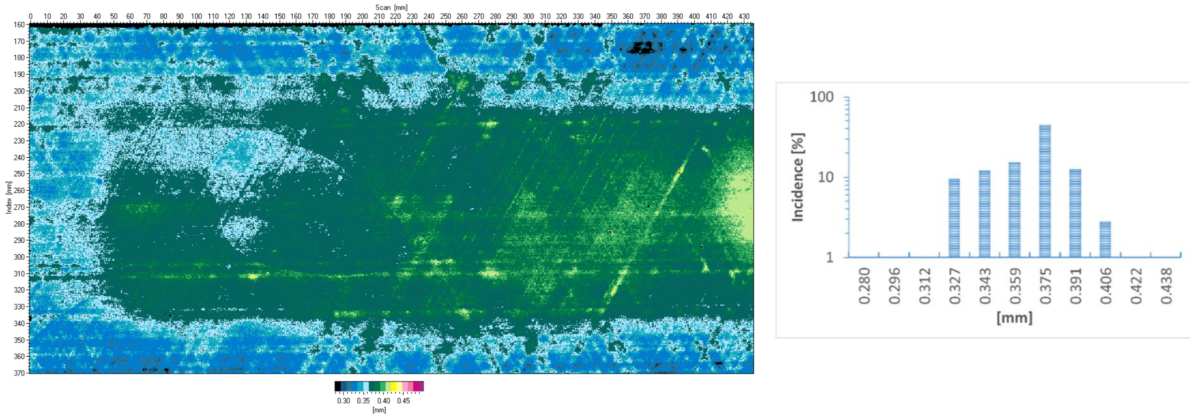


Figure 2.47. Panel Face ID 73 (0/60/-60/0) 100g/m^2

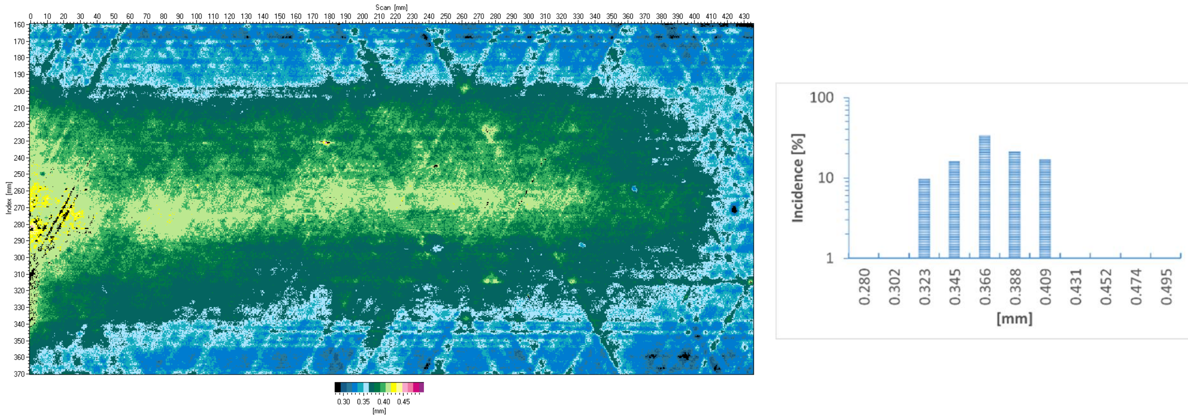


Figure 2.48. Panel Face ID 74 (0/60/-60/0) 100g/m^2

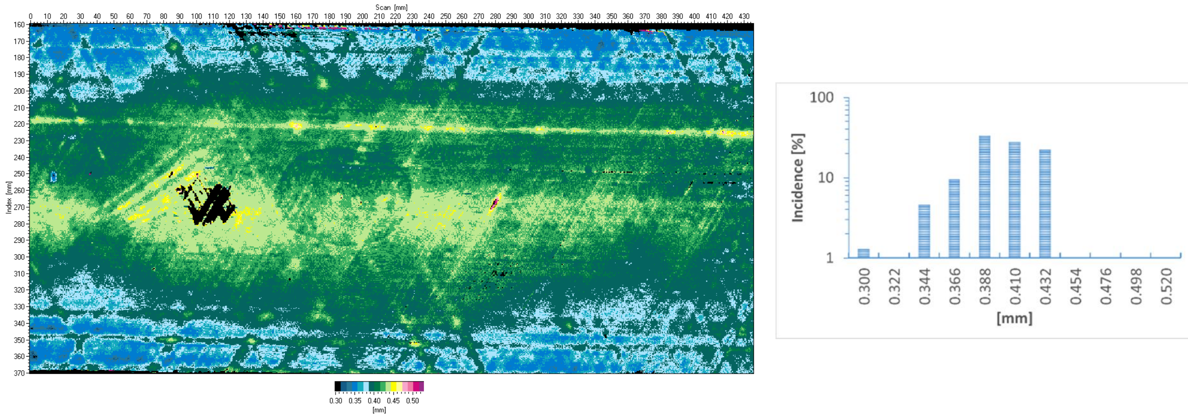


Figure 2.49. Panel Face ID 75 (0/60/-60/0) 100g/m^2

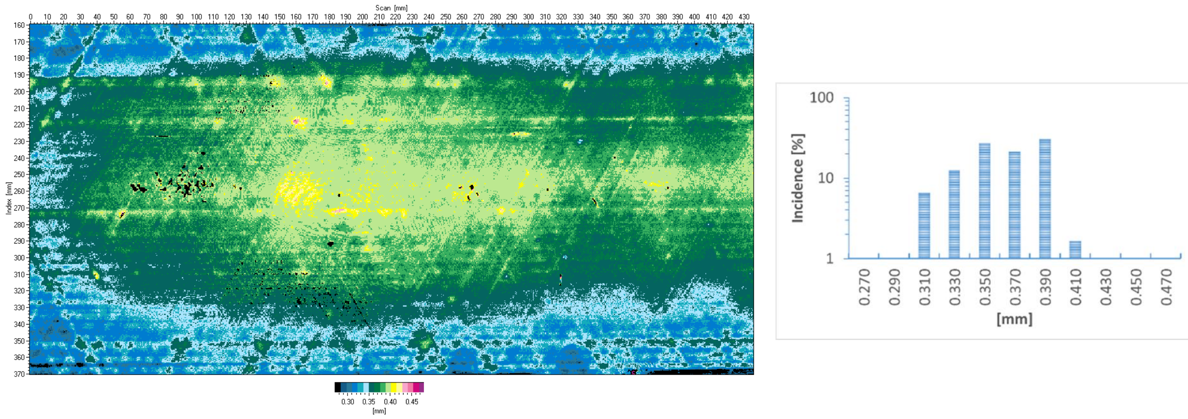


Figure 2.50. Panel Face ID 76 (0/60/-60/0) 100g/m^2

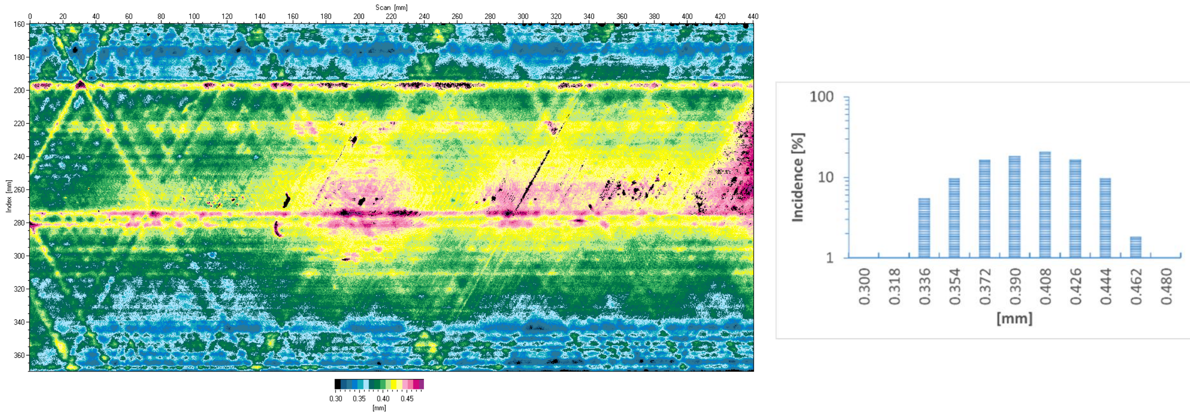


Figure 2.51. Panel Face ID 77 (0/60/-60/0) 100g/m²

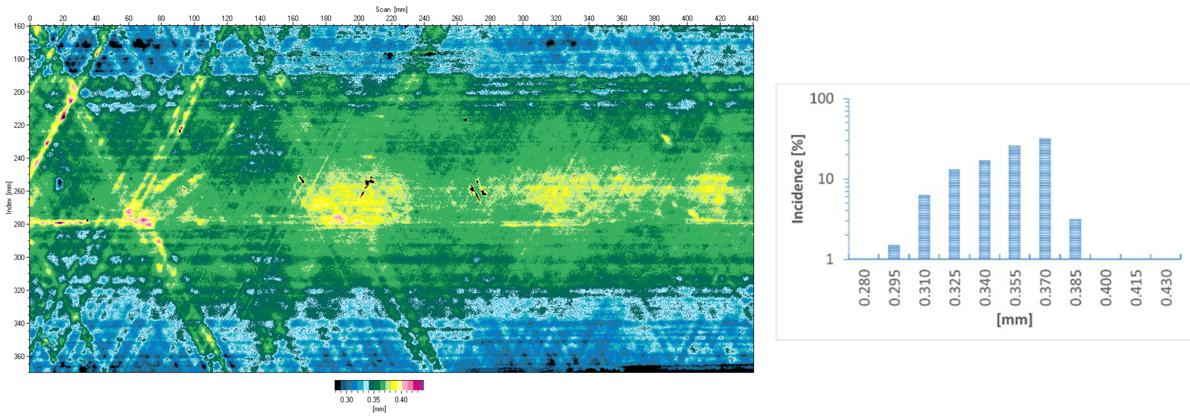


Figure 2.52. Panel Face ID 78 (0/60/-60/0) 100g/m²

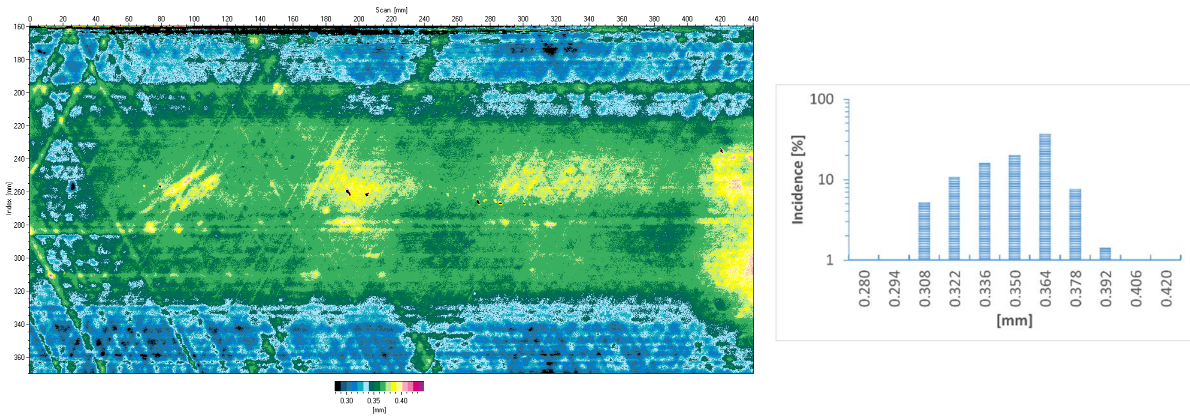


Figure 2.53. Panel Face ID 79 (0/60/-60/0) 100g/m²

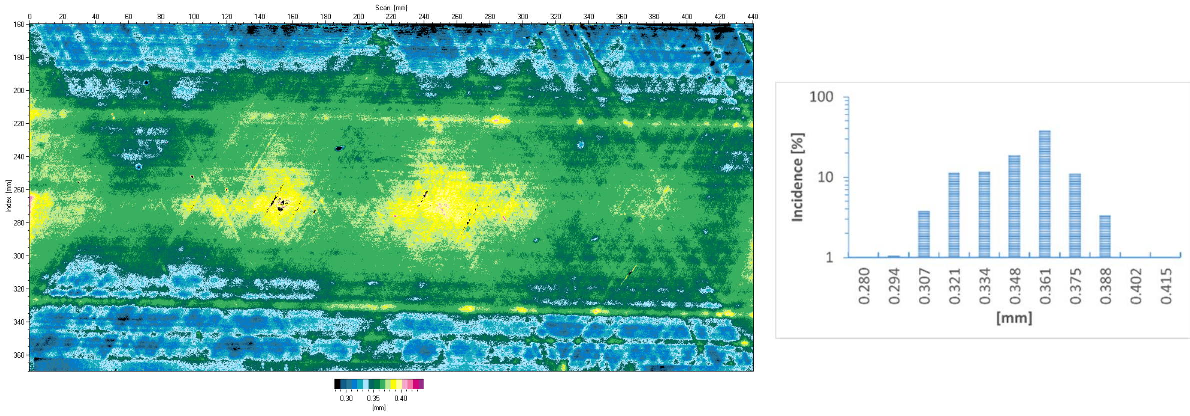


Figure 2.54. Panel Face ID 80 (0/60/-60/0) 100g/m^2

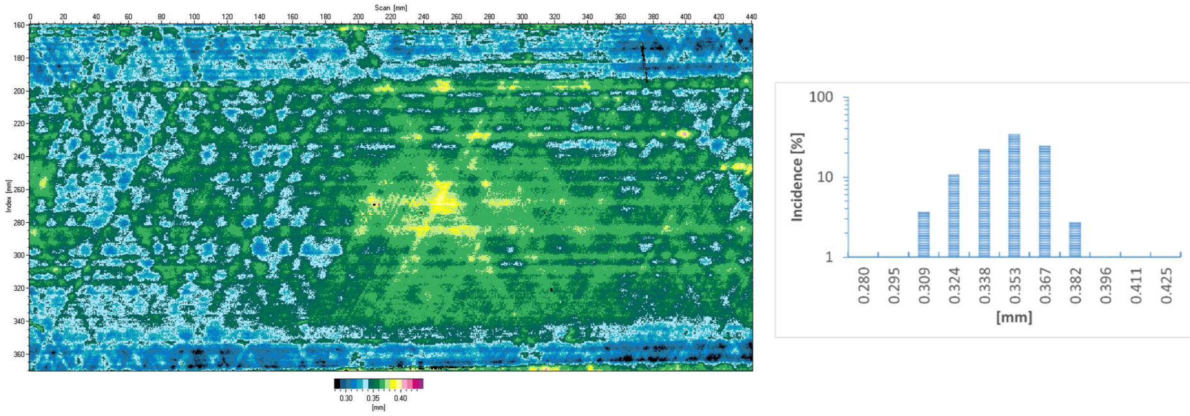


Figure 2.55. Panel Face ID 107 (0/60/-60/0) 100g/m^2

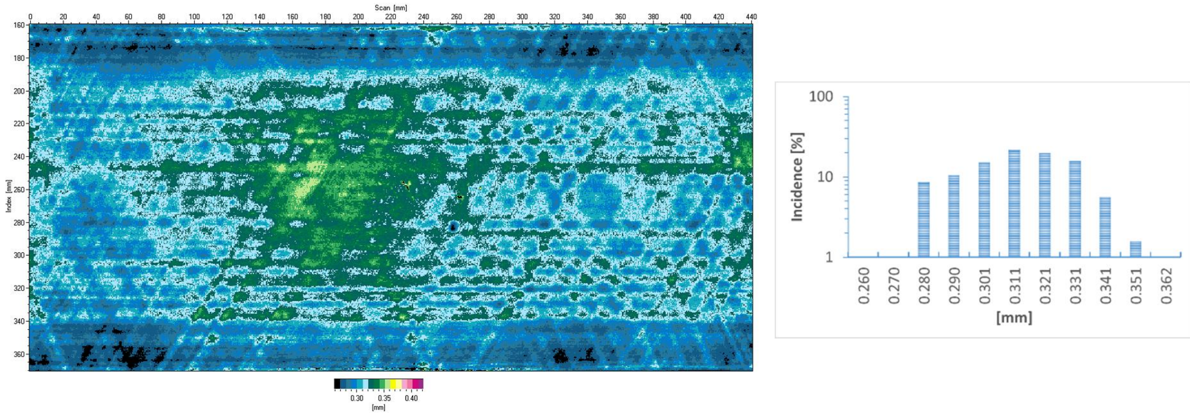


Figure 2.56. Panel Face ID 108 (0/60/-60/0) 100g/m^2

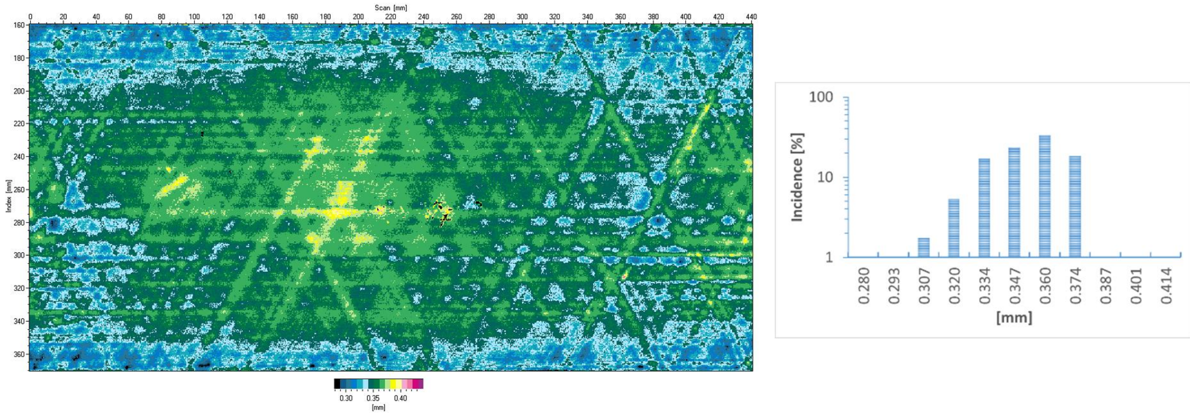


Figure 2.57. Panel Face ID 109 (0/60/-60/0) 100g/m^2

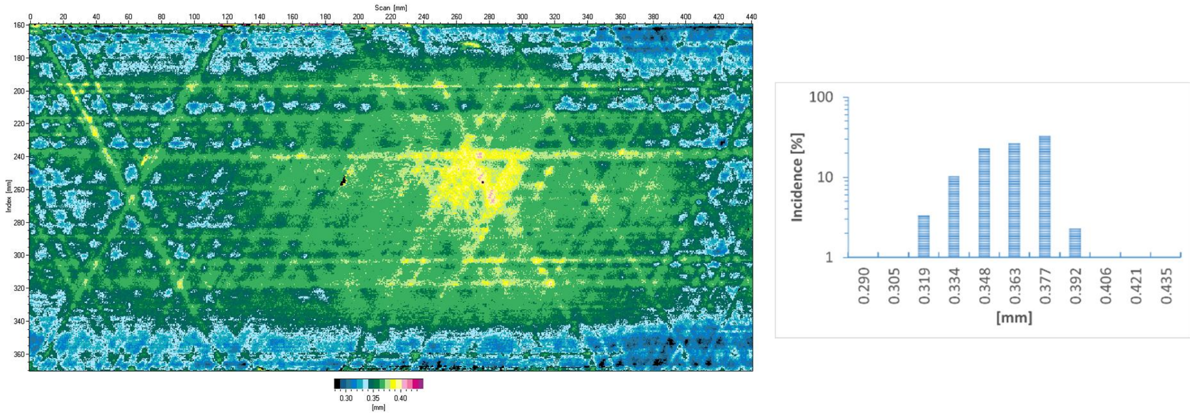


Figure 2.58. Panel Face ID 110 (0/60/-60/0) 100g/m^2

2.3 Face sheet lay-up 90/0

Panels made of two-ply lay-up 0/90 was inspected. By summarising all 8 samples the average thickness of 0.175 mm and STD is 0.0134 was set for numerical analysis.

Table 2.3. Average measured thickness of full-scale panels by layup [90/0]

	Panel ID	Face ID	AVE	STD	Min	Max	Histogram max		δ–2σ	δ	δ+2σ
[90/0]	ESA_022	53	0.19	0.019	0.140	0.250	0.184	Ok	0.149	0.175	0.202
		54	0.19	0.020	0.140	0.235	0.178	Ok			
	ESA_023	55	0.19	0.020	0.140	0.280	0.196	Ok			
		56	0.19	0.020	0.140	0.256	0.186	Ok			
	ESA_039	87	0.17	0.015	0.120	0.250	0.172	Ok			
		88	0.16	0.024	0.120	0.270	0.18	Ok			
	ESA_040	89	0.18	0.016	0.140	0.279	0.1956	Ok			
		90	0.18	0.016	0.140	0.289	0.185	Ok			
	ESA_041	91	0.18	0.018	0.140	0.236	0.169	Ok			
		92	**0.15**	**0.012**	**0.100**	**0.245**	**0.144**	**Poor**			
	ESA_042	93	0.19	0.014	0.130	0.260	0.195	Ok			
		94	0.19	0.011	0.130	0.270	0.2	Ok			
	ESA_043	95	0.16	0.013	0.120	0.230	0.164	Ok			
		96	0.17	0.013	0.120	0.230	0.164	Ok			
	ESA_044	97	0.16	0.009	0.120	0.240	0.164	Ok			
		98	0.16	0.012	0.120	0.260	0.162	Ok			

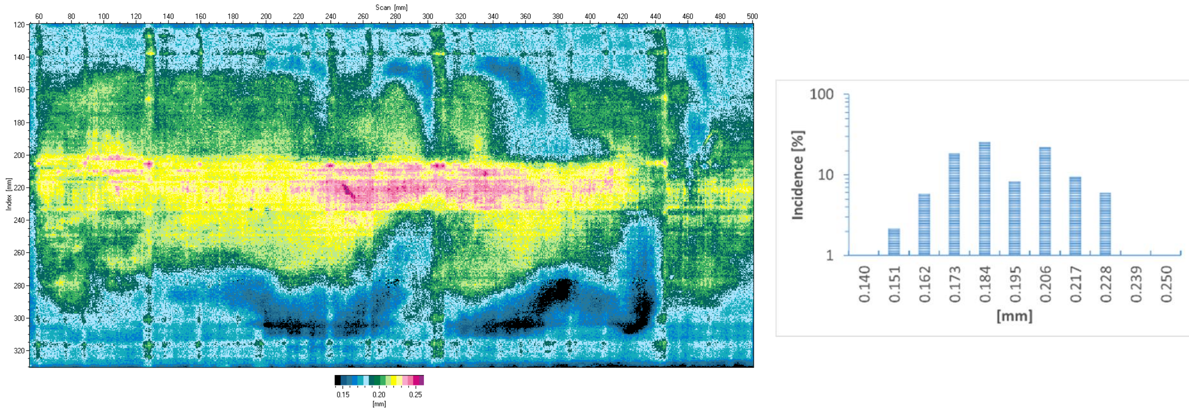


Figure 2.59. Panel Face ID 53 (90/0) 100g/m^2

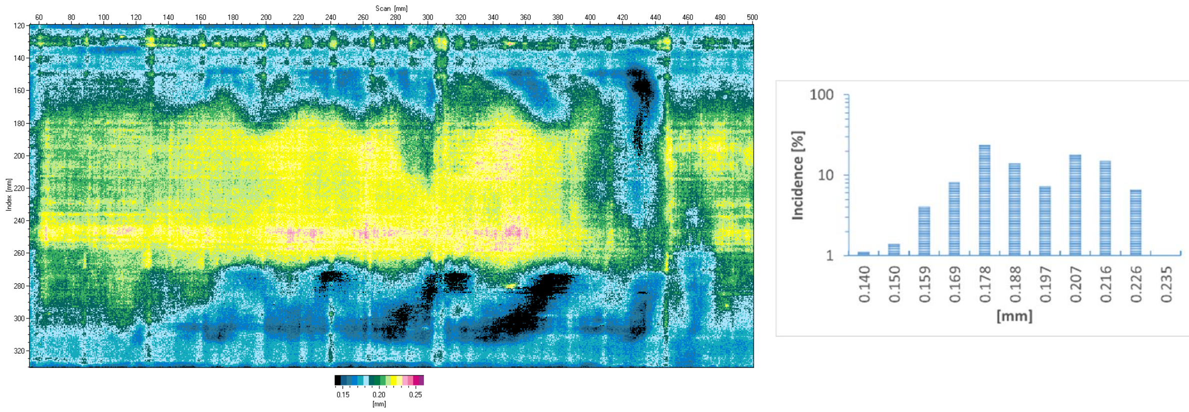


Figure 2.60. Panel Face ID 54 (90/0) 100g/m^2

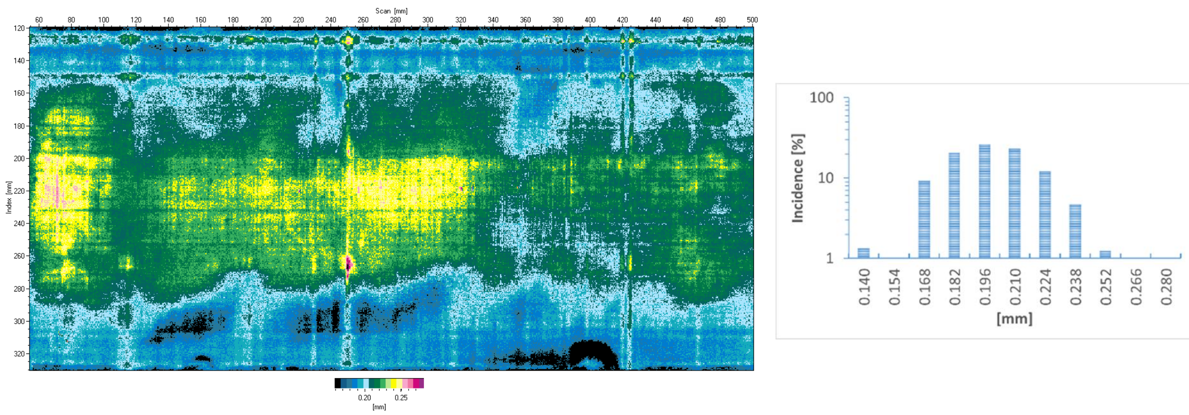


Figure 2.61. Panel Face ID 55 (90/0) 100g/m^2

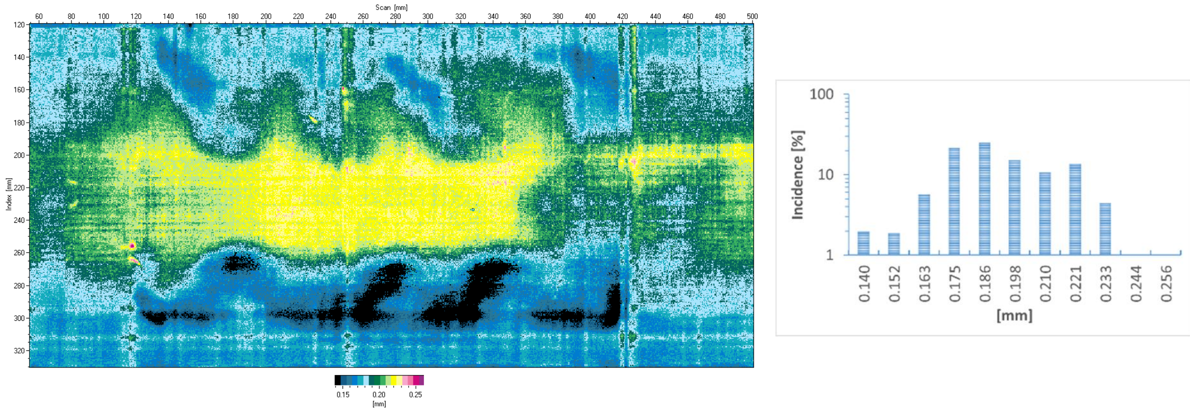


Figure 2.62. Panel Face ID 56 (90/0) 100g/m^2

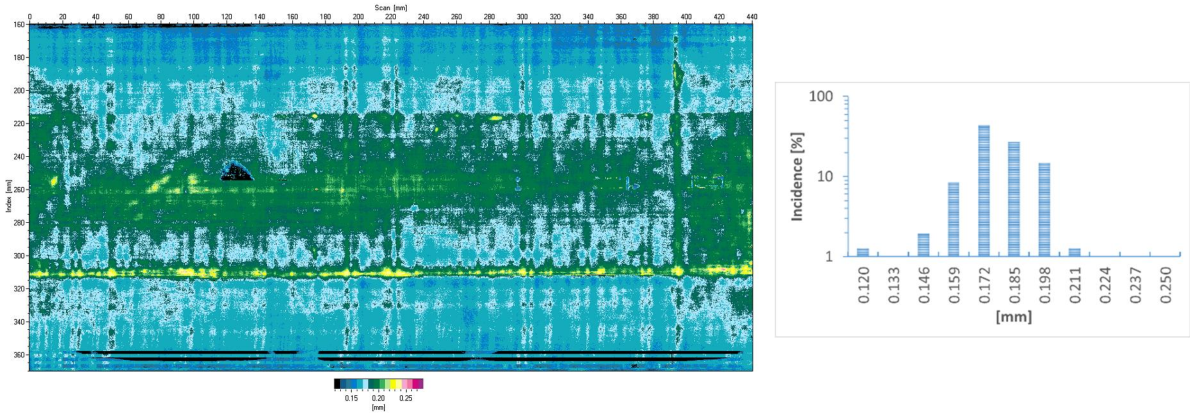


Figure 2.63. Panel Face ID 87 (90/0) 100g/m^2

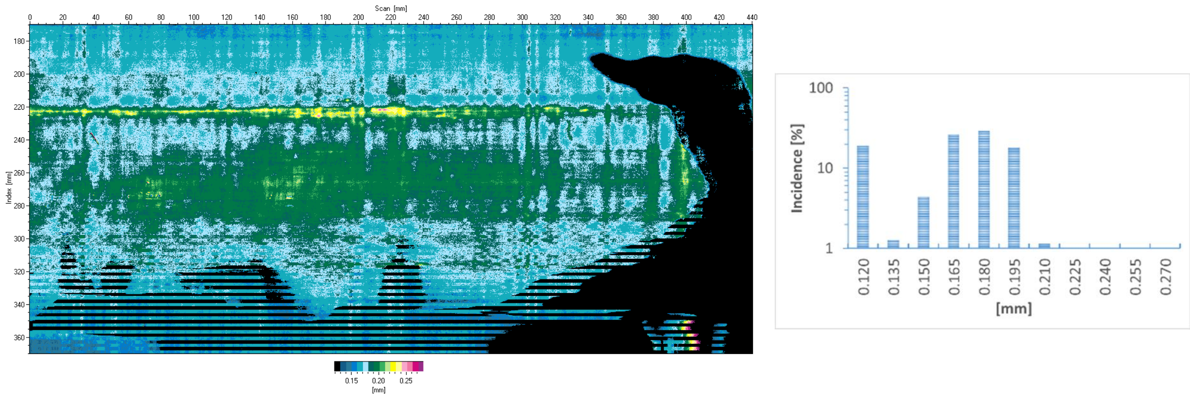


Figure 2.64. Panel Face ID 88 (90/0) 100g/m^2

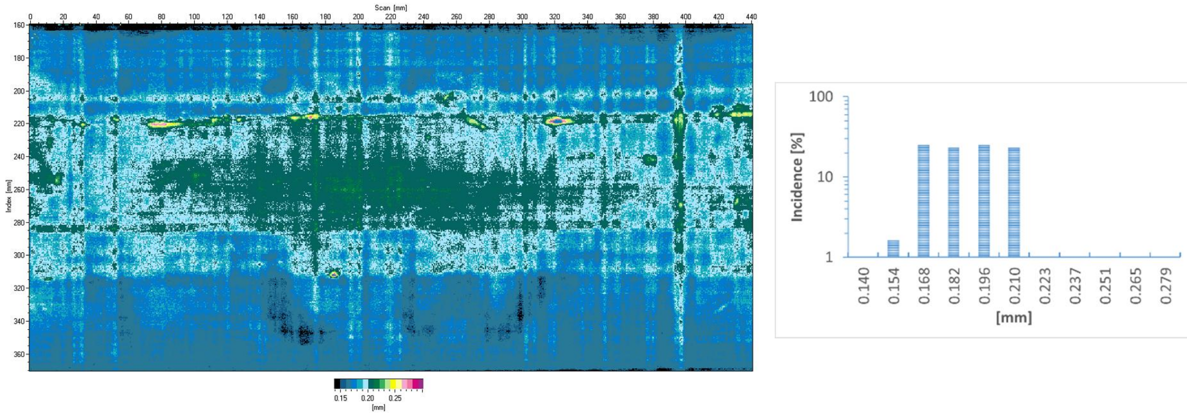


Figure 2.65. Panel Face ID 89 (90/0) 100g/m^2

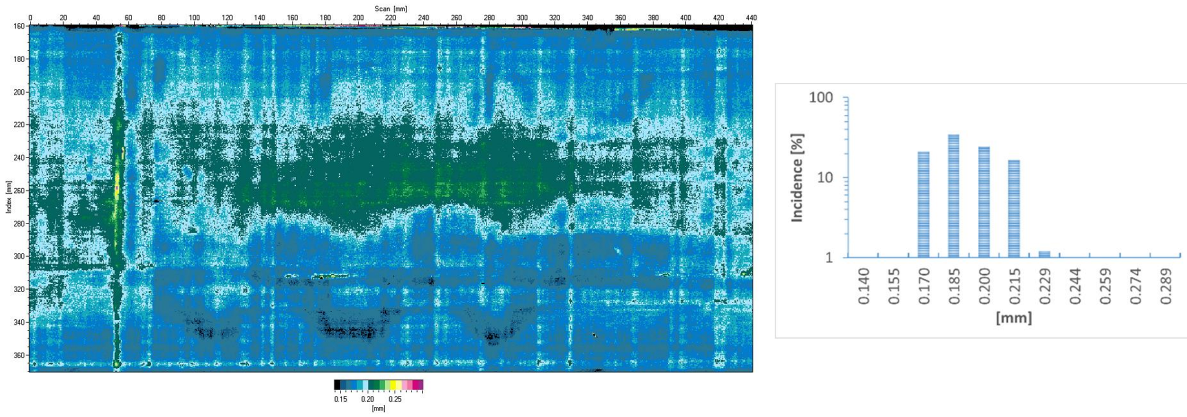


Figure 2.66. Panel Face ID 90 (90/0) 100g/m^2

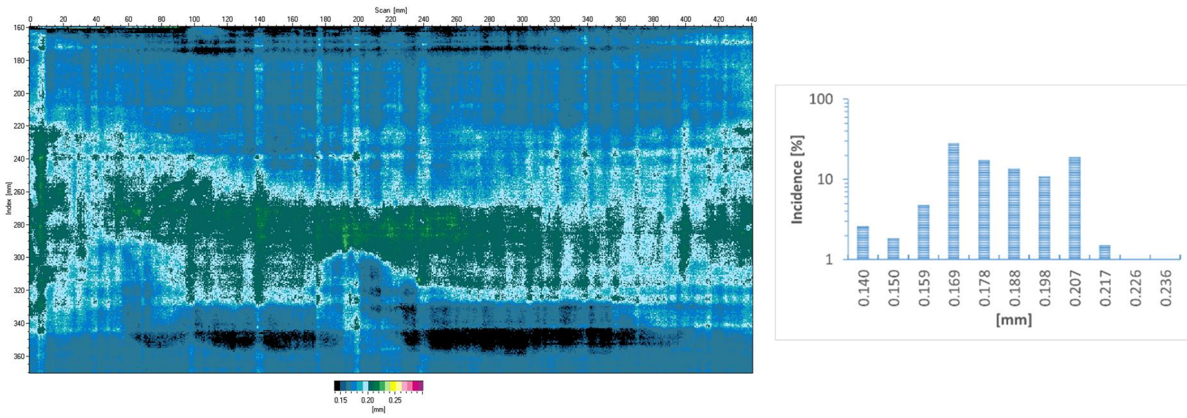


Figure 2.67. Panel Face ID 91 (90/0) 100g/m^2

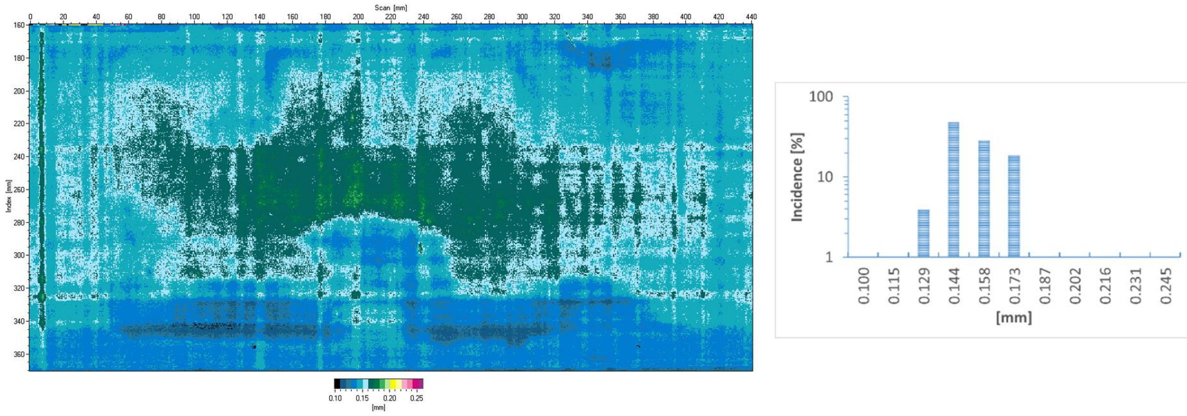


Figure 2.68. Panel Face ID 92 (90/0) 100g/m^2

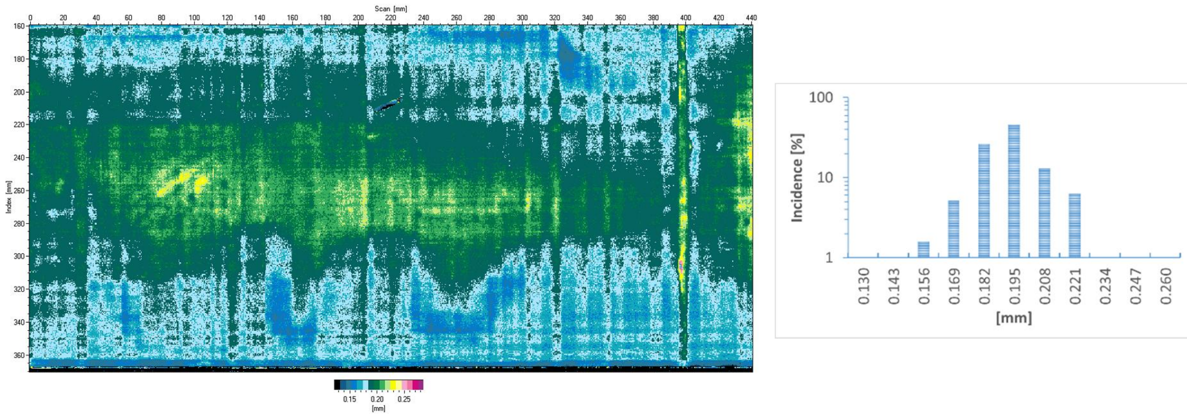


Figure 2.69. Panel Face ID 93 (90/0) 100g/m^2

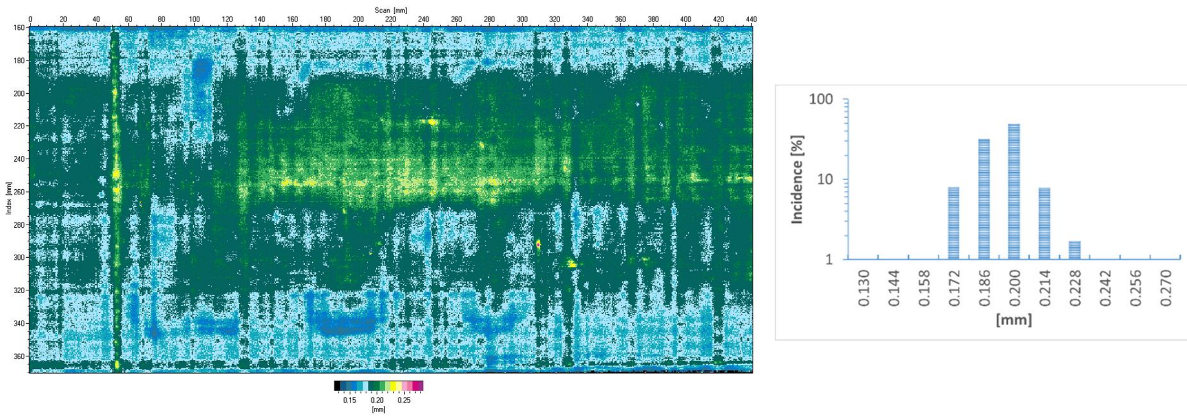


Figure 2.70. Panel Face ID 94 (90/0) 100g/m^2

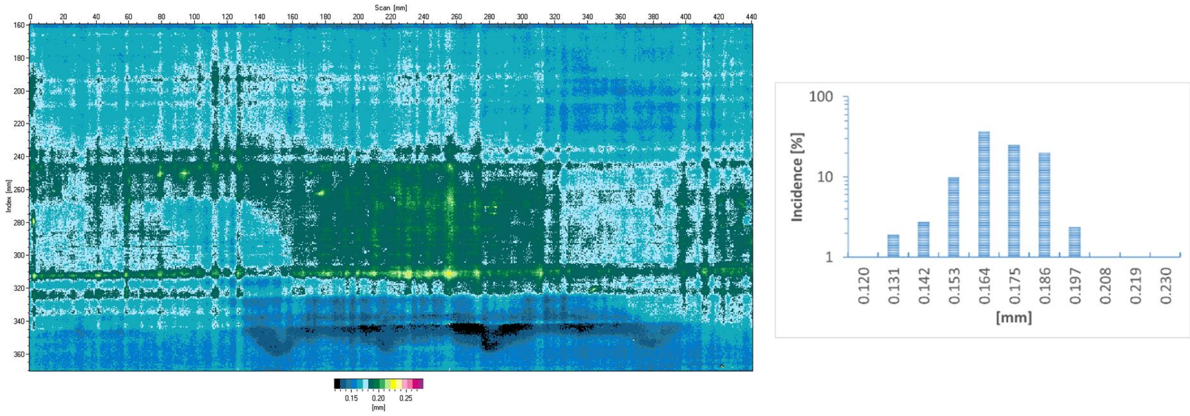


Figure 2.71. Panel Face ID 95 (90/0) 100g/m^2

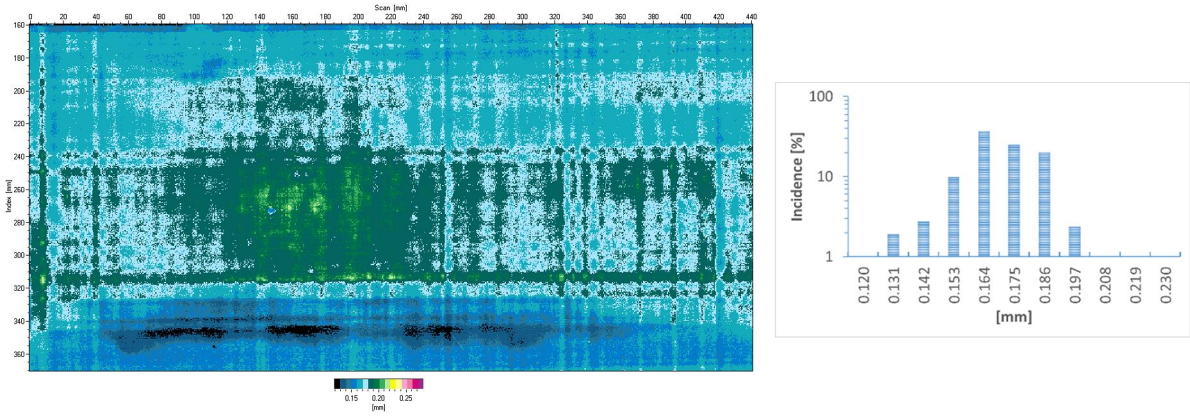


Figure 2.72. Panel Face ID 96 (90/0) 100g/m^2

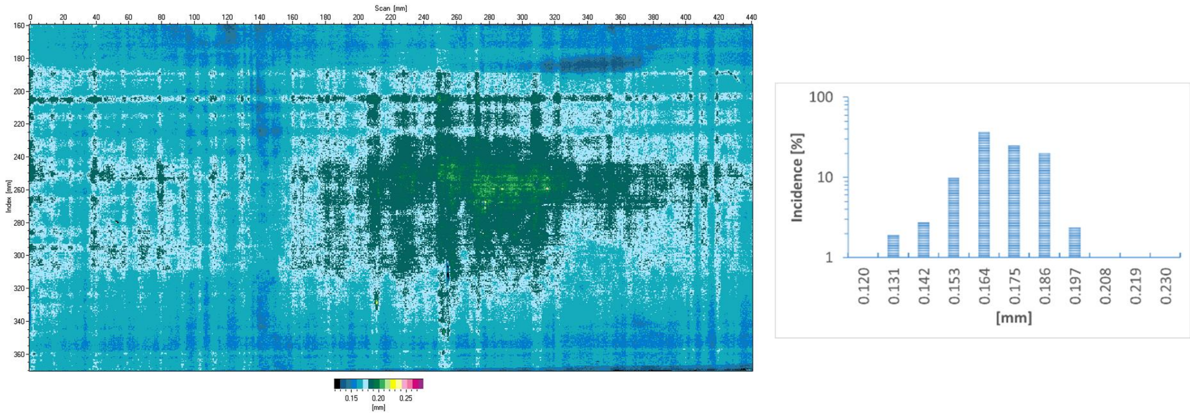


Figure 2.73. Panel Face ID 97 (90/0) 100g/m^2

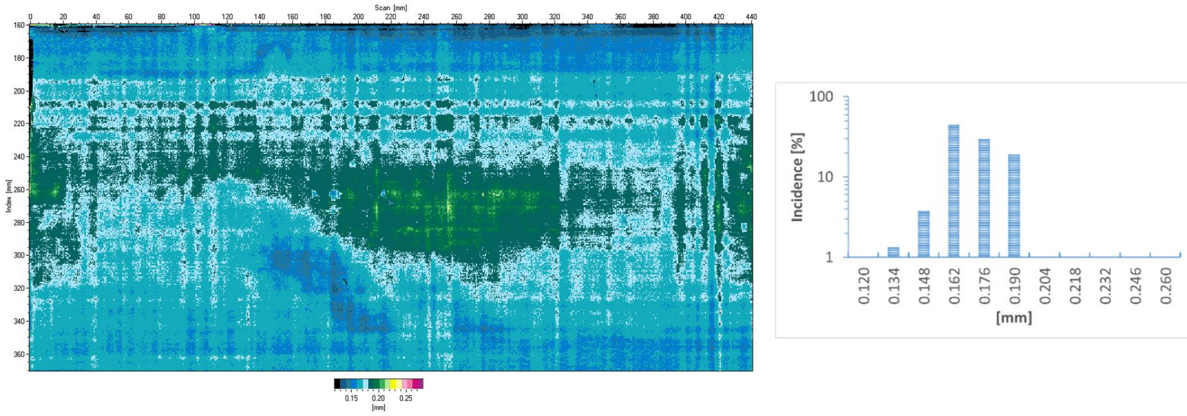


Figure 2.74. Panel Face ID 98 (90/0) 100g/m^2

2.4 Face sheet lay-up -60/60/0

Panels made of three-ply lay-up -60/60/0 was inspected. By summarising all 8 samples the average thickness of 0.263mm and STD is 0.0203 was set for numerical analysis.

Table 2.4. Average measured thickness of full-scale panels by layup [-60/60/0]

	Panel ID	Face ID	AVE	STD	Min	Max	Histogram max		δ–2σ	δ	δ+2σ
[-60/60/0]	ESA_026	61	0.29	0.041	0.180	0.355	0.32	Ok	0.222	0.263	0.304
		62	0.26	0.021	0.180	0.355	0.285	Ok			
	ESA_036	**81**	**0.30**	**0.009**	**0.280**	**0.329**	**0.305**	**Poor**			
		82	**0.31**	**0.010**	**0.280**	**0.327**	**0.313**	**Poor**			
	ESA_037	83	0.27	0.027	0.190	0.338	0.264	Ok			
		84	0.26	0.024	0.180	0.328	0.254	Ok			
	ESA_038	85	0.24	0.024	0.180	0.313	0.233	Ok			
		86	0.25	0.024	0.180	0.319	0.233	Ok			
	ESA_045	99	0.26	0.025	0.200	0.340	0.27	Ok			
		100	0.27	0.024	0.200	0.340	0.298	Ok			
	ESA_046	101	0.23	0.025	0.180	0.299	0.228	Ok			
		102	0.25	0.025	0.180	0.335	0.273	Ok			
	ESA_047	103	0.26	0.024	0.180	0.330	0.27	Ok			
		104	0.25	0.020	0.180	0.335	0.273	Ok			
	ESA_048	105	0.26	0.024	0.160	0.320	0.272	Ok			
		106	0.25	0.024	0.160	0.320	0.272	Ok			

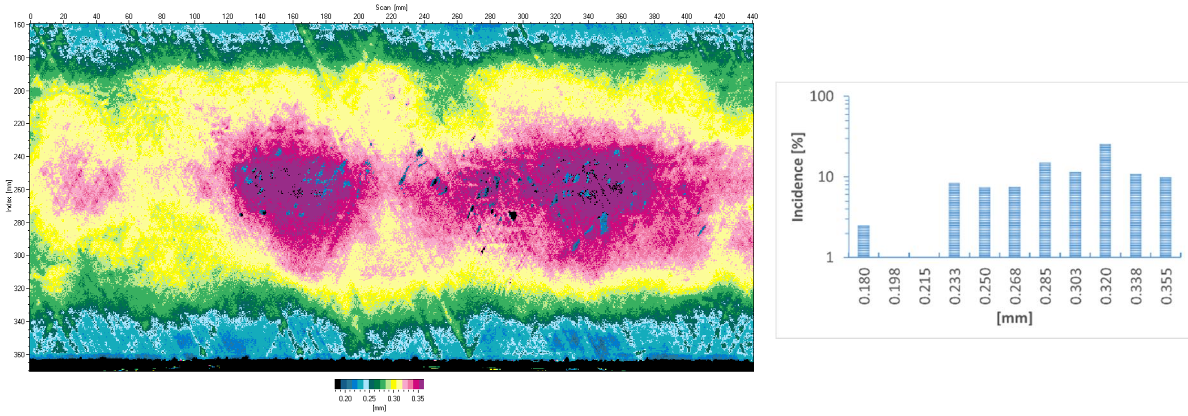


Figure 2.75. Panel Face ID 61 (-60/60/0) 100g/m^2

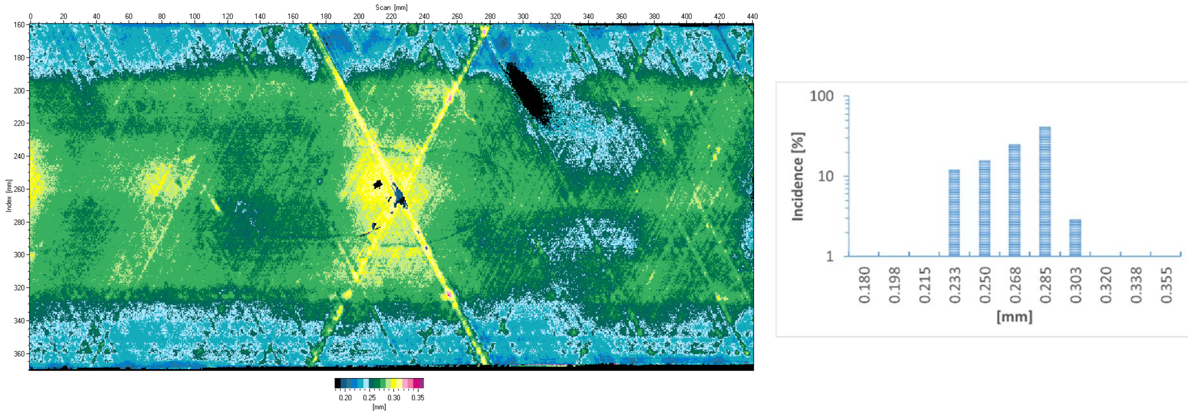


Figure 2.76. Panel Face ID 62 (-60/60/0) 100g/m^2

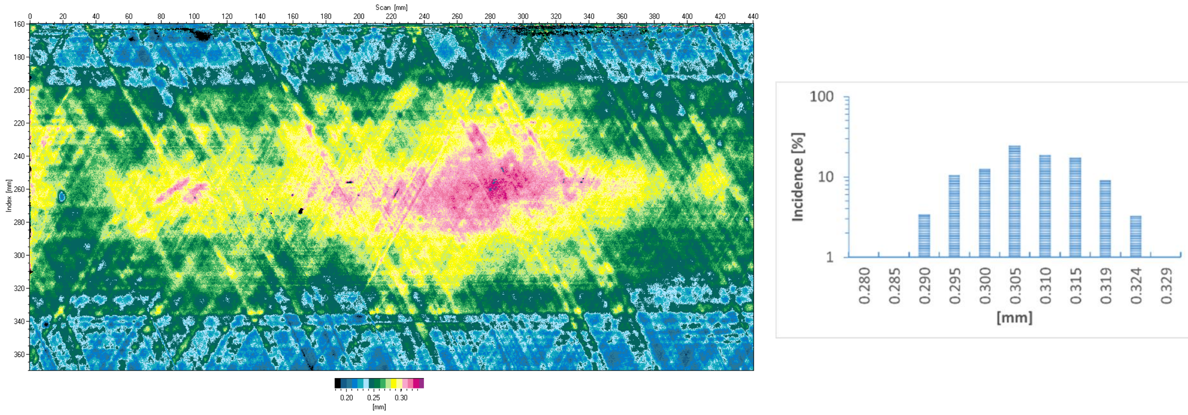


Figure 2.77. Panel Face ID 81 (-60/60/0) 100g/m^2

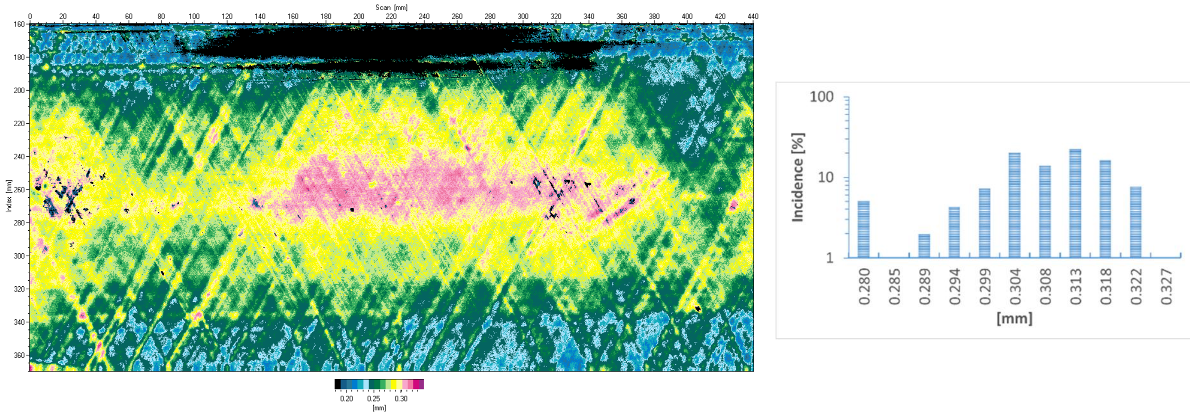


Figure 2.78. Panel Face ID 82 (-60/60/0) 100g/m^2

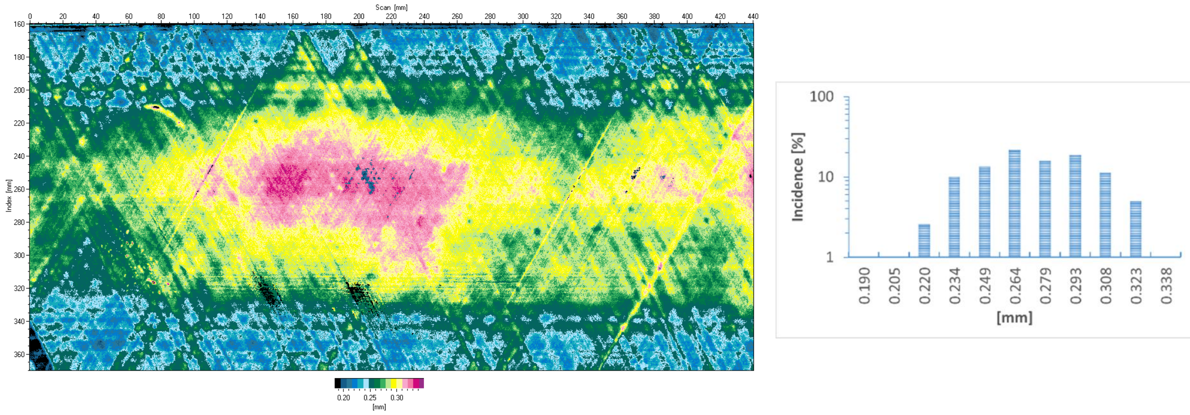


Figure 2.79. Panel Face ID 83 (-60/60/0) 100g/m^2

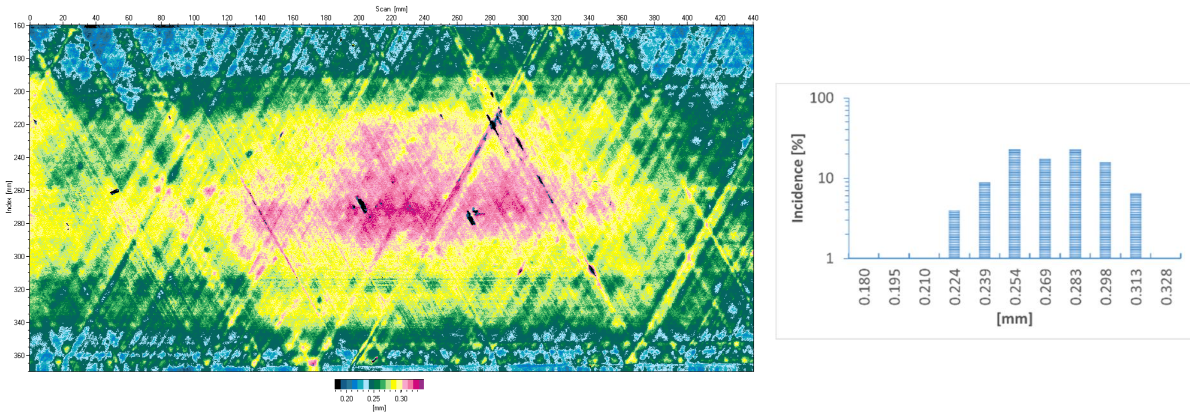


Figure 2.80. Panel Face ID 84 (-60/60/0) 100g/m^2

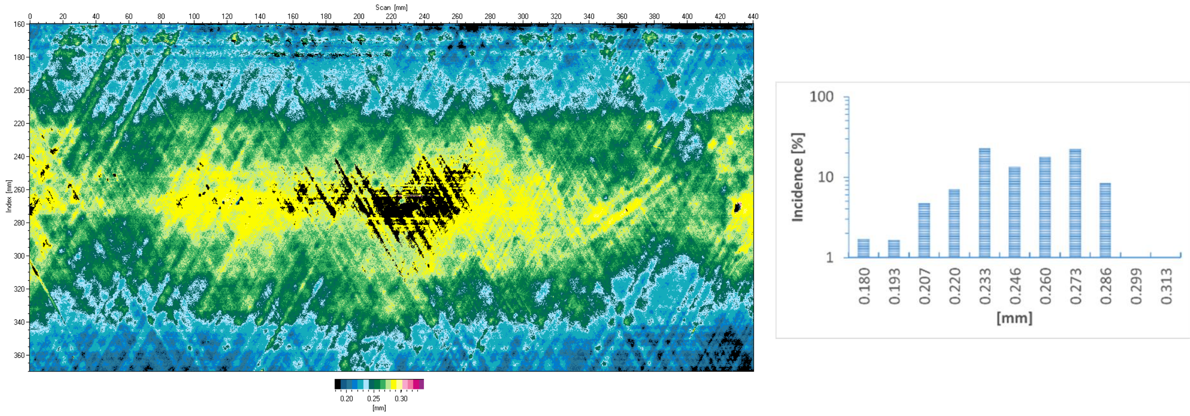


Figure 2.81. Panel Face ID 85 (-60/60/0) 100g/m^2

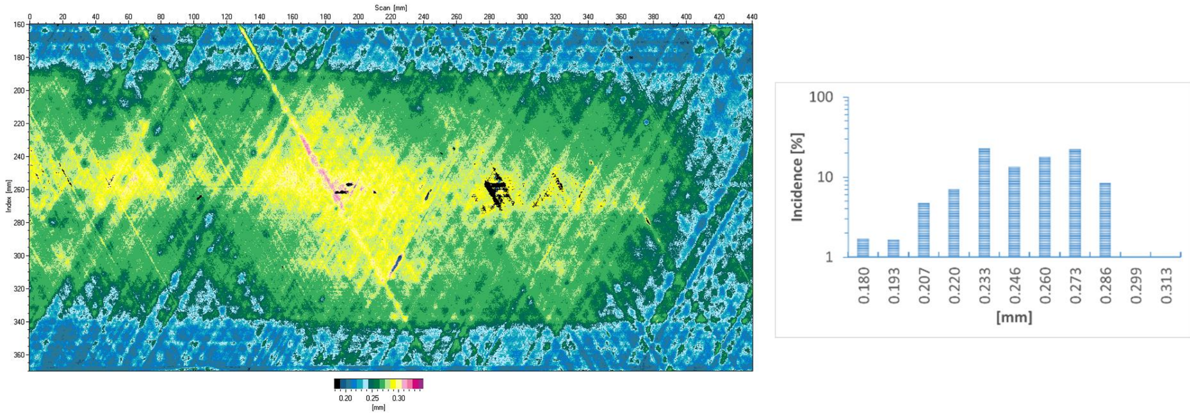


Figure 2.82. Panel Face ID 86 (-60/60/0) 100g/m^2

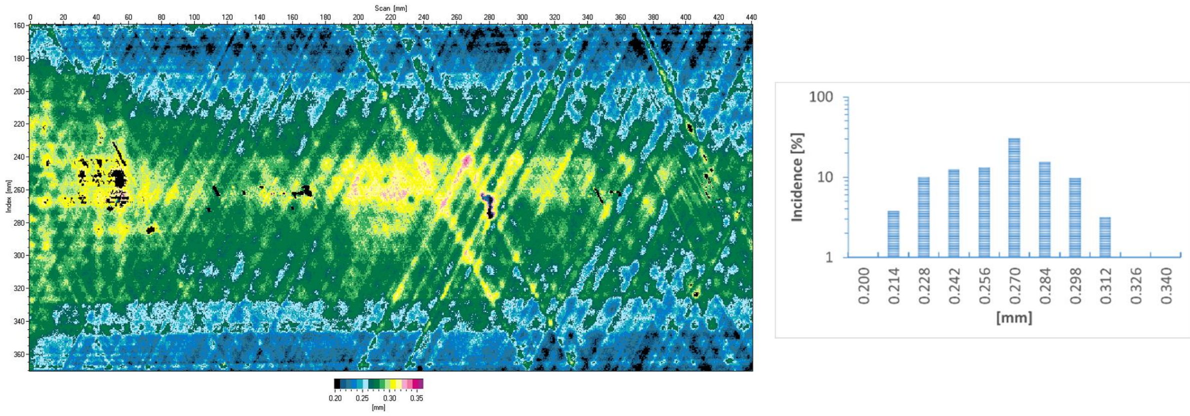


Figure 2.83. Panel Face ID 99 (-60/60/0) 100g/m^2

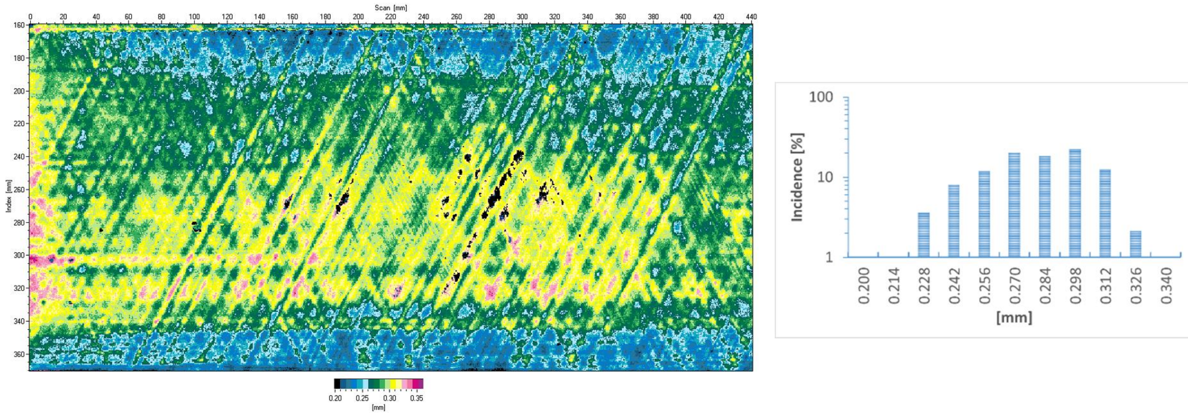


Figure 2.84. Panel Face ID 100 (-60/60/0) 100g/m^2

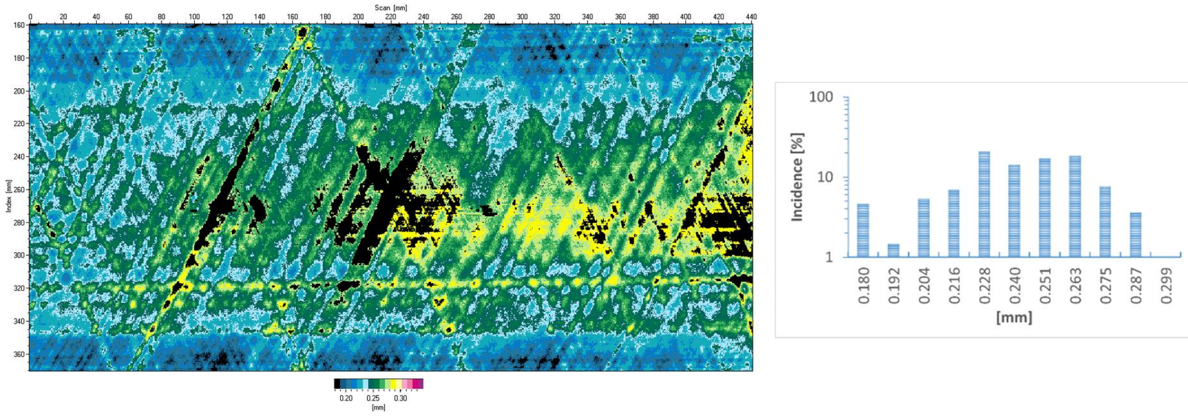


Figure 2.85. Panel Face ID 101 (-60/60/0) 100g/m^2

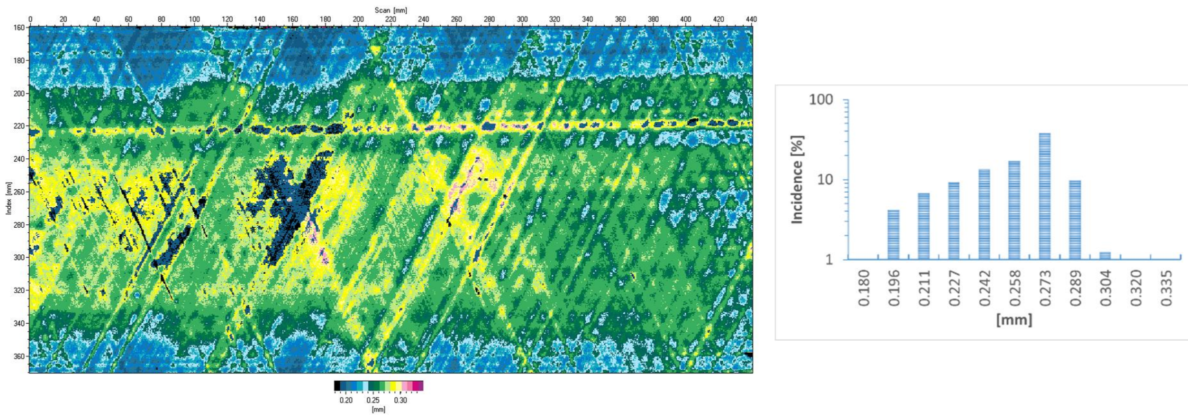


Figure 2.86. Panel Face ID 102 (-60/60/0) 100g/m^2

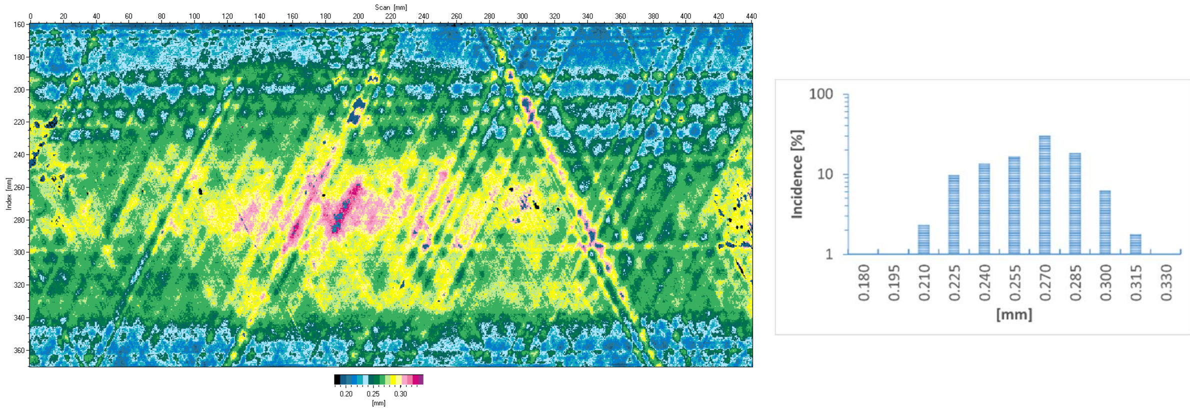


Figure 2.87. Panel Face ID 103 (-60/60/0) 100g/m^2

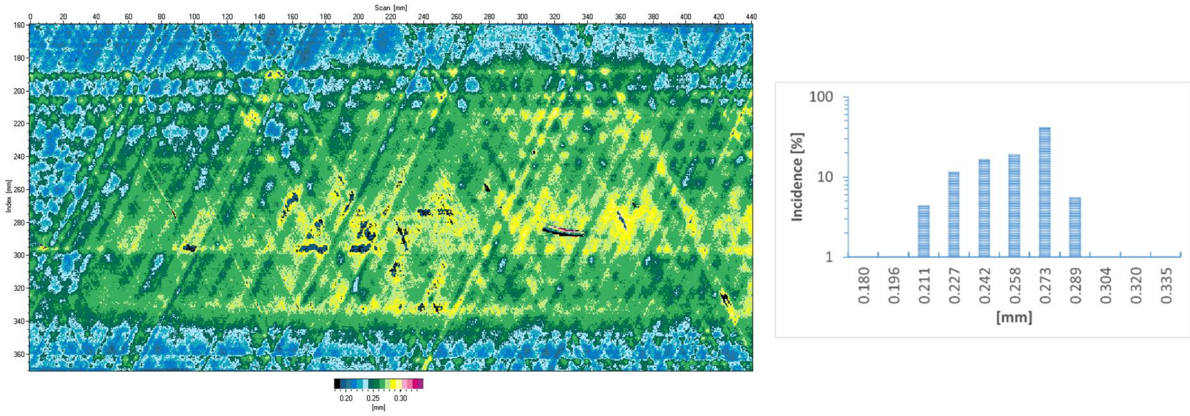


Figure 2.88. Panel Face ID 104 (-60/60/0) 100g/m^2

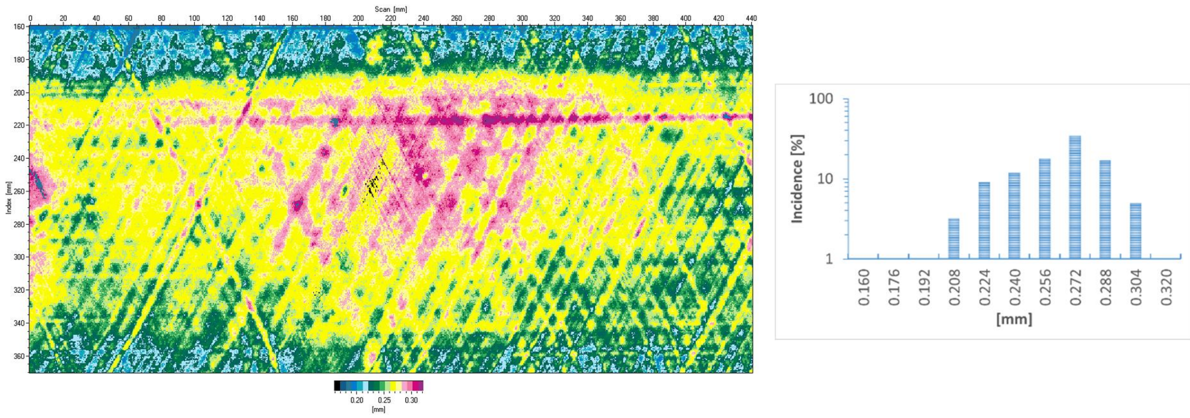


Figure 2.89. Panel Face ID 105 (-60/60/0) 100g/m^2

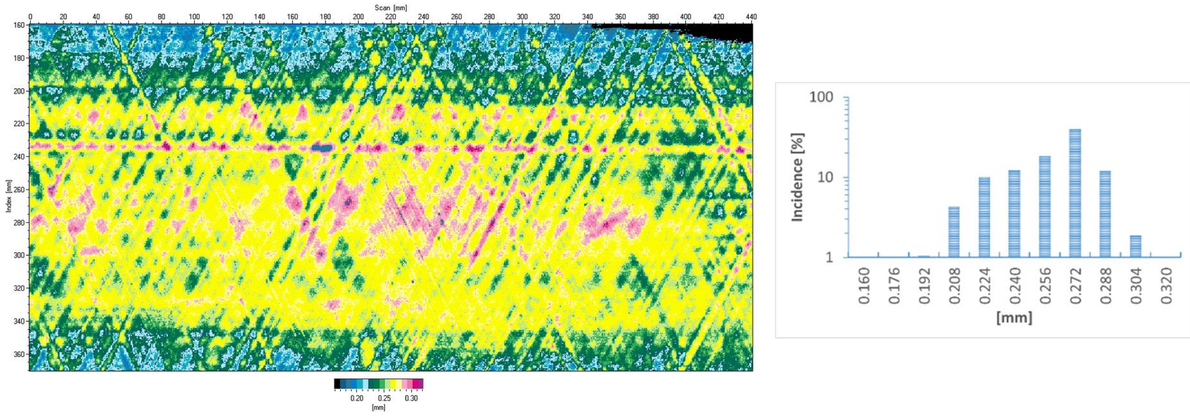


Figure 2.90. Panel Face ID 106 (-60/60/0) 100g/m^2

3 Impact damage analysis

A dedicated equipment for barely visible impact damage assessed with laser distance meter was mounted on ultrasound inspection machine manipulator replacing NDE probe, see Figure 3.1. NDE inspection software provides desired control over X-Y movement of the laser sensor over the surface of the measured panel, while actual X-Y coordinates along the distance to the panel surface were measured and recorded by MGCplus data acquisition system. X and Y-axis coordinates was measured by draw wire sensors (DWS) with corresponding distance data, forming xyz point cloud of the measured surface, see Figure 3.2. Acquitted data was transformed into contour plot with any MatLab software available to represent indentation area and size (see in Figure 3.3 and whole list of indentation depth are summarised in Table 3.1-Table 3.1532), as well as, directly implemented into FE model. The developed numerical tools for assessment of imperfections are are available on the project homepage *http://bnm4eks.rtu.lv/tools.html*.

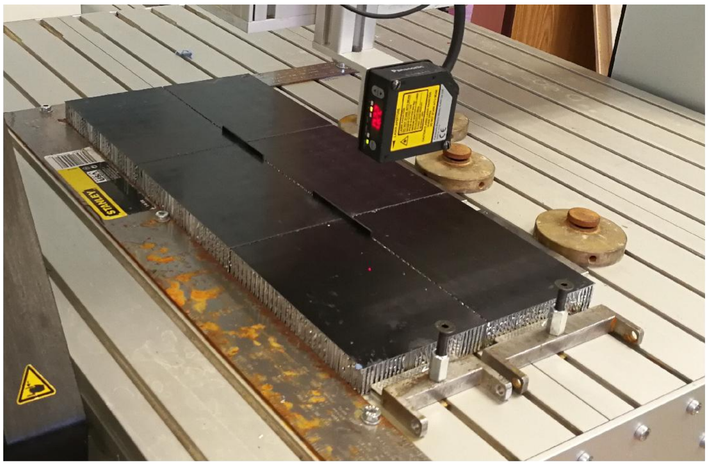


Figure 3.1. Surface imperfection measurement on sample

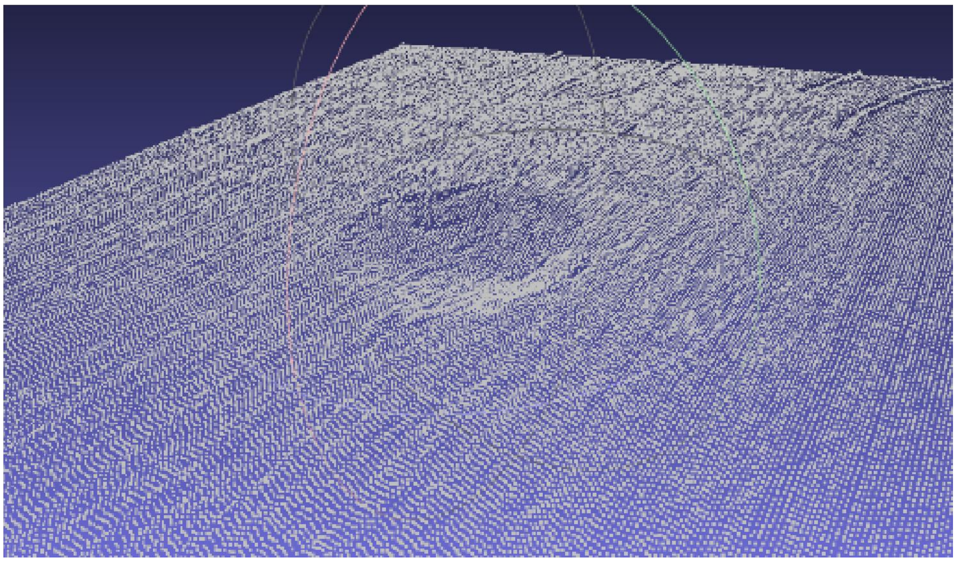


Figure 3.2. Indentation measurement xyz point example

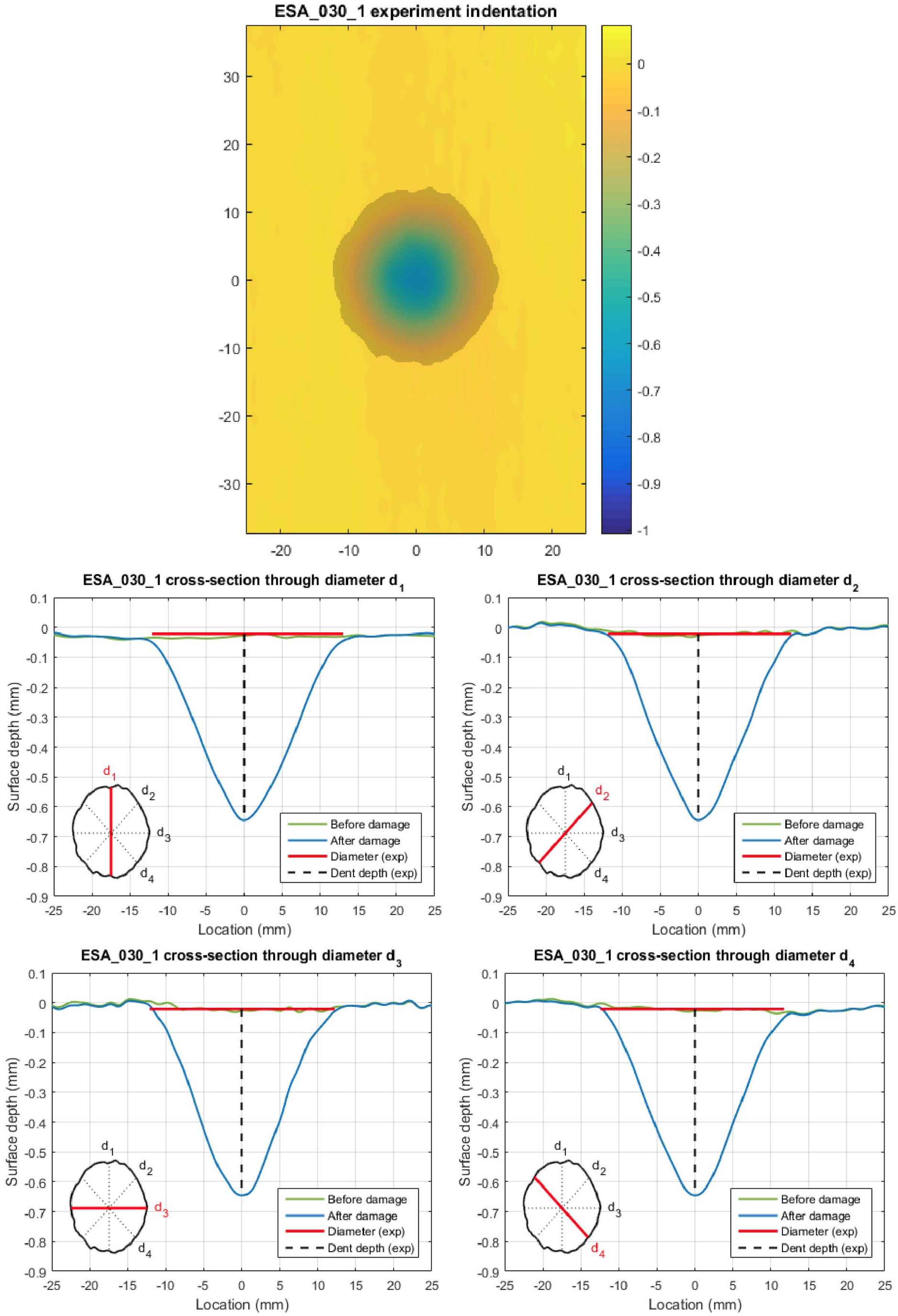


Figure 3.3. Indentation measurement example for ESA_030_1 sample

Table 3.1. Indentation measurement of full-scale ESA_001 panel.

Panel	Depth	Ø1	Ø2	Ø3	Ø4	AVE Ø	Max Ø	Area	Volume
ESA_001_1	0.47	18	20.6	20.2	18.4	19.3	20.6	288	46
ESA_001_2	0.43	16.5	19.9	20.3	19.1	19	20.3	302	41
ESA_001_3	0.64	20.1	22.1	23.7	21.1	21.7	23.7	374	87
ESA_001_4	0.66	22.6	24.5	25.3	23.8	24	25.3	482	92
ESA_001_5	2.21	24.7	26.9	27.8	25.2	26.1	27.8	554	272
ESA_001_6	2.49	24.3	27.7	28	25	26.3	28	559	281

Table 3.2. Indentation measurement of full-scale ESA_003 panel.

Panel	Depth	Ø1	Ø2	Ø3	Ø4	AVE Ø	Max Ø	Area	Volume
ESA_003_1	0.46	15.4	17.5	18	16.3	16.8	18	231	35
ESA_003_2	0.46	16.5	18	19.3	15.6	17.3	19.3	248	38
ESA_003_3	0.41	17	18.8	19.7	18.1	18.4	19.7	287	36
ESA_003_4	0.48	14.8	16.7	18.7	15.1	16.3	18.7	230	38
ESA_003_5	0.41	15.7	16.5	18.9	15.4	16.6	18.9	242	27
ESA_003_6	0.44	13.9	17	18.4	15	16.1	18.4	230	35

Table 3.3. Indentation measurement of full-scale ESA_004 panel.

Panel	Depth	Ø1	Ø2	Ø3	Ø4	AVE Ø	Max Ø	Area	Volume
ESA_004_5	1.04	31	31.3	33.4	32.4	32	33.4	795	340

Table 3.4. Indentation measurement of full-scale ESA_013 panel.

Panel	Depth	Ø1	Ø2	Ø3	Ø4	AVE Ø	Max Ø	Area	Volume
ESA_013_6	0.87	29.7	28.7	29.3	32.8	30.1	32.8	710	242

Table 3.5. Indentation measurement of full-scale ESA_016 panel.

Panel	Depth	Ø1	Ø2	Ø3	Ø4	AVE Ø	Max Ø	Area	Volume
ESA_016_2	0.43	18.2	17	16.4	16.4	17	18.2	232	34
ESA_016_3	0.38	17.2	17.8	16.4	17.5	17.2	17.8	236	32
ESA_016_4	0.38	16.4	16.5	16.1	15.4	16.1	16.5	231	30
ESA_016_5	0.38	15.9	14.7	15.3	16.7	15.6	16.7	188	29
ESA_016_6	0.43	18.3	18.4	17.3	18	18	18.4	255	34

Table 3.6. Indentation measurement of full-scale ESA_017 panel.

Panel	Depth	Ø1	Ø2	Ø3	Ø4	AVE Ø	Max Ø	Area	Volume
ESA_017_5	1.09	34.3	33.5	34.6	36.3	34.7	36.3	979	433

Table 3.7. Indentation measurement of full-scale ESA_022 panel.

Panel	Depth	Ø1	Ø2	Ø3	Ø4	AVE Ø	Max Ø	Area	Volume
ESA_022_2	0.28	14.3	13.6	16.6	15.8	15.1	16.6	183	21
ESA_022_3	0.33	12.6	13.4	14.8	11.7	13.1	14.8	138	17

Table 3.8. Indentation measurement of full-scale ESA_023 panel.

Panel	Depth	Ø1	Ø2	Ø3	Ø4	AVE Ø	Max Ø	Area	Volume
ESA_023_3	0.35	12.3	14.1	17.1	15.6	14.8	17.1	180	23
ESA_023_4	0.14	8.6	8.2	10.7	11.5	9.7	11.5	80	7
ESA_023_5	0.2	10.3	10.6	14.8	11.3	11.8	14.8	115	10
ESA_023_6	0.27	10.9	10.9	14.9	11	11.9	14.9	129	14

Table 3.9. Indentation measurement of full-scale ESA_026 panel.

Panel	Depth	Ø1	Ø2	Ø3	Ø4	AVE Ø	Max Ø	Area	Volume
ESA_026_1	0.17	16.5	16.4	16.2	15.3	16.1	16.5	204	12
ESA_026_2	0.13	13	12.3	12.6	11.3	12.3	13	126	7
ESA_026_3	0.22	14.6	14.8	15.7	16.3	15.4	16.3	180	15
ESA_026_4	0.22	15.4	16.5	16.6	16.8	16.3	16.8	227	19
ESA_026_5	0.28	19.2	22.3	21.3	19.5	20.6	22.3	335	31
ESA_026_6	0.29	17.5	19.8	18.9	19	18.8	19.8	286	29

Table 3.10. Indentation measurement of full-scale ESA_027 panel.

Panel	Depth	Ø1	Ø2	Ø3	Ø4	AVE Ø	Max Ø	Area	Volume
ESA_027_1	0.28	23	23.5	19.7	21.6	22	23.5	386	38
ESA_027_2	0.95	44.9	42.6	38.9	43	42.3	44.9	1416	407
ESA_027_3	0.5	32.4	28.6	27.4	28.6	29.2	32.4	695	114
ESA_027_4	0.5	30.3	27.2	25.8	28.3	27.9	30.3	615	125
ESA_027_5	0.7	40.3	35.9	33.6	38.2	37	40.3	1081	288
ESA_027_6	0.69	37.9	34.5	31.7	36.1	35	37.9	966	238

Table 3.11. Indentation measurement of full-scale ESA_028 panel.

Panel	Depth	Ø1	Ø2	Ø3	Ø4	AVE Ø	Max Ø	Area	Volume
ESA_028_1	0.2	22	19.8	18.7	19	19.9	22	308	25
ESA_028_2	0.2	21.5	20.4	20.8	22.2	21.2	22.2	363	26
ESA_028_3	0.51	32.2	29.8	29.6	30.4	30.5	32.2	724	135
ESA_028_4	0.73	39	35.9	36.3	38	37.3	39	1116	309
ESA_028_5	0.99	46.2	45.3	43.4	45.5	45.1	46.2	1600	588
ESA_028_6	1.17	53.7	50.8	48.3	51.1	51	53.7	2084	944

Table 3.12. Indentation measurement of full-scale ESA_029 panel.

Panel	Depth	Ø1	Ø2	Ø3	Ø4	AVE Ø	Max Ø	Area	Volume
ESA_029_1	0.63	35.5	31.3	29.9	33.7	32.6	35.5	844	193
ESA_029_2	0.82	39.2	36.2	37.6	38	37.8	39.2	1090	341
ESA_029_3	0.98	38.2	38.3	36	36.1	37.1	38.3	1095	330
ESA_029_4	0.67	37.5	33	31.4	32.7	33.6	37.5	882	205
ESA_029_5	1	48.3	44	41.9	42.4	44.2	48.3	1511	533
ESA_029_6	1.32	45.3	38.2	38	38	39.9	45.3	1272	518

Table 3.13. Indentation measurement of full-scale ESA_030 panel.

Panel	Depth	Ø1	Ø2	Ø3	Ø4	AVE Ø	Max Ø	Area	Volume
ESA_030_1	0.62	25.1	24	24.3	24.2	24.4	25.1	487	96
ESA_030_2	1	27.2	26.6	24.1	24.2	25.5	27.2	520	134
ESA_030_3	0.9	26.9	26	24.5	24.9	25.6	26.9	520	125

Table 3.14. Indentation measurement of full-scale ESA_031 panel.

Panel	Depth	Ø1	Ø2	Ø3	Ø4	AVE Ø	Max Ø	Area	Volume
ESA_031_1	0.51	22.4	22.3	20.3	20.9	21.5	22.4	363	61
ESA_031_2	0.48	22.6	21.8	21.1	22.2	21.9	22.6	387	59
ESA_031_3	0.82	27.1	23.8	22.7	25.2	24.7	27.1	483	108
ESA_031_4	0.65	27.5	25.3	25.5	26.3	26.2	27.5	539	119
ESA_031_5	1.17	30.4	27.9	25.1	25.6	27.2	30.4	592	171
ESA_031_6	1.15	31.2	28.3	24.1	25.2	27.2	31.2	593	184

Table 3.15. Indentation measurement of full-scale ESA_032 panel.

Panel	Depth	Ø1	Ø2	Ø3	Ø4	AVE Ø	Max Ø	Area	Volume
ESA_032_1	2.76	32	29	28.4	27.3	29.2	32	686	348
ESA_032_2	0.89	31.1	31.5	28.9	30.5	30.5	31.5	739	198
ESA_032_3	0.52	27	24.5	22.7	24.5	24.7	27	487	85
ESA_032_4	0.54	27.8	25.3	23.8	25.6	25.6	27.8	520	100
ESA_032_5	0.91	34.9	34.6	33.5	33.1	34	34.9	928	332
ESA_032_6	0.87	35.5	33.5	33.3	34.1	34.1	35.5	917	320

Table 3.16. Indentation measurement of full-scale ESA_034 panel.

Panel	Depth	Ø 1	Ø 2	Ø 3	Ø 4	Avg Ø	Max Ø	Area	Volume
ESA_034_1	0.30	26.0	23.1	19.4	22.6	22.8	26.0	425	44
ESA_034_2	0.30	26.2	22.5	22.9	24.7	24.1	26.2	477	49
ESA_034_3	0.50	31.9	28.1	25.7	29.8	28.9	31.9	675	120
ESA_034_4	0.53	33.0	30.8	27.4	30.8	30.5	33.0	730	129
ESA_034_5	0.73	40.9	38.6	32.2	37.6	37.3	40.9	1090	279
ESA_034_6	0.77	39.3	32.0	32.3	33.7	34.3	39.3	921	258

Table 3.17. Indentation measurement of full-scale ESA_035 panel.

Panel	Depth	Ø 1	Ø 2	Ø 3	Ø 4	Avg Ø	Max Ø	Area	Volume
ESA_035_1	0.53	31.5	29.1	29.1	31.5	30.3	31.5	711	148
ESA_035_2	0.53	33.2	27.3	27.0	28.7	29.1	33.2	635	149
ESA_035_3	0.79	41.0	34.5	34.6	34.4	36.1	41.0	1052	340
ESA_035_4	0.79	38.9	33.5	34.6	34.8	35.5	38.9	1009	342
ESA_035_5	1.00	45.5	43.4	44.9	41.3	43.8	45.5	1570	623
ESA_035_6	0.98	44.4	39.5	39.8	42.0	41.4	44.4	1363	568

Table 3.18. Indentation measurement of full-scale ESA_036 panel.

Panel	Depth	Ø 1	Ø 2	Ø 3	Ø 4	Avg Ø	Max Ø	Area	Volume
ESA_036_1	0.76	35.6	35.6	32.7	34.1	34.5	35.6	960	271
ESA_036_2	0.74	35.0	32.8	35.1	36.8	34.9	36.8	974	245
ESA_036_3	0.80	37.2	36.3	40.6	38.3	38.1	40.6	1157	331
ESA_036_4	0.84	33.4	34.6	35.7	35.6	34.8	35.7	992	316
ESA_036_5	1.33	38.1	36.8	39.5	44.5	39.7	44.5	1244	461
ESA_036_6	1.85	37.7	35.1	37.2	40.0	37.5	40.0	1141	481

Table 3.19. Indentation measurement of full-scale ESA_037 panel.

Panel	Depth	Ø 1	Ø 2	Ø 3	Ø 4	Avg Ø	Max Ø	Area	Volume
ESA_037_1	0.32	18.1	17.3	18.1	19.7	18.3	19.7	276	32
ESA_037_2	0.31	20.4	18.7	18.4	18.8	19.1	20.4	285	35
ESA_037_3	0.54	24.0	25.3	27.5	25.6	25.6	27.5	526	109
ESA_037_4	0.56	24.7	22.9	24.4	24.2	24.0	24.7	463	98
ESA_037_5	0.76	29.6	29.7	31.7	34.5	31.4	34.5	788	233

Table 3.20. Indentation measurement of full-scale ESA_038 panel.

Panel	Depth	Ø 1	Ø 2	Ø 3	Ø 4	Avg Ø	Max Ø	Area	Volume
ESA_038_1	0.79	35.3	34.2	37.0	35.2	35.4	37.0	989	333
ESA_038_2	1.05	43.7	40.4	44.2	43.7	43.0	44.2	1444	638
ESA_038_3	0.51	25.1	25.0	23.8	24.2	24.5	25.1	469	95
ESA_038_4	0.99	41.7	38.3	42.0	40.4	40.6	42.0	1294	566

Table 3.21. Indentation measurement of full-scale ESA_039 panel.

Panel	Depth	Ø 1	Ø 2	Ø 3	Ø 4	Avg Ø	Max Ø	Area	Volume
ESA_039_1	0.62	26.2	24.9	28.4	27.9	26.8	28.4	576	135
ESA_039_2	0.63	25.6	26.6	30.2	28.7	27.8	30.2	642	144
ESA_039_3	0.92	32.7	31.4	33.5	33.9	32.9	33.9	866	322
ESA_039_4	1.20	37.5	36.2	40.9	41.0	38.9	41.0	1234	593
ESA_039_5	1.20	41.2	37.2	41.2	37.2	39.2	41.2	1209	609

Table 3.22. Indentation measurement of full-scale ESA_040 panel.

Panel	Depth	Ø 1	Ø 2	Ø 3	Ø 4	Avg Ø	Max Ø	Area	Volume
ESA_040_1	0.33	14.3	14.4	17.7	16.4	15.7	17.7	203	24
ESA_040_2	0.36	15.8	16.3	20.2	16.0	17.1	20.2	244	33
ESA_040_3	0.56	20.8	20.6	22.6	20.1	21.0	22.6	356	66
ESA_040_4	0.76	31.2	27.2	31.4	28.7	29.6	31.4	692	180
ESA_040_5	0.80	29.7	28.3	30.6	28.8	29.4	30.6	677	173

Table 3.23. Indentation measurement of full-scale ESA_041 panel.

Panel	Depth	Ø 1	Ø 2	Ø 3	Ø 4	Avg Ø	Max Ø	Area	Volume
ESA_041_1	0.37	15.4	12.0	14.5	12.2	13.5	15.4	148	20
ESA_041_2	0.63	20.8	16.5	20.1	17.5	18.7	20.8	280	60
ESA_041_3	0.65	21.2	16.1	19.7	17.0	18.5	21.2	264	60
ESA_041_4	0.84	23.1	18.8	23.2	19.0	21.0	23.2	347	110
ESA_041_5	0.90	22.3	19.5	24.1	19.5	21.4	24.1	354	125

Table 3.24. Indentation measurement of full-scale ESA_042 panel.

Panel	Depth	Ø 1	Ø 2	Ø 3	Ø 4	Avg Ø	Max Ø	Area	Volume
ESA_042_1	0.72	24.6	23.6	25.7	24.0	24.5	25.7	485	146
ESA_042_2	1.09	31.6	30.0	31.8	30.5	31.0	31.8	765	351
ESA_042_3	1.07	30.6	29.4	32.1	30.4	30.6	32.1	734	341
ESA_042_4	1.42	35.8	34.6	37.1	34.9	35.6	37.1	1043	649
ESA_042_5	1.41	35.9	34.4	37.9	34.9	35.8	37.9	1074	646

Table 3.25. Indentation measurement of full-scale ESA_043 panel.

Panel	Depth	Ø 1	Ø 2	Ø 3	Ø 4	Avg Ø	Max Ø	Area	Volume
ESA_043_1	0.39	15.0	13.6	15.6	13.2	14.3	15.6	168	24
ESA_043_2	0.59	20.1	17.0	20.2	16.8	18.5	20.2	271	58
ESA_043_3	0.61	20.4	15.4	19.0	16.4	17.8	20.4	255	58
ESA_043_4	0.86	25.3	20.4	25.9	20.6	23.1	25.9	415	121
ESA_043_5	0.86	23.1	20.8	26.1	20.4	22.6	26.1	409	121

Table 3.26. Indentation measurement of full-scale ESA_044 panel.

Panel	Depth	Ø 1	Ø 2	Ø 3	Ø 4	Avg Ø	Max Ø	Area	Volume
ESA_044_1	0.68	21.0	17.7	19.8	17.7	19.0	21.0	286	72
ESA_044_2	0.82	22.3	19.9	23.4	20.9	21.6	23.4	388	115
ESA_044_3	1.02	28.2	22.5	28.4	23.1	25.5	28.4	504	193
ESA_044_4	0.80	25.6	25.9	25.8	25.9	25.8	25.9	530	193
ESA_044_5	0.90	27.7	27.2	28.1	27.4	27.6	28.1	593	246
ESA_044_6	1.08	29.9	29.7	31.4	29.4	30.1	31.4	732	362

Table 3.27. Indentation measurement of full-scale ESA_045 panel.

Panel	Depth	Ø 1	Ø 2	Ø 3	Ø 4	Avg Ø	Max Ø	Area	Volume
ESA_045_1	0.34	16.1	14.8	16.0	17.4	16.1	17.4	203	25
ESA_045_2	0.58	21.2	19.9	22.6	24.5	22.1	24.5	387	77
ESA_045_3	0.57	20.3	19.7	22.5	20.5	20.7	22.5	355	73
ESA_045_4	3.76	24.7	23.3	27.9	23.3	24.8	27.9	492	401
ESA_045_5	0.76	24.3	24.9	26.9	23.9	25.0	26.9	509	150

Table 3.28. Indentation measurement of full-scale ESA_046 panel.

Panel	Depth	Ø 1	Ø 2	Ø 3	Ø 4	Avg Ø	Max Ø	Area	Volume
ESA_046_1	0.51	21.6	19.8	21.0	21.6	21.0	21.6	353	63
ESA_046_2	0.66	24.3	23.1	25.4	23.8	24.1	25.4	472	111
ESA_046_3	0.75	26.4	25.5	27.8	27.4	26.8	27.8	567	156
ESA_046_4	0.64	24.4	24.7	24.9	26.0	25.0	26.0	500	136
ESA_046_5	0.75	27.8	26.6	28.7	29.6	28.2	29.6	624	195
ESA_046_6	0.88	29.5	28.3	30.7	29.0	29.4	30.7	696	283

Table 3.29. Indentation measurement of full-scale ESA_047 panel.

Panel	Depth	Ø 1	Ø 2	Ø 3	Ø 4	Avg Ø	Max Ø	Area	Volume
ESA_047_1	0.55	21.6	19.1	21.1	22.8	21.1	22.8	353	69
ESA_047_2	0.66	25.3	23.9	26.0	26.0	25.3	26.0	502	113
ESA_047_3	0.80	27.7	24.2	28.9	29.6	27.6	29.6	601	163
ESA_047_4	0.69	27.2	25.6	28.9	29.0	27.7	29.0	606	163
ESA_047_5	0.76	28.5	27.6	30.6	31.0	29.4	31.0	681	205
ESA_047_6	0.91	31.1	30.3	31.4	33.5	31.6	33.5	808	301

Table 3.30. Indentation measurement of full-scale ESA_048 panel.

Panel	Depth	Ø 1	Ø 2	Ø 3	Ø 4	Avg Ø	Max Ø	Area	Volume
ESA_048_1	0.58	23.3	21.6	23.3	22.6	22.7	23.3	407	81
ESA_048_2	0.58	23.3	19.8	23.9	25.5	23.1	25.5	405	80
ESA_048_3	1.54	38.9	27.7	29.0	28.1	30.9	38.9	763	333
ESA_048_4	0.72	27.0	26.2	28.6	28.8	27.7	28.8	613	174
ESA_048_5	1.01	33.9	31.8	34.7	32.1	33.1	34.7	892	368
ESA_048_6	1.25	37.7	37.6	40.7	39.7	38.9	40.7	1184	636

Table 3.31. Indentation measurement of full-scale ESA_049 panel.

Panel	Depth	Ø 1	Ø 2	Ø 3	Ø 4	Avg Ø	Max Ø	Area	Volume
ESA_049_1	0.45	24.9	21.9	21.9	22.6	22.8	24.9	416	65
ESA_049_2	0.56	28.4	24.9	24.6	26.3	26.0	28.4	534	102
ESA_049_3	0.73	29.8	26.0	27.1	28.0	27.7	29.8	608	153
ESA_049_4	0.57	25.8	25.5	25.9	25.2	25.6	25.9	534	132
ESA_049_5	0.66	30.7	29.4	30.7	31.3	30.5	31.3	773	186
ESA_049_6	0.78	34.1	32.2	33.1	33.8	33.3	34.1	866	266

Table 3.32. Indentation measurement of full-scale ESA_050 panel.

Panel	Depth	Ø 1	Ø 2	Ø 3	Ø 4	Avg Ø	Max Ø	Area	Volume
ESA_050_1	0.35	20.6	17.5	17.4	19.7	18.8	20.6	284	33
ESA_050_2	0.60	23.3	21.9	21.8	23.6	22.7	23.6	404	70
ESA_050_3	1.06	27.5	25.6	23.7	24.9	25.4	27.5	508	135
ESA_050_4	0.64	28.9	28.0	29.9	30.0	29.2	30.0	683	163
ESA_050_5	0.90	36.3	33.0	34.0	35.5	34.7	36.3	956	333
ESA_050_6	1.09	41.0	39.3	39.4	39.0	39.7	41.0	1246	568

4 Modal testing sandwich panels

The **Polytec PSV-400 Vibrometer** is an ultimate vibration scaning tool set for non-contact measurement, visualization and analysis of structural vibrations. It determines the operational deflection shapes and Eigen modes as easily as taking a photograph. Entire surfaces can be scanned automatically using flexible and interactive measurement grids. Measurements can be made over a wide frequency bandwidth. The PSV-400 offers technical excellence with powerful software for dynamic measurement, analysis and real-time chromatic display of data. Designed for resolving noise and vibration issues in R&D and manufacturing, the system is versatile and easy to use. Additional test machine parameters are given in Table 4.1.

Table 4.1. Testing equipment Polytec PSV-400 technical details.

Parametrs	Value	Unit
Bandwidth	3,2	kHz
FFTLine	6400	
Resolution	500	mHz

For ease of navigating throught, the panel tests a dedicated number and accounting system was set as shown in following chart:

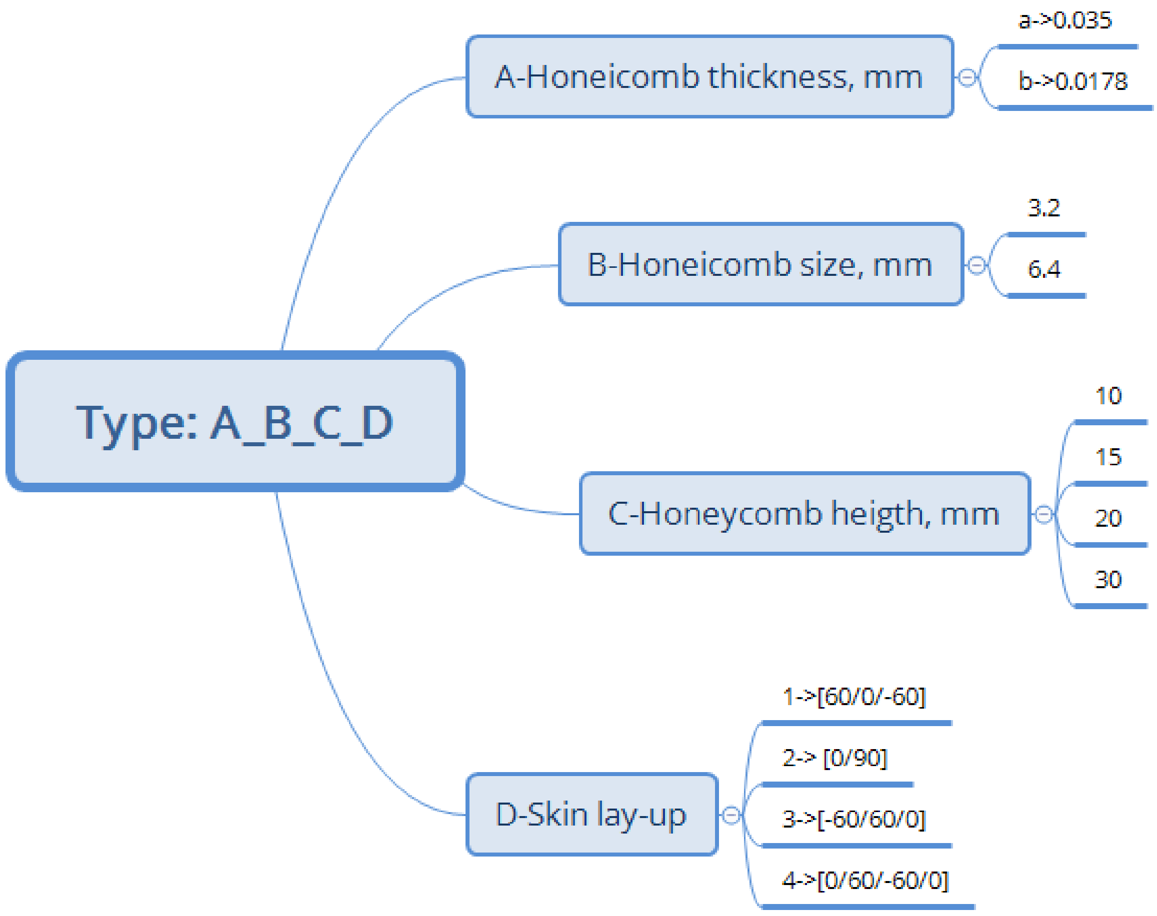
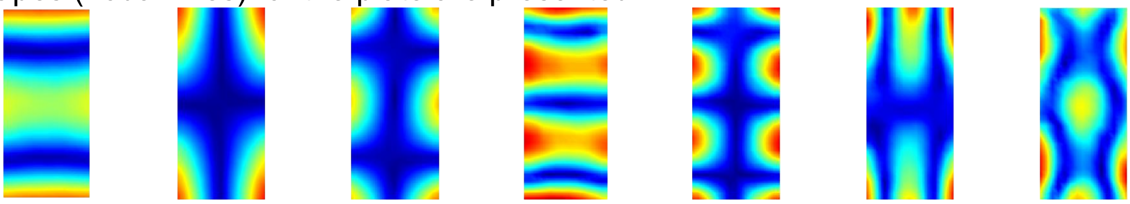


Figure 4.1. Panel accounting system

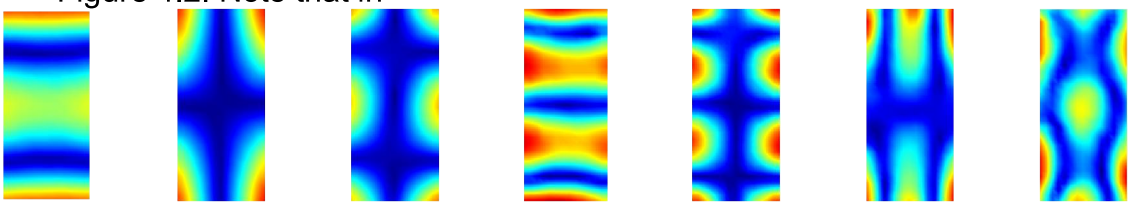
4.1 Modal analysis.

The self-frequency mode shapes were recorded in physical testing. The mode shapes (nodal lines) for the plate are presented in



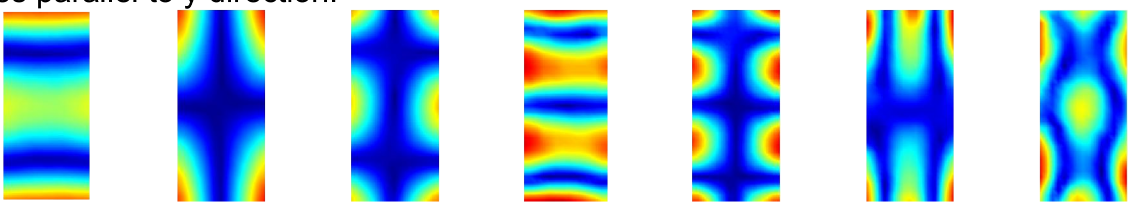
(0; 2) (1; 1) (1; 2) (0; 3) (1; 3) (2; 1) (2; 0)

Figure 4.2. Note that in



(0; 2) (1; 1) (1; 2) (0; 3) (1; 3) (2; 1) (2; 0)

Figure 4.2 is horizontal axis and y is vertical axis. The measured self-frequencies are given in Table 4.2-Table 4.17 and graph in Figure 4.3 to Figure 4.18 where experimental plate flexural frequencies are presented. The quantity n denotes the number of nodal lines parallel to x direction and m denotes the number of nodal lines parallel to y direction.



(0; 2) (1; 1) (1; 2) (0; 3) (1; 3) (2; 1) (2; 0)

Figure 4.2. Vibration modes (n, m) of ESA plate

Where summary of all **Type:_a_3.2_10_1** (*ESA_001-ESA_008*) series frequency versus signal magnitude response are outlined in Figure 4.3. A correlation among series self-frequency responses are summarised in Table 4.12

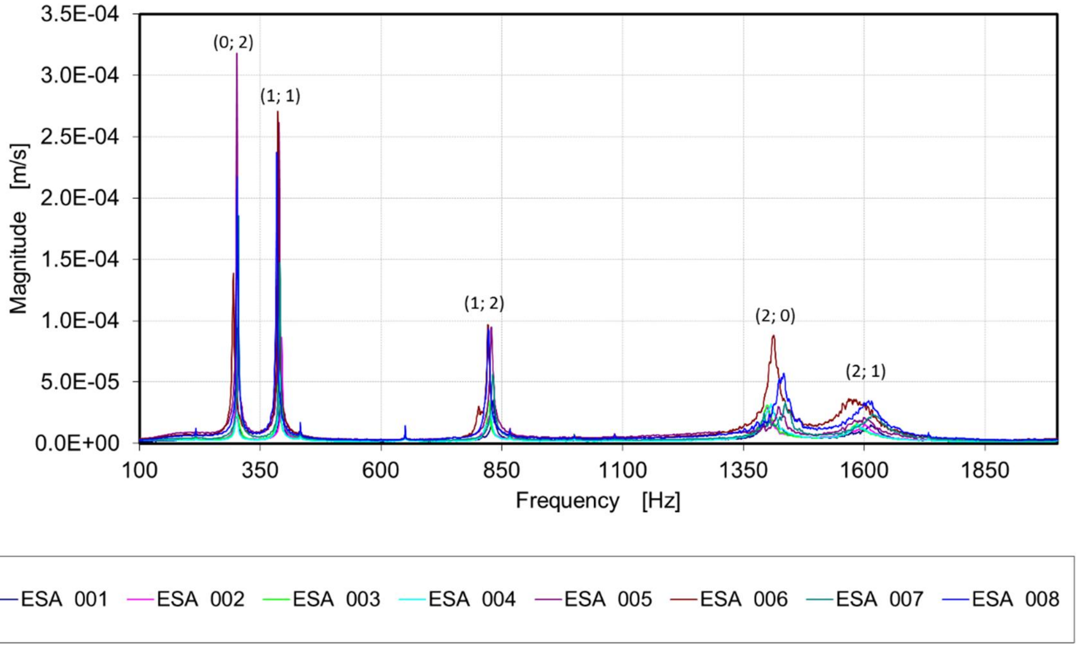


Figure 4.3. Frequency response for **Type:_a_3.2_10_1**

Table 4.2. **Type:_a_3.2_10_1** series corresponding natural frequency, deviation from average value of whole set and quality distribution - specimen natural frequencies within 2σ range.

(m; n)	ESA_001		ESA_002		ESA_003		ESA_004	
(0; 2)	301.3	-0.20	299.4	0.44	300.9	-0.06	300	0.24
(1; 1)	393.1	-0.89	395	-1.37	388.4	0.32	390	-0.09
(1; 2)	832.2	-0.72	824.4	0.22	822.8	0.42	827.5	-0.15
(2; 0)	1410.6	0.30	1397.8	1.20	1398.4	1.16	1407.5	0.52
(2; 1)	1615.0	-0.73	1601.3	0.13	1585.3	1.12	1586.3	1.06

ESA_005		ESA_006		ESA_007		ESA_008		$\delta-2\sigma$	δ	$\delta+2\sigma$
301.9	-0.40	**294.38**	**2.11**	305	-1.43	302.8	-0.70	**294.93**	**300.7**	**306.49**
389.4	0.06	386.88	0.71	390.63	-0.25	383.8	1.50	**383.13**	**389.7**	**396.18**
828.4	-0.26	820.94	0.64	831.25	-0.61	822.5	0.45	**818.37**	**826.2**	**834.13**
1421.9	-0.50	1412.5	0.17	1436.88	-1.56	1433.1	-1.29	**1387.39**	**1414.8**	**1442.28**
1608.8	-0.34			1616.88	-0.85	1609.7	-0.40	**1579.31**	**1603.3**	**1627.34**

Where summary of all **Type:_a_3.2_20_1** (*ESA_009-ESA_010*) series frequency versus signal magnitude response are outlined in Figure 4.4. A correlation among series self-frequency responses are summarised in Table 4.3

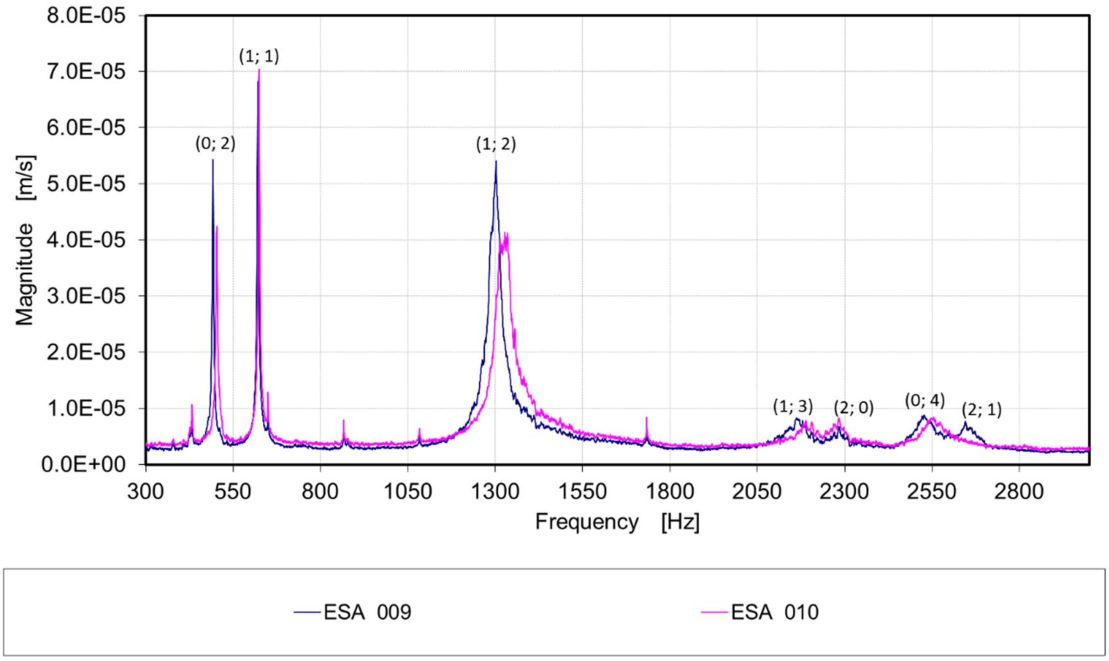


Figure 4.4. Frequency response for **Type:_a_3.2_20_1**

Table 4.3. **Type:_a_3.2_20_1** series corresponding natural frequency, deviation from average value of whole.

(m; n)	ESA_009	ESA_010	AVE
(0; 2)	492.50	503.13	**497.81**
(1; 1)	621.25	624.38	**622.81**
(1; 2)	1302.50	1319.06	**1310.78**
(1; 3)	2161.56	2189.06	**2175.31**
(2; 0)	2284.06	2283.75	**2283.91**
(0; 4)	2527.81	2551.88	**2539.84**
(2; 1)	2645.00		**2645.00**

Where summary of all **Type:_a_3.2_10_4** (*ESA_016-ESA_017*) series frequency versus signal magnitude response are outlined in Figure 4.5. A correlation among series self-frequency responses are summarised in Table 4.4

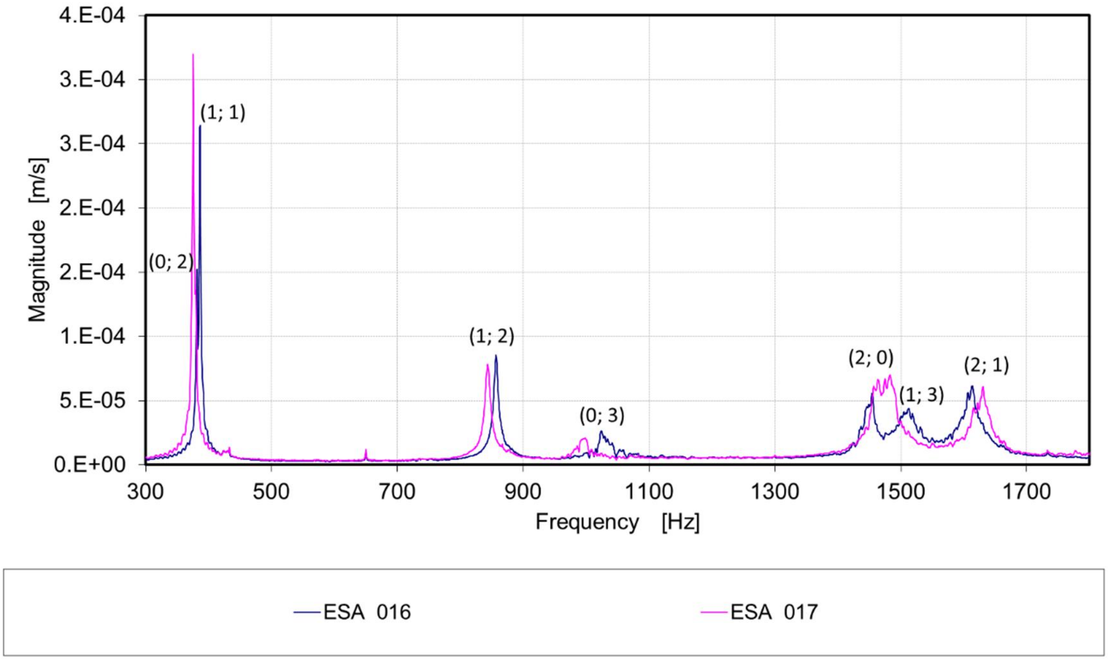


Figure 4.5. Frequency response for **Type:_a_3.2_10_4**

Table 4.4. **Type:_a_3.2_10_4** series corresponding natural frequency, deviation from average value of whole.

(m; n)	ESA_016	ESA_017	AVE
(0; 2)	381.25	377.81	**379.53**
(1; 1)	386.88	380.00	**383.44**
(1; 2)	856.88	843.75	**850.31**
(0; 3)	1023.75	998.13	**1010.94**
(2; 0)	1454.38	1483.44	**1468.91**
(1; 3)	1512.50		**1512.50**
(2; 1)	1613.44	1630.63	**1622.03**

Where summary of all **Type:_b_6.4_20_2** (*ESA_022-ESA_023*) series frequency versus signal magnitude response are outlined in Figure 4.6. A correlation among series self-frequency responses are summarised in Table 4.5

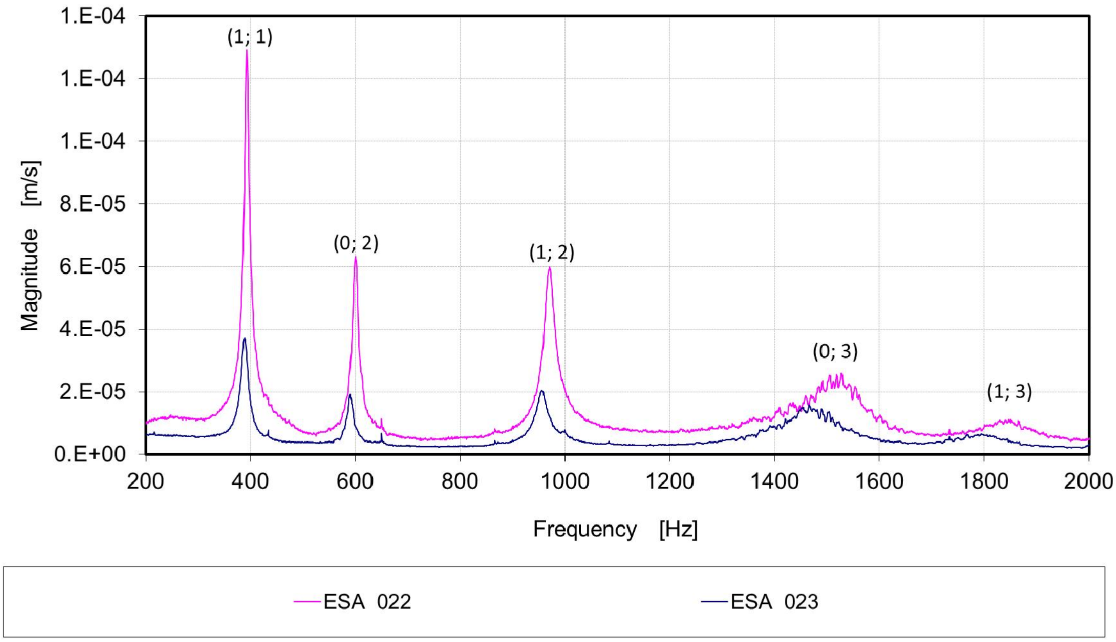


Figure 4.6. Frequency response for **Type:_b_6.4_20_2**

Table 4.5. **Type:_b_6.4_20_2** series corresponding natural frequency, deviation from average value of whole.

(m; n)	ESA_022	ESA_023	AVE
(1; 1)	393.36	389.06	**391.21**
(0; 2)	600.00	589.84	**594.92**
(1; 2)	970.31	955.08	**962.70**
(0; 3)	1516.41	1466.41	**1491.41**
(1; 3)	1844.15	1794.53	**1819.34**

Where summary of all **Type:_b_6.4_20_4** (*ESA_027-ESA_029*) series frequency versus signal magnitude response are outlined in Figure 4.7. A correlation among series self-frequency responses are summarised in Table 4.6

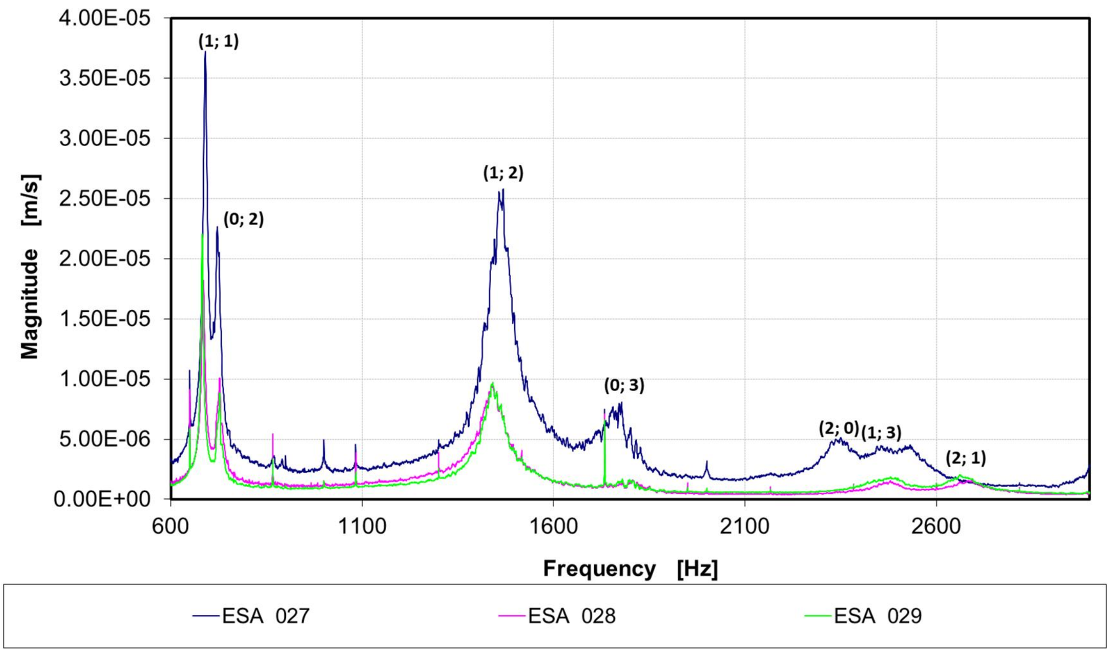


Figure 4.7. Frequency response for **Type:_b_6.4_20_4**

Table 4.6. **Type:_b_6.4_20_4** series corresponding natural frequency, deviation from average value of whole.

(m; n)	ESA 027		ESA 028		ESA 029		δ−2σ	δ	δ+2σ
(1; 1)	690.00	-0.64	684.75	0.12	682.00	0.52	677.45	**685.58**	693.71
(0; 2)	721.56	0.57	727.75	-0.28	727.75	-0.28	718.54	**725.69**	732.83
(1; 2)	1462.81	-1.04	1439.50	0.57	1441.00	0.47	1421.67	**1447.77**	1473.87
(0; 3)	1778.13	0.73	1806.50	-0.85	1789.00	0.12	1762.58	**1791.21**	1819.84
(2; 0)	2350.63	3.14	2449.50	-0.94	2480.00	-2.20	2291.44	**2426.71**	2561.97
(1; 3)	2455.94	0.00						**2455.94**	
(2; 1)	2531.25	3.72	2694.25	-2.49	2661.25	-1.23	2456.56	**2628.92**	2801.27

Where summary of all **Type:_b_6.4_20_4** (*ESA_027-ESA_029*) series frequency versus signal magnitude response are outlined in Figure 4.8. A correlation among series self-frequency responses are summarised in Table 4.67

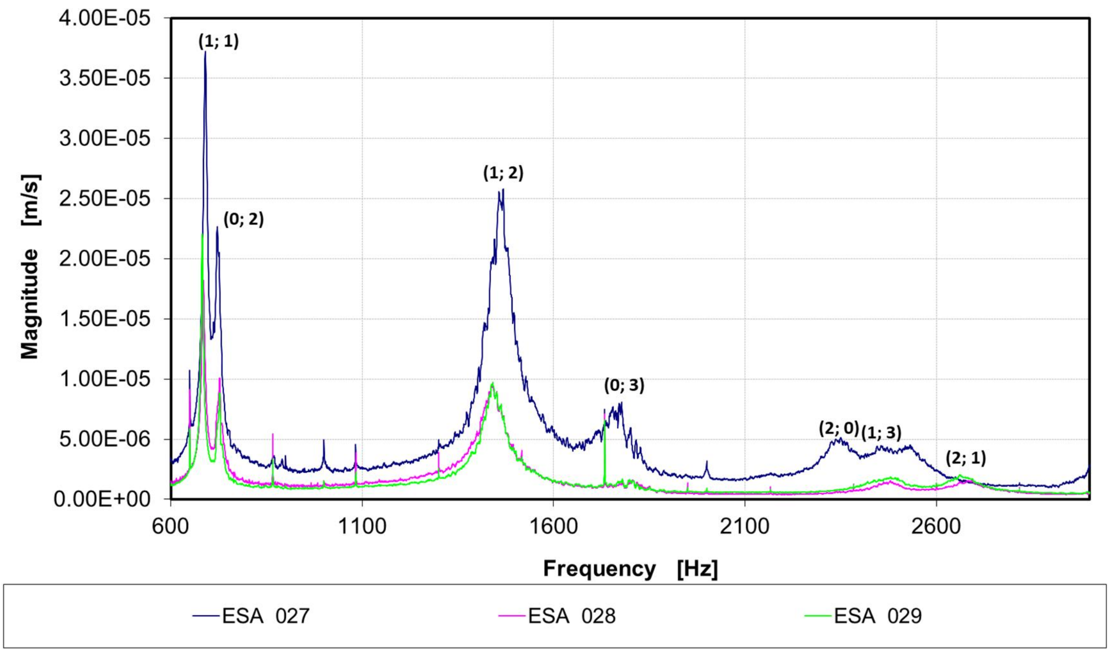


Figure 4.8. Frequency response for **Type:_b_6.4_20_4**

Table 4.7. **Type:_b_6.4_20_4** series corresponding natural frequency, deviation from average value of whole.

(m; n)	ESA 027		ESA 028		ESA 029		δ–2σ	δ	δ+2σ
(1; 1)	690.00	-0.64	684.75	0.12	682.00	0.52	677.45	**685.58**	693.71
(0; 2)	721.56	0.57	727.75	-0.28	727.75	-0.28	718.54	**725.69**	732.83
(1; 2)	1462.81	-1.04	1439.50	0.57	1441.00	0.47	1421.67	**1447.77**	1473.87
(0; 3)	1778.13	0.73	1806.50	-0.85	1789.00	0.12	1762.58	**1791.21**	1819.84
(2; 0)	2350.63	3.14	2449.50	-0.94	2480.00	-2.20	2291.44	**2426.71**	2561.97
(1; 3)	2455.94	0.00						**2455.94**	
(2; 1)	2531.25	3.72	2694.25	-2.49	2661.25	-1.23	2456.56	**2628.92**	2801.27

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Where summary of all **Type:_b_3.2_20_4** (*ESA_030-ESA_033*) series frequency versus signal magnitude response are outlined in Figure 4.9. A correlation among series self-frequency responses are summarised in Table 4.8

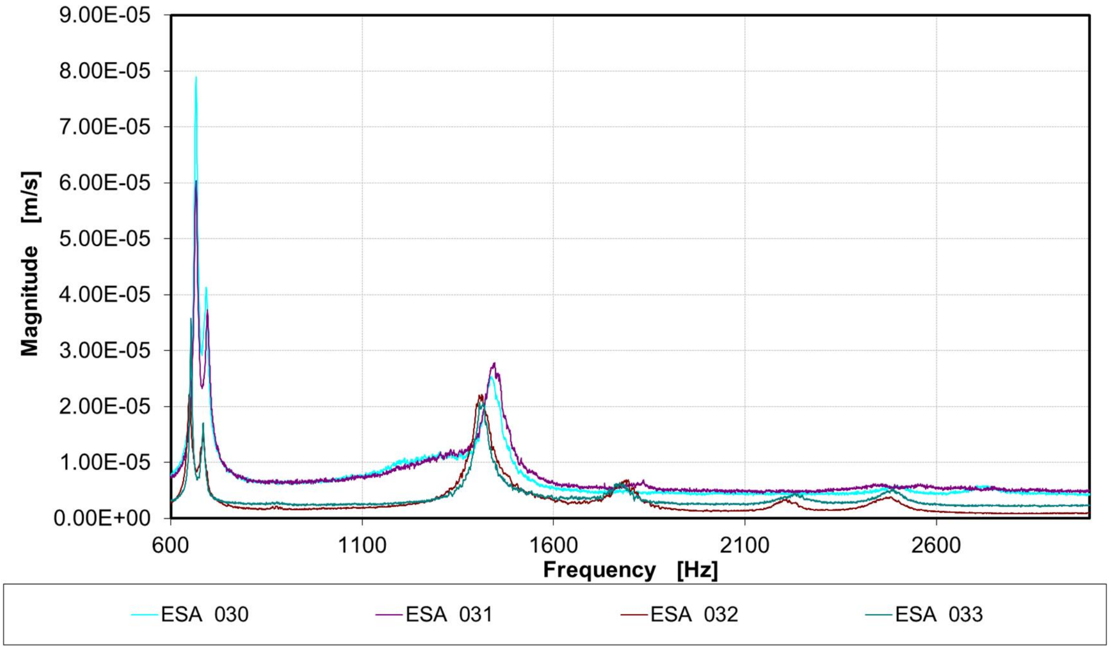


Figure 4.9. Frequency response for **Type:_b_3.2_20_4**

Table 4.8. **Type:_b_3.2_20_4** series corresponding natural frequency, deviation from average value of whole.

(m; n)	ESA 030		ESA 031		ESA 032		ESA 033		δ−2σ	δ	δ+2σ
(1; 1)	665.94	-1.10	665.94	-1.10	649.38	1.41	653.44	0.79	641.5679	**658.67**	675.7758
(0; 2)	693.13	-0.52	695.63	-0.88	685.00	0.66	684.38	0.75	678.1489	**689.53**	700.9136
(1; 2)	1436.88	-0.86	1445.94	-1.49	1409.06	1.10	1406.88	1.25	1385.334	**1424.69**	1464.041
(0; 3)			1833.75	-1.86	1795.00	0.30	1772.19	1.56	1738.066	**1800.31**	1862.559
(2; 0)	2495.31	-6.32	2454.38	-4.58	2207.50	5.94	2230.63	4.96	2049.118	**2346.95**	2644.788
(1; 3)			2557.75	-1.53	2480.63	1.53			2410.116	**2519.19**	2628.259
(2; 1)	2731.56	-4.76					2483.44	4.76	2256.598	**2607.50**	2958.402

Where summary of all **Type:_b_6.4_30_4** (*ESA_034-ESA_035*) series frequency versus signal magnitude response are outlined in Figure 4.10. A correlation among series self-frequency responses are summarised in Table 4.9

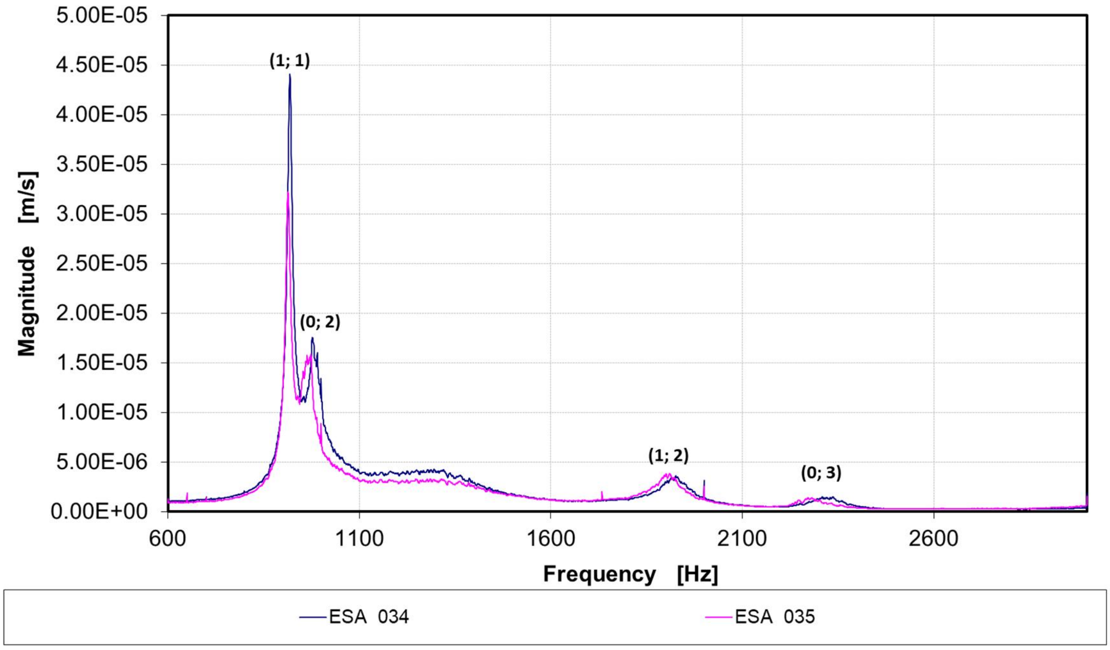


Figure 4.10. Frequency response for **Type:_b_6.4_30_4**

Table 4.9. **Type:_b_6.4_30_4** series corresponding natural frequency, deviation from average value of whole.

(m; n)	ESA 034	ESA 035	AVE
(1; 1)	918.75	913.25	**916.00**
(0; 2)	977.00	969.00	**973.00**
(1; 2)	1926.00	1906.50	**1916.25**
(0; 3)	2336.50	2277.50	**2307.00**

Where summary of all **Type:_b_6.4_30_3** (*ESA_036-ESA_037*) series frequency versus signal magnitude response are outlined in Figure 4.11. A correlation among series self-frequency responses are summarised in Table 4.10

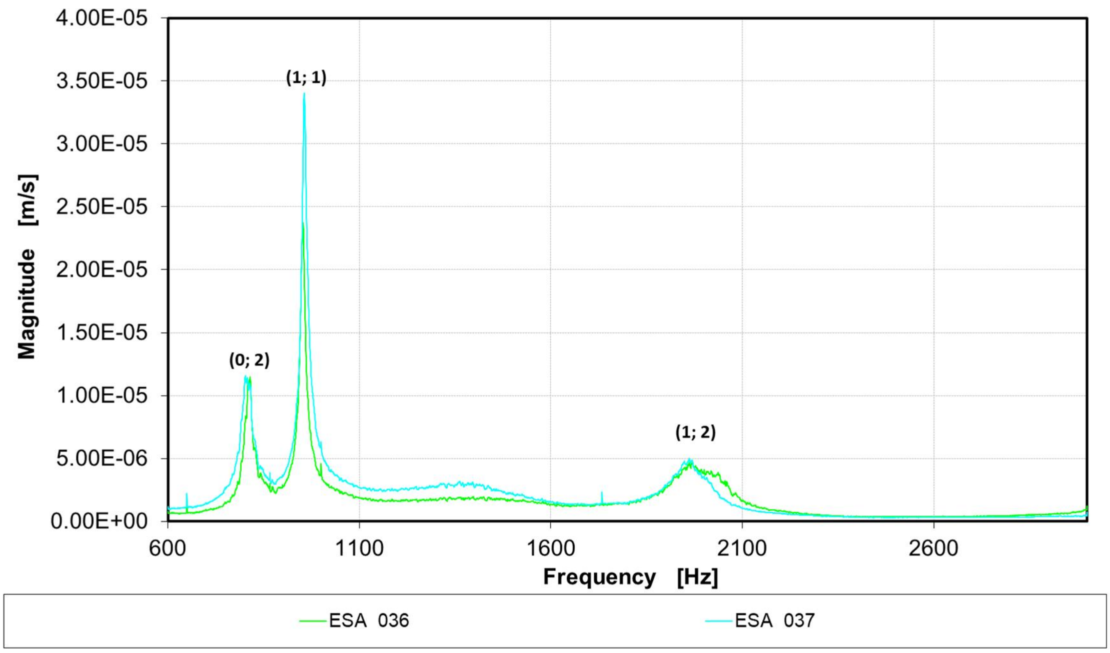


Figure 4.11. Frequency response for **Type:_b_6.4_30_3**

Table 4.10. **Type:_b_6.4_30_3** series corresponding natural frequency, deviation from average value of whole.

(m; n)	ESA 036	ESA 037	AVE
(0; 2)	815.00	805.25	810.13
(1; 1)	953.00	956.50	954.75
(1; 2)	1966.50	1961.75	1964.13

Where summary of **Type:_b_6.4_20_3** (*ESA_038*) series frequency versus signal magnitude response are outlined in Figure 4.12. A correlation among series self-frequency responses are summarised in Table 4.11

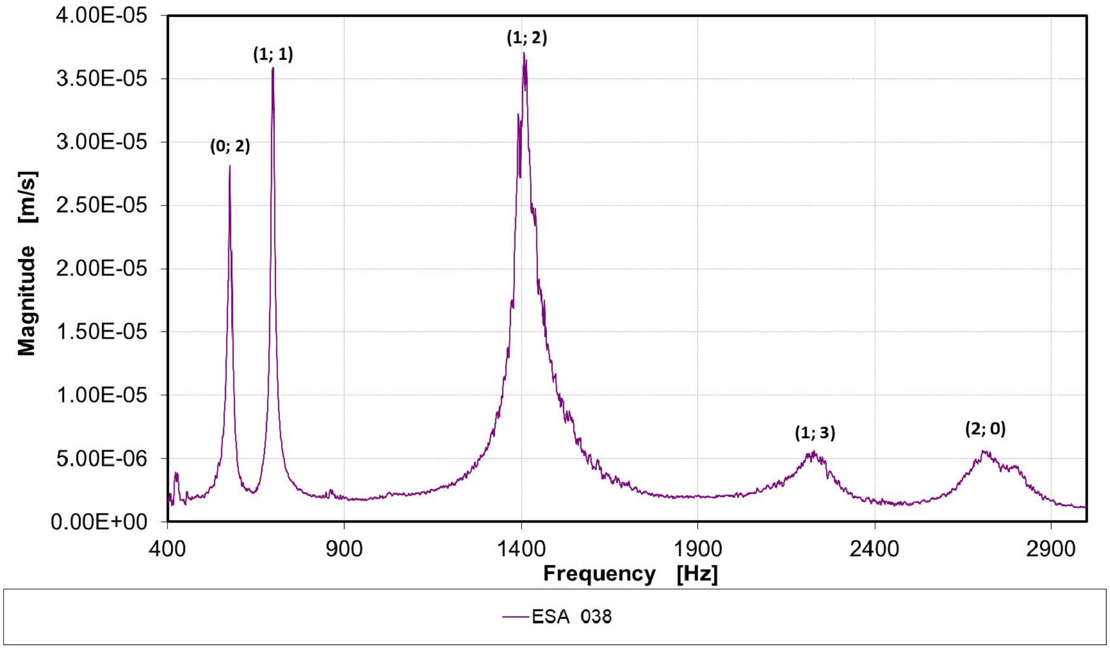


Figure 4.22. Frequency response for **Type:_b_6.4_20_3**

Table 4.11. **Type:_b_6.4_20_3** series corresponding natural frequency, deviation from average value of whole.

(m; n)	ESA 038
(0; 2)	576.56
(1; 1)	697.19
(1; 2)	1400.00
(1; 3)	2228.13
(2; 0)	2705.00

Where summary of **Type:_b_6.4_30_2** (*ESA_039*) series frequency versus signal magnitude response are outlined in Figure 4.33. A correlation among series self-frequency responses are summarised in Table 4.12

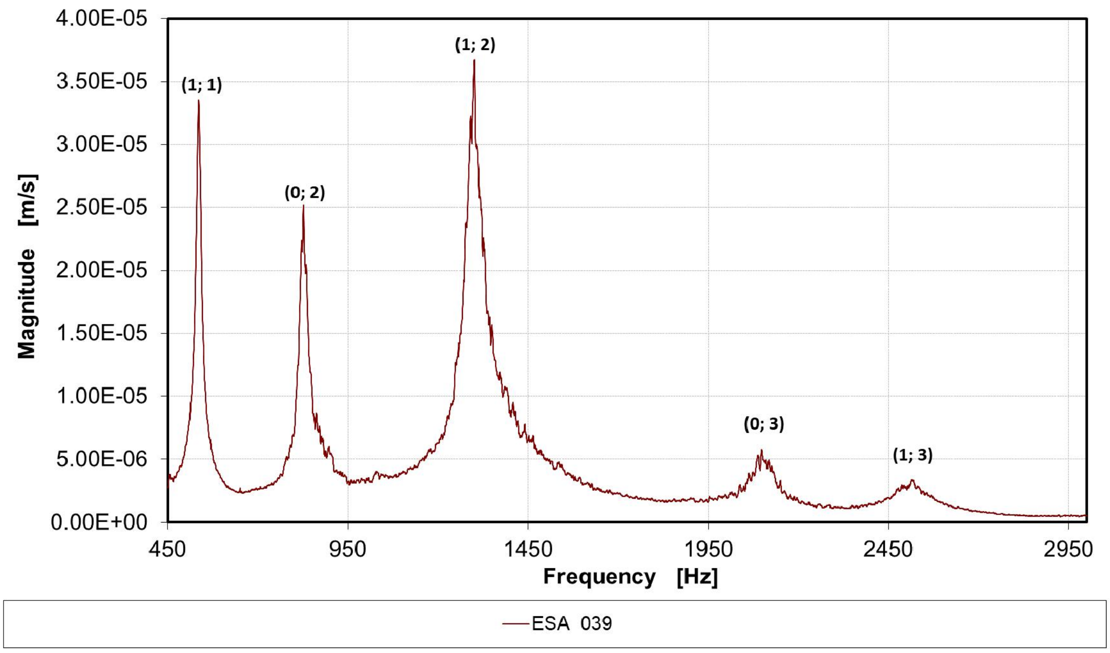


Figure 4.33. Frequency response for **Type:_b_6.4_30_2**

Table 4.12. **Type:_b_6.4_30_2** series corresponding natural frequency, deviation from average value of whole.

(m; n)	ESA 039
(1; 1)	535.63
(0; 2)	826.88
(1; 2)	1301.25
(0; 3)	2098.13
(1; 3)	2514.69

Where summary of all **Type:_b_3.2_20_2** (*ESA_041-ESA_042*) series frequency versus signal magnitude response are outlined in Figure 4.44 A correlation among series self-frequency responses are summarised in Table 4.13

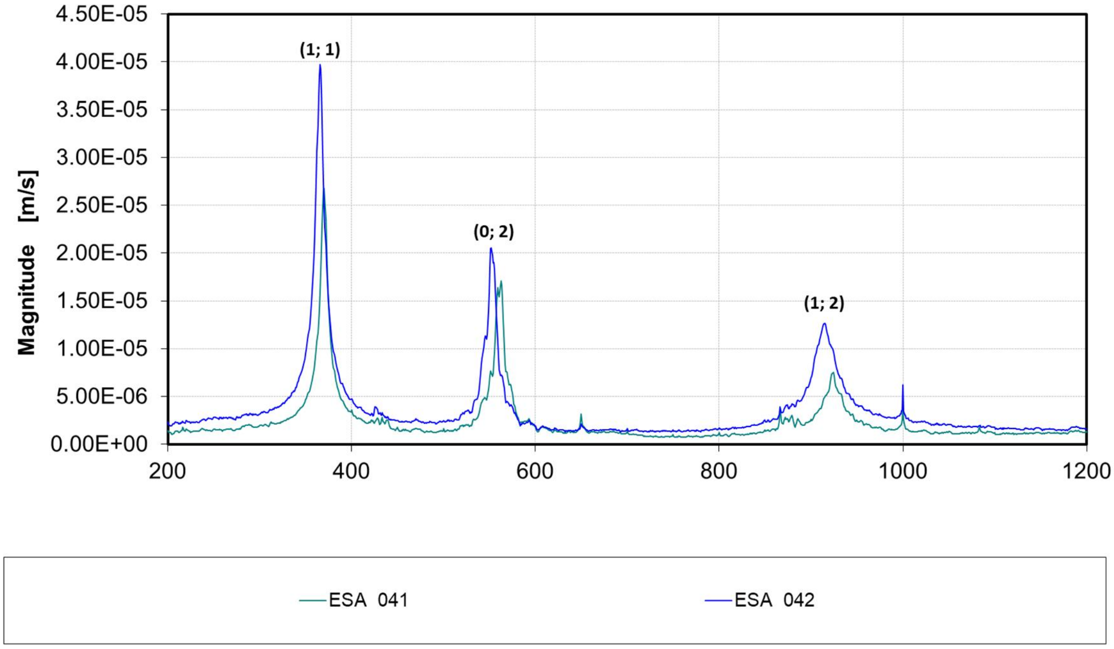


Figure 4.44. Frequency response for **Type:_b_3.2_30_2**

Table 4.13. **Type:_b_3.2_30_2** series corresponding natural frequency, deviation from average value of whole.

(m; n)	ESA 041	ESA 042	AVE
(1; 1)	370.31	366.02	368.16
(0; 2)	562.50	552.34	557.42
(1; 2)	924.22	914.45	919.34

Where summary of all **Type:_b_3.2_30_2** (*ESA_043-ESA_044*) series frequency versus signal magnitude response are outlined in Figure 4.55 A correlation among series self-frequency responses are summarised in Table 4.14

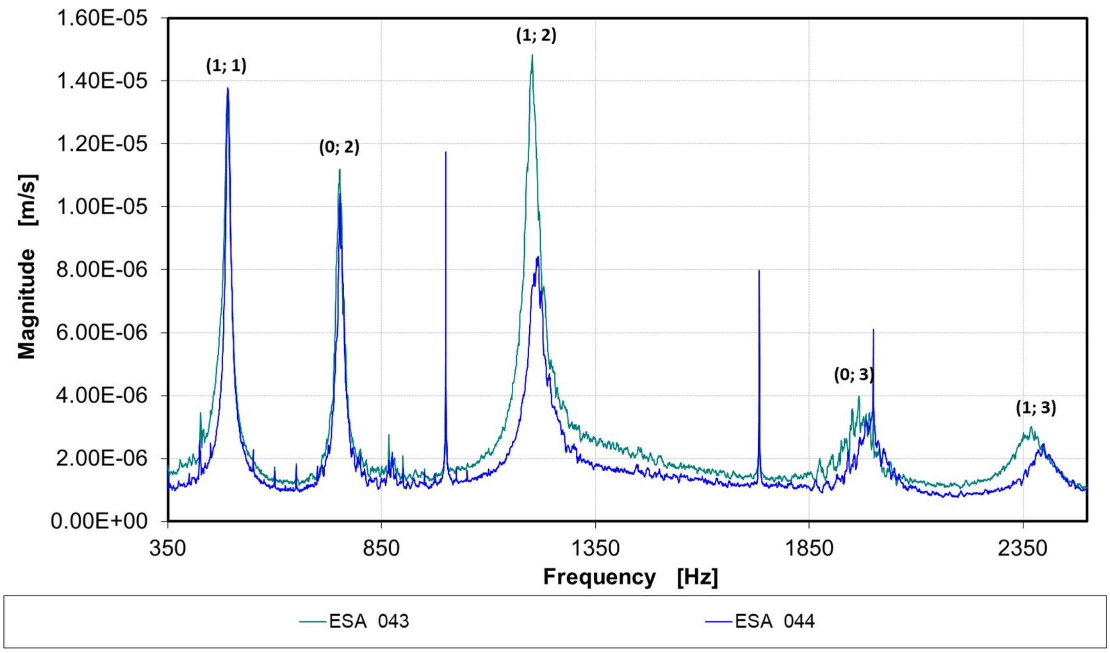


Figure 4.55. Frequency response for **Type:_b_3.2_30_2**

Table 4.14. **Type:_b_3.2_30_2** series corresponding natural frequency, deviation from average value of whole.

(m; n)	ESA 043	ESA 044	AVE
(1; 1)	489.45	490.94	490.20
(0; 2)	751.95	752.19	752.07
(1; 2)	1202.29	1215.94	1209.11
(0; 3)	1966.02	1982.81	1974.41
(1; 3)	2369.53	2397.19	2383.36

Where summary of all **Type:_b_3.2_20_3** (*ESA_045-ESA_046*) series frequency versus signal magnitude response are outlined in Figure 4.66 A correlation among series self-frequency responses are summarised in Table 4.15

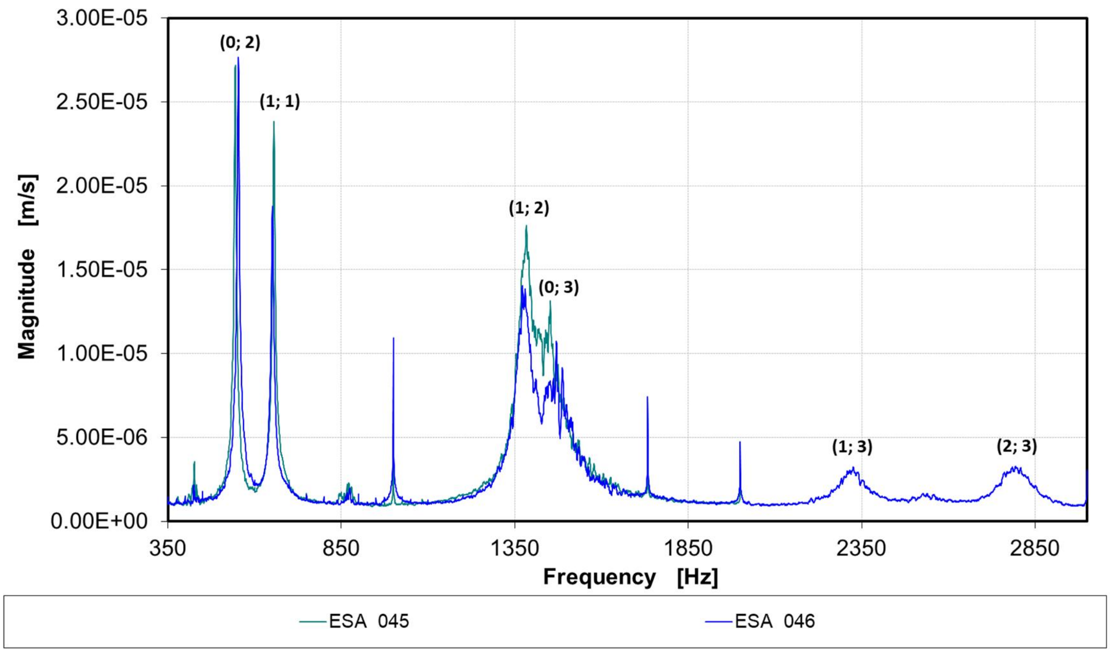


Figure 4.66. Frequency response for **Type:_b_3.2_20_3**

Table 4.15. **Type:_b_3.2_20_3** series corresponding natural frequency, deviation from average value of whole.

(m; n)	ESA 045	ESA 046	AVE
(0; 2)	544.06	554.06	549.06
(1; 1)	655.63	651.56	653.59
(1; 2)	1383.13	1372.19	1377.66
(0; 3)	1452.50	1470.31	1461.41
(1; 3)		2325.94	2325.94
(2; 3)		2793.75	2793.75

Where summary of all **Type:_b_3.2_30_3** (*ESA_047-ESA_048*) series frequency versus signal magnitude response are outlined in Figure 4.77 A correlation among series self-frequency responses are summarised in Table 4.16

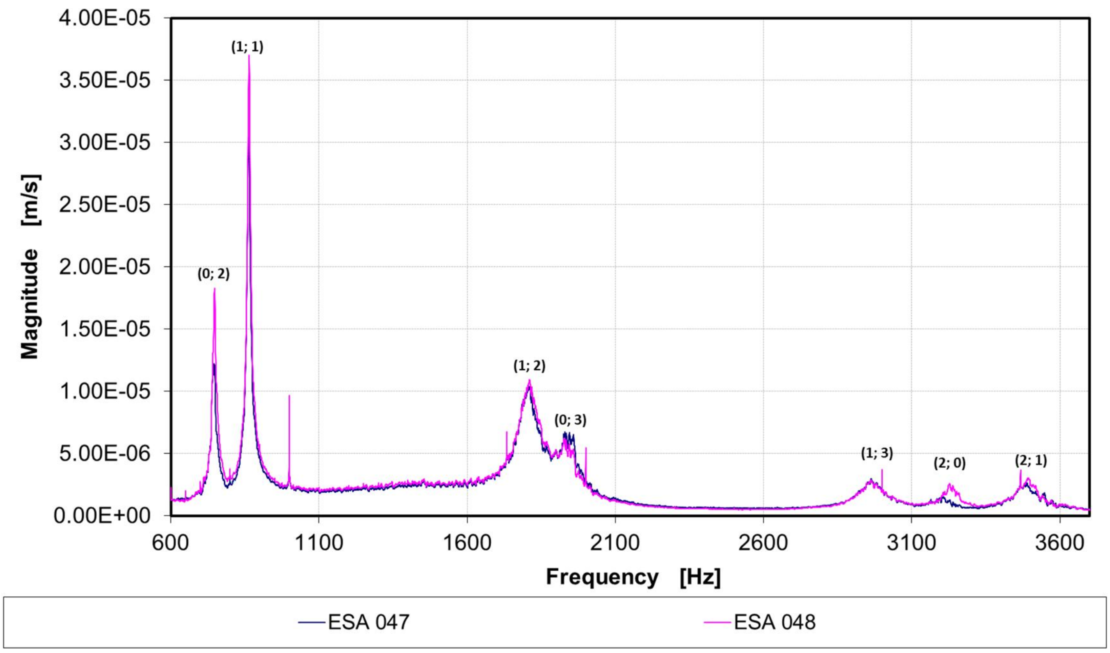


Figure 4.77. Frequency response for **Type:_b_3.2_30_3**

Table 4.16. **Type:_b_3.2_30_3** series corresponding natural frequency, deviation from average value of whole.

(m; n)	ESA 047	ESA 048	AVE
(0; 2)	744.69	748.13	746.41
(1; 1)	863.13	864.38	863.75
(1; 2)	1808.44	1809.69	1809.06
(0; 3)	1929.38	1926.88	1928.13
(1; 3)	2963.44	2961.88	2962.66
(2; 0)	3204.38	3227.81	3216.09
(2; 1)	3488.44	3490.63	3489.53

Where summary of all **Type:_b_3.2_30_4** (*ESA_049-ESA_050*) series frequency versus signal magnitude response are outlined in Figure 4.88 A correlation among series self-frequency responses are summarised in Table 4.17

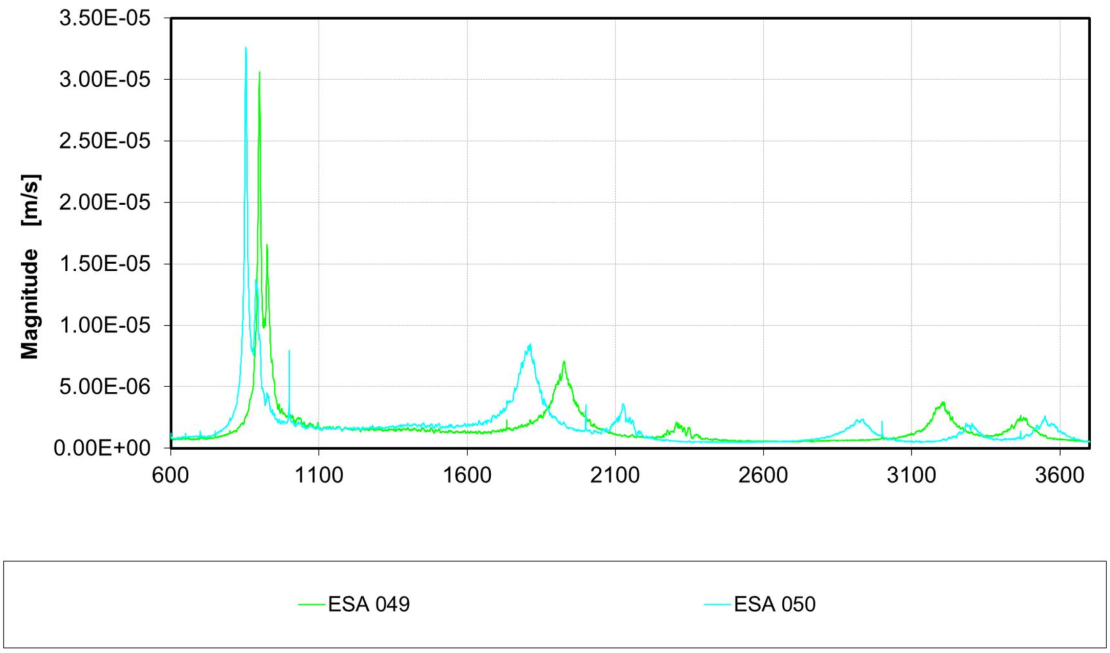


Figure 4.88. Frequency response for **Type:_b_3.2_30_4**

Table 4.17. **Type:_b_3.2_30_4** series corresponding natural frequency, deviation from average value of whole.

(m; n)	ESA 049	ESA 050
(1; 1)	899.38	853.75
(0; 2)	925.00	887.50
(1; 2)	1926.88	1813.13
(0; 3)	2306.56	2125.94
(1; 3)		2931.19
(2; 0)	3204.06	3283.13
(2; 1)	3466.88	3564.06

4.2 Modal assurance criterion.

A Modal Assurance Criterion technique for quality control and sensitivity analysis between obtained self-frequency modes analysed. Initially MAC has been programmed in Mathlab code for more effieicnet assessment of self-frequency response. Obtained modal assurance criterion plots are outlined in Figure 4.99-Figure 4.26 showing confirmation between tested panels.

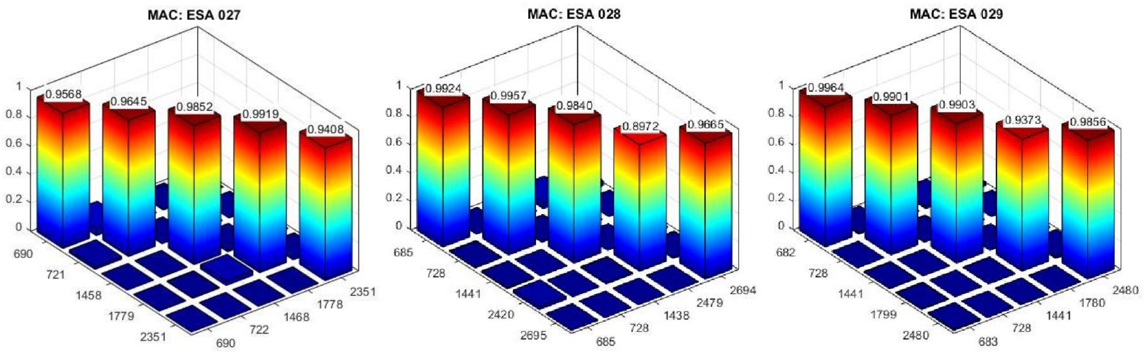


Figure 4.99. Modal assurance criterion plot for ESA_027 left, ESA_028 middle, ESA_029 right.

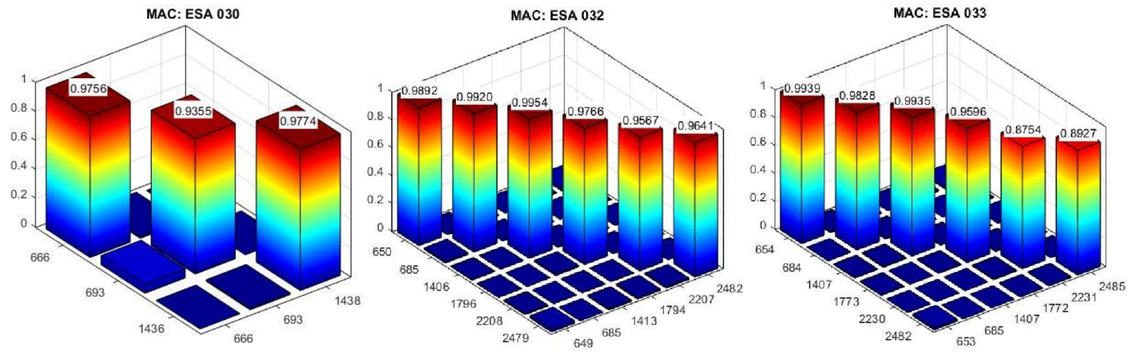


Figure 4.100. Modal assurance criterion plot for ESA_030 left, ESA_032 middle, ESA_033 right.

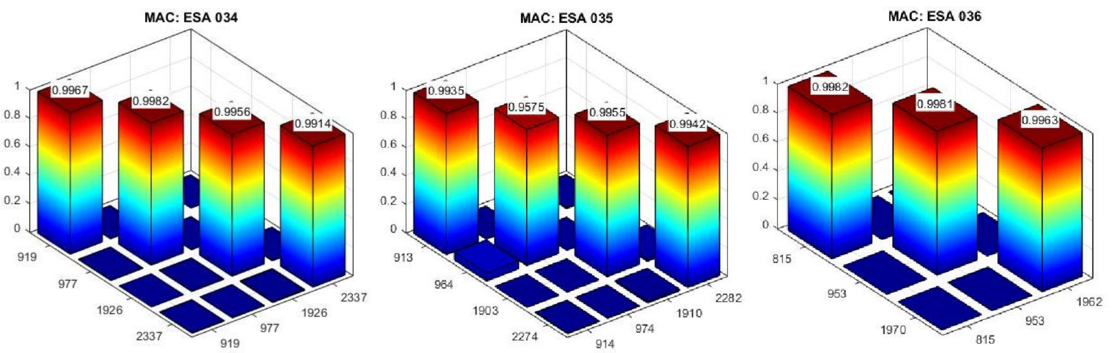


Figure 4.111. Modal assurance criterion plot for ESA_034 left, ESA_035 middle, ESA_036 right.

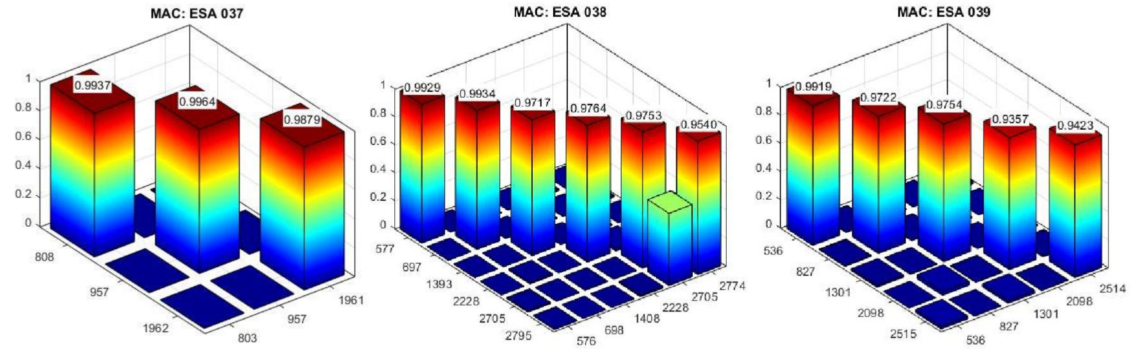


Figure 4.122. Modal assurance criterion plot for ESA_037 left, ESA_038 middle, ESA_039 right.

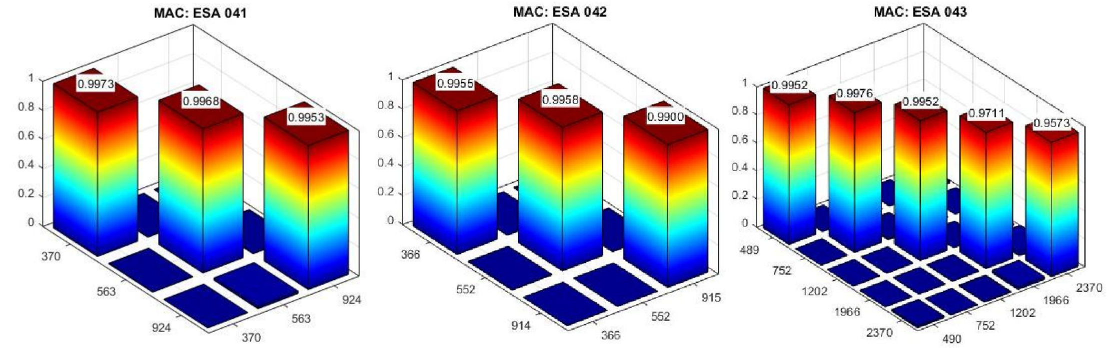


Figure 4.23. Modal assurance criterion plot for ESA_041 left, ESA_042 middle, ESA_043 right.

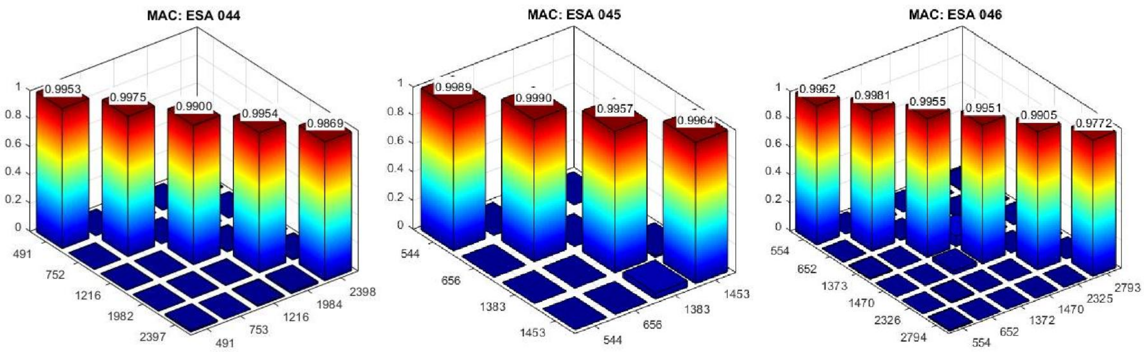


Figure 4.24. Modal assurance criterion plot for ESA_044 left, ESA_045 middle, ESA_046 right.

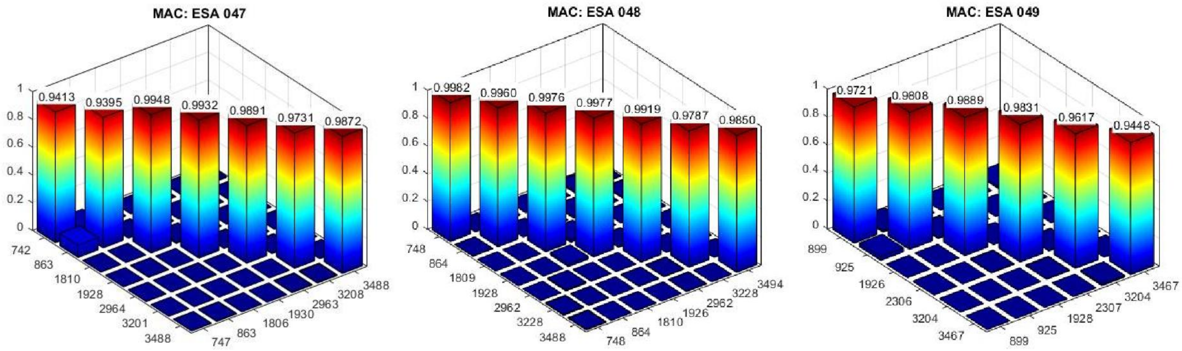


Figure 4.25. Modal assurance criterion plot for ESA_047 left, ESA_048 middle, ESA_049 right.

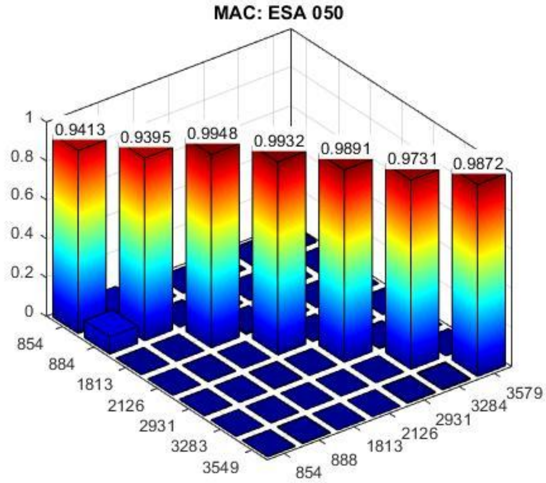


Figure 4.26. Modal assurance criterion plot for ESA_050

5 Ultrasound quality inspections

Table 5.1. After damage US test ESA_026 panel.

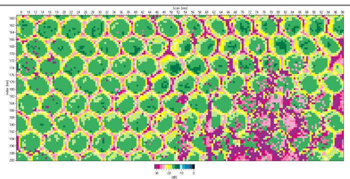
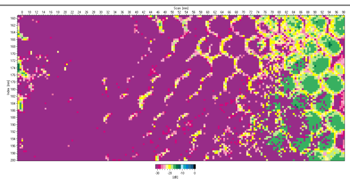
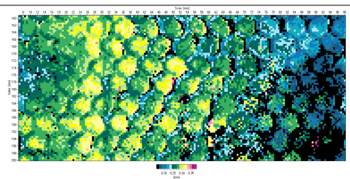
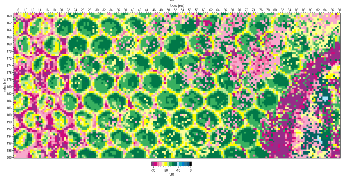
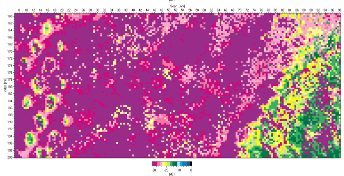
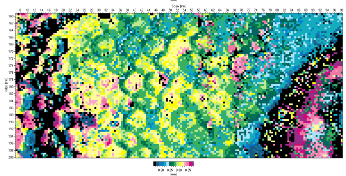
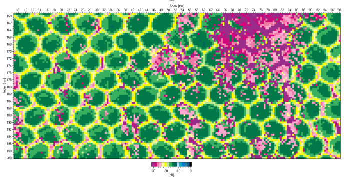
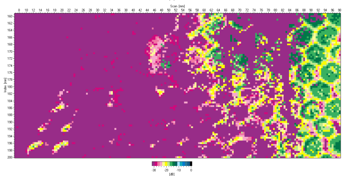
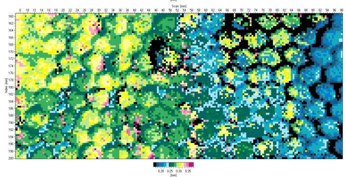
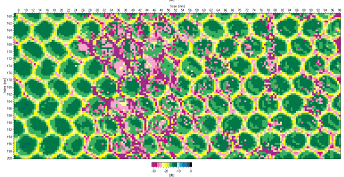
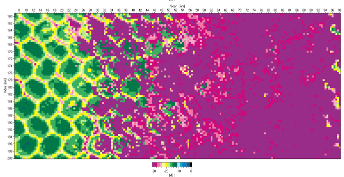
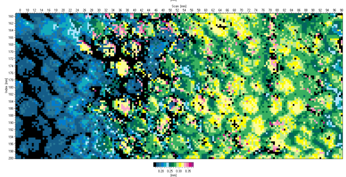
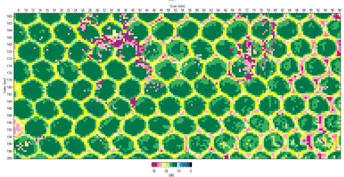
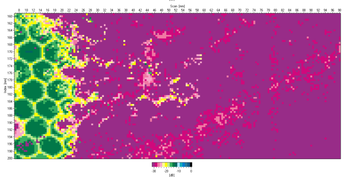
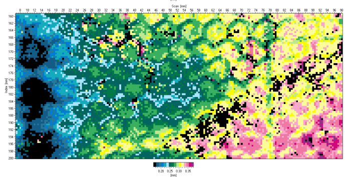
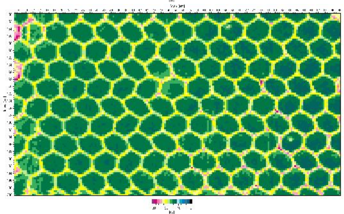
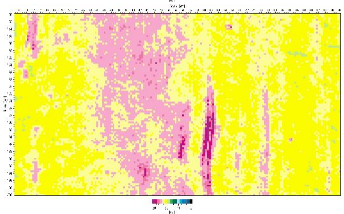
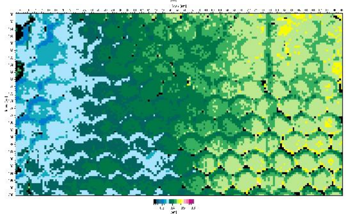
Panel ID	Backwall	Flaw echo	Thickness
ESA 026_1			
ESA 026_2			
ESA 026_3			
ESA 026_4			
ESA 026_5			
ESA 026_6			

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Table 5.2. After damage US test ESA_027 panel.

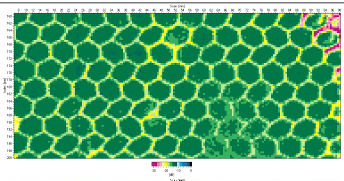
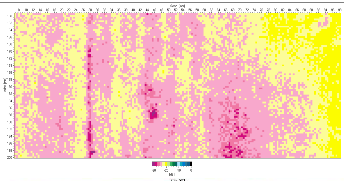
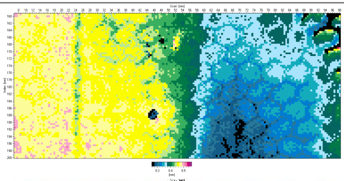
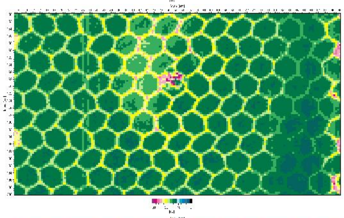
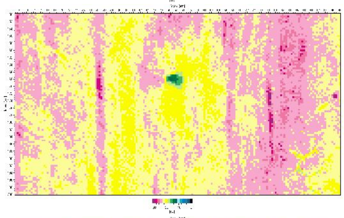
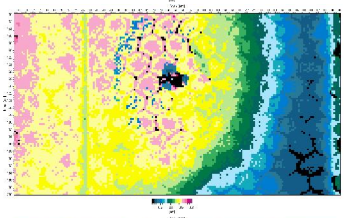
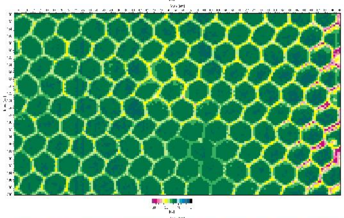
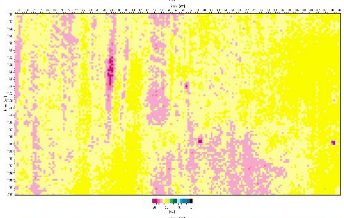
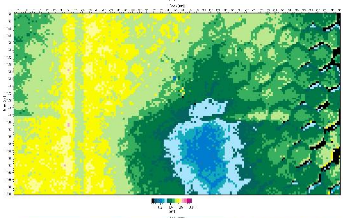
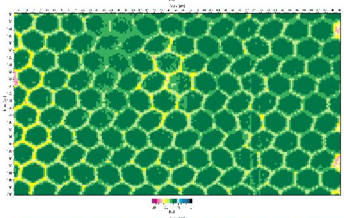
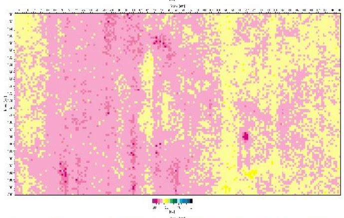
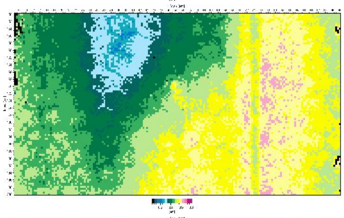
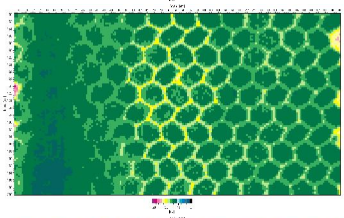
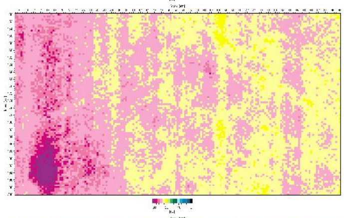
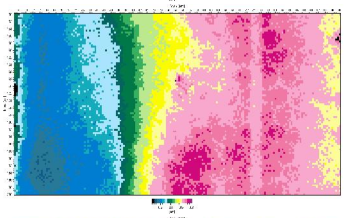
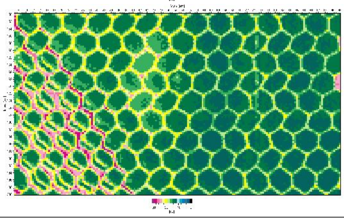
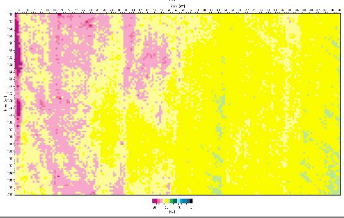
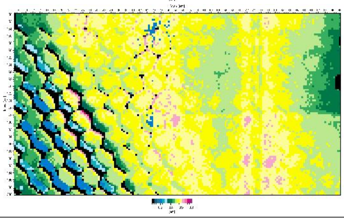
Panel ID	Backwall	Flaw echo	Thickness
ESA 027_1			
ESA 027_2			
ESA 027_3			
ESA 027_4			
ESA 027_5			
ESA 027_6			

Table 5.3. After damage US test ESA_028 panel.

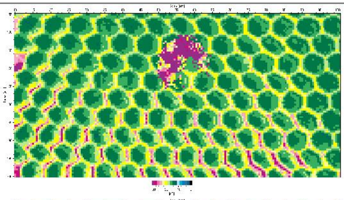
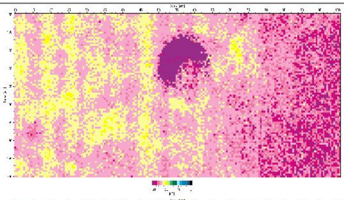
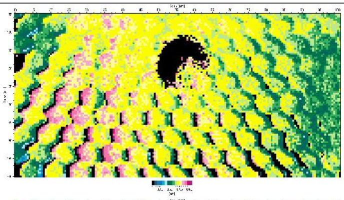
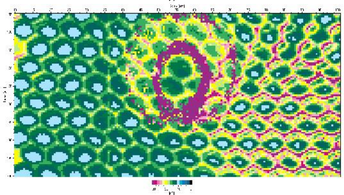
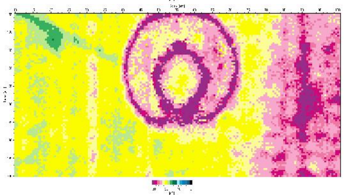
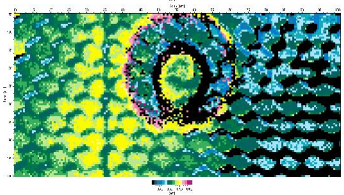
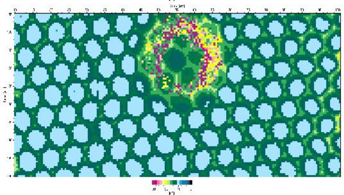
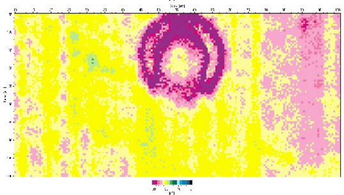
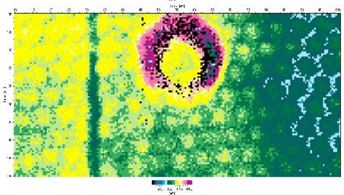
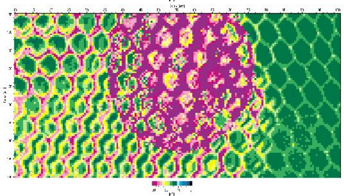
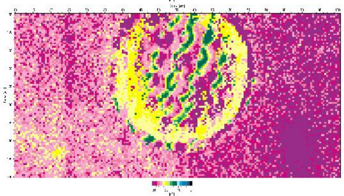
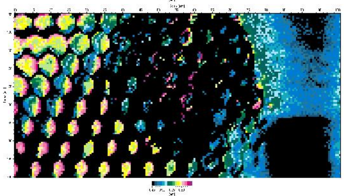
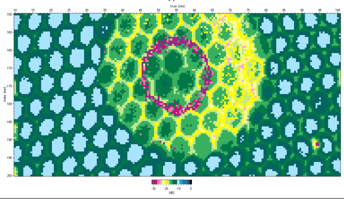
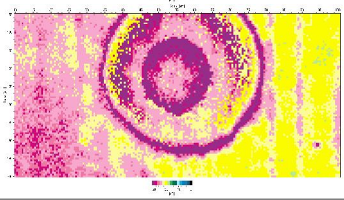
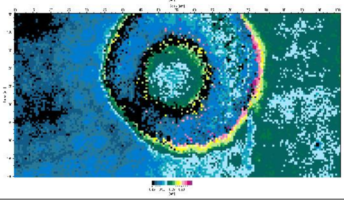
Panel ID	Backwall	Flaw echo	Thickness
ESA 028_1			
ESA 028_2			
ESA 028_3			
ESA 028_5			
ESA 028_6			

Table 5.4. After damage US test ESA_029 panel.

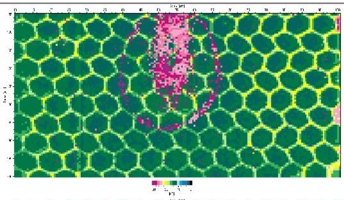
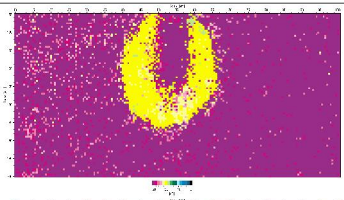
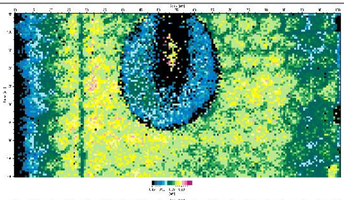
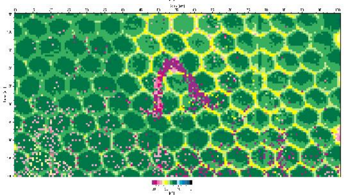
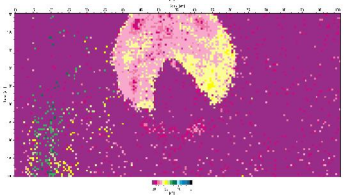
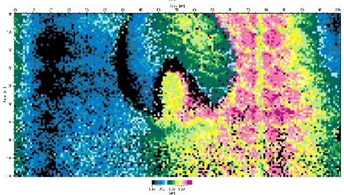
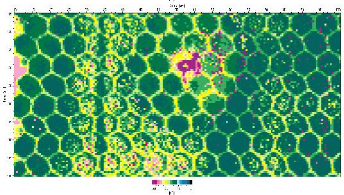
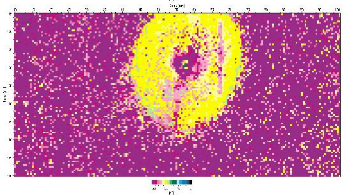
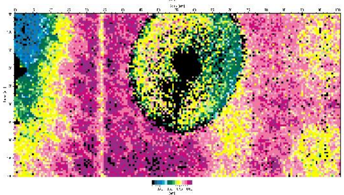
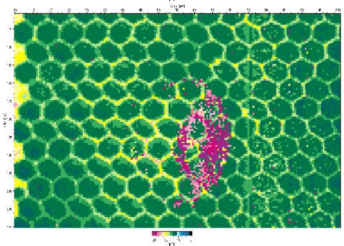
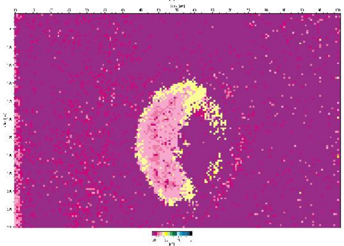
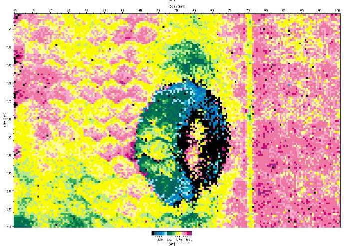
Panel ID	Backwall	Flaw echo	Thickness
ESA 029_1			
ESA 029_2			
ESA 029_3			
ESA 029_4			

Table 5.5. After damage US test ESA_030 panel.

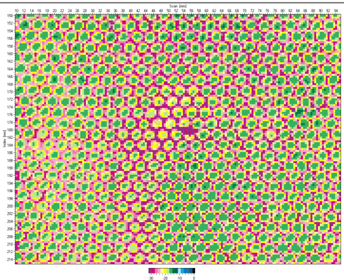
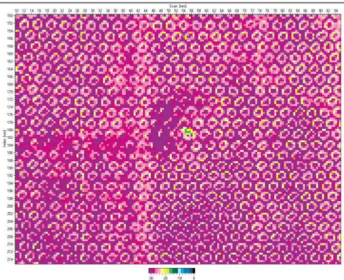
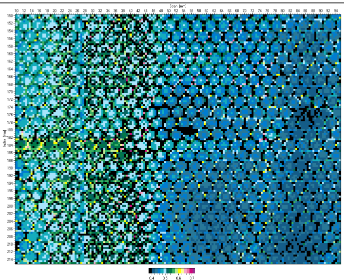
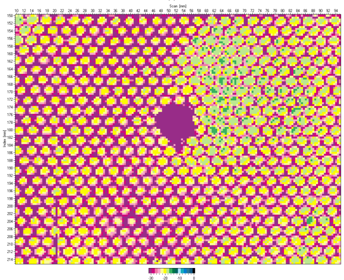
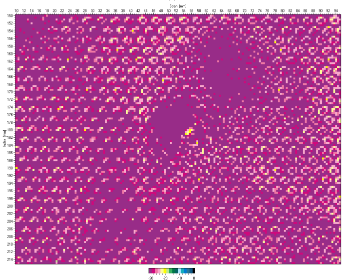
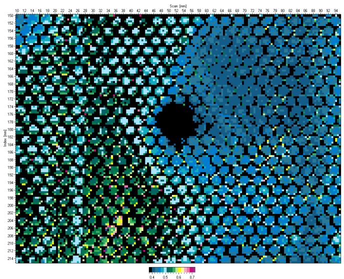
Panel ID	Backwall	Flaw echo	Thickness
ESA 030_1			
ESA 030_2			

Table 5.6. After damage US test ESA_031 panel.

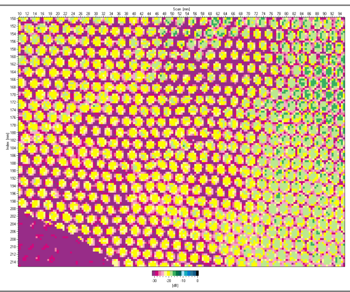
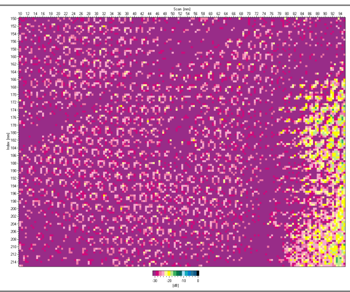
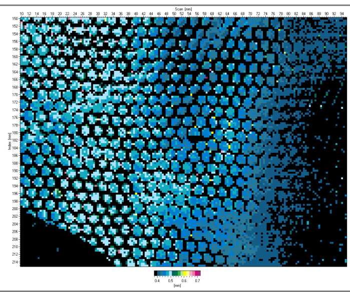
Panel ID	Backwall	Flaw echo	Thickness
ESA 031_1			

Table 5.7. After damage US test ESA_037 panel.

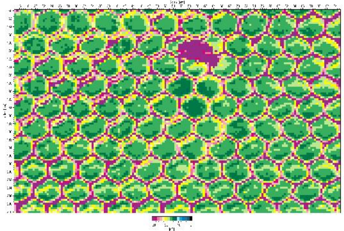
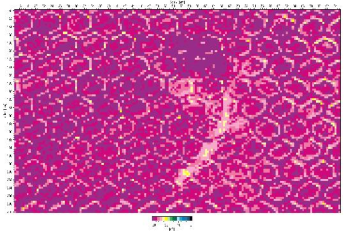
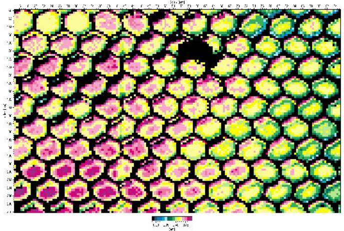
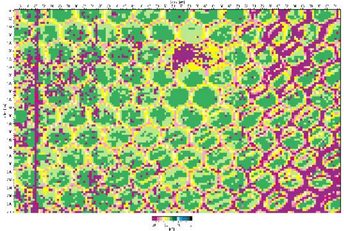
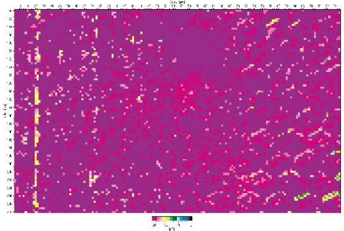
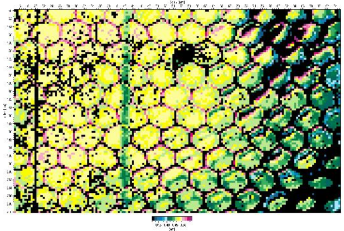
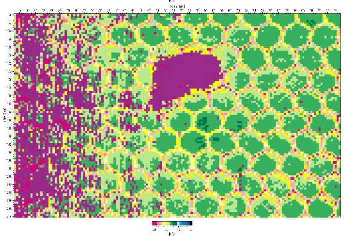
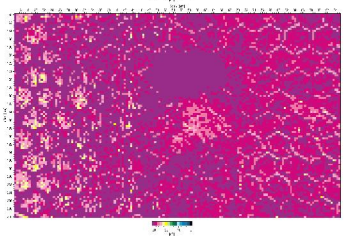
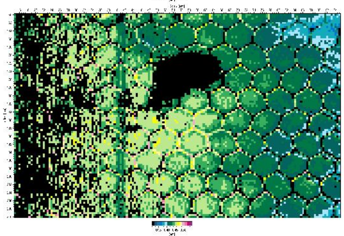
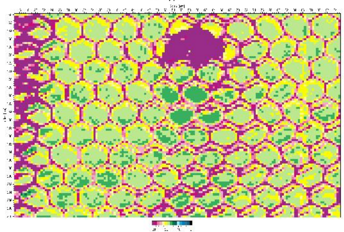
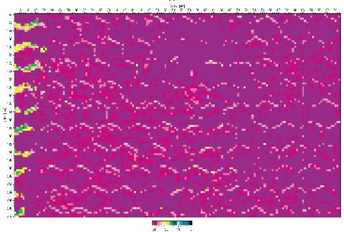
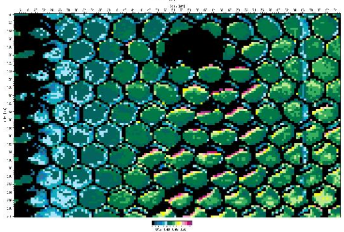
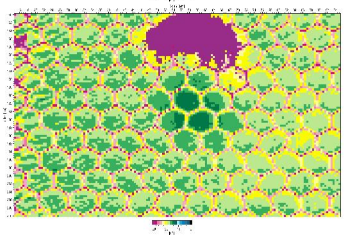
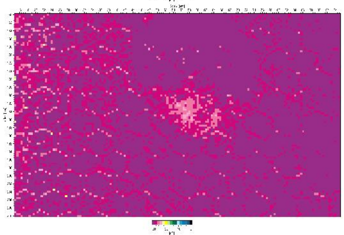
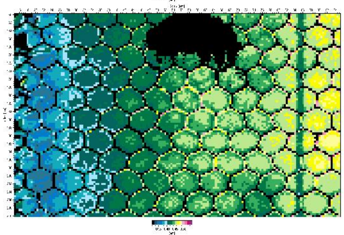
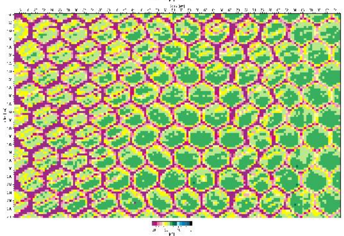
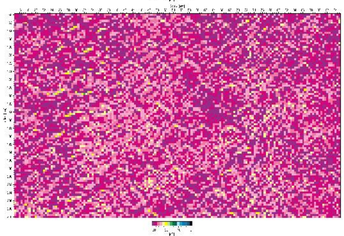
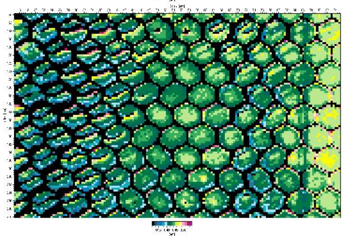
Panel ID	Backwall	Flaw echo	Thickness
ESA 037_1			
ESA 037_2			
ESA 037_3			
ESA 037_4			
ESA 037_5			
ESA 037_6			

Table 5.8. After damage US test ESA_038 panel.

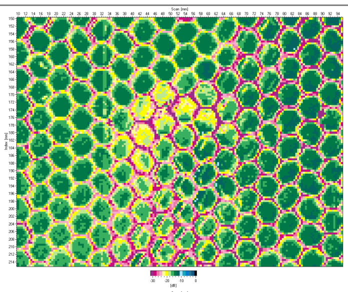
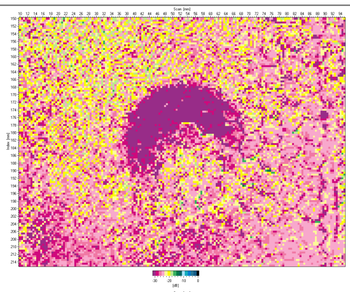
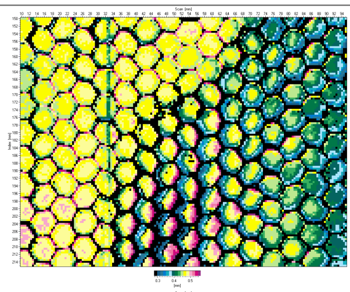
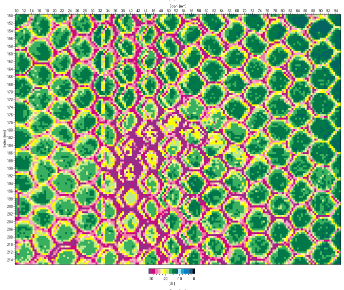
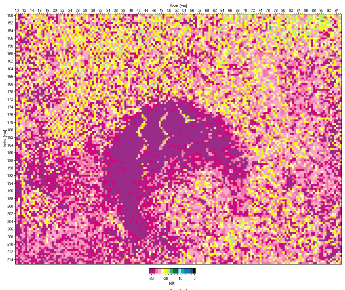
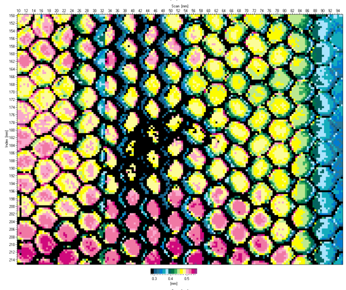
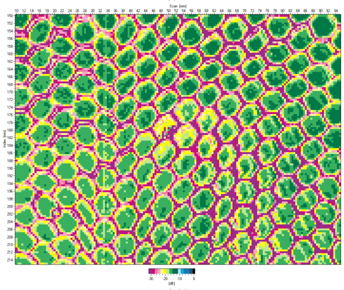
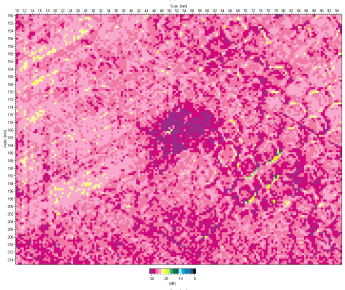
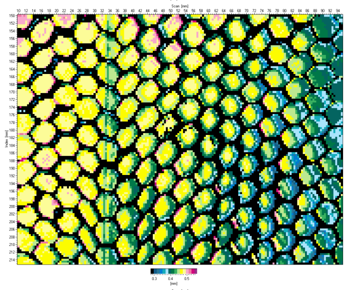
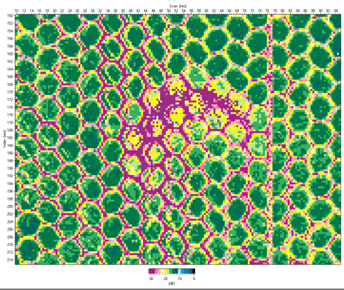
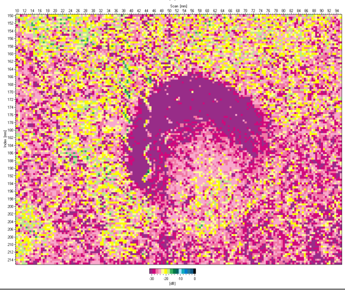
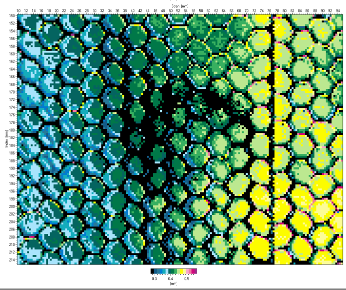
Panel ID	Backwall	Flaw echo	Thickness
ESA 038_1			
ESA 038_2			
ESA 038_3			
ESA 038_4			

Table 5.9. After damage US test ESA_039 panel.

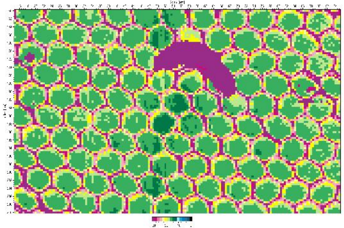
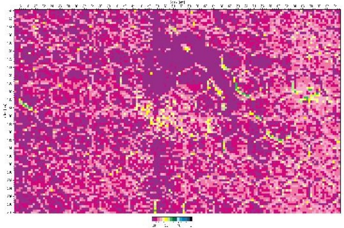
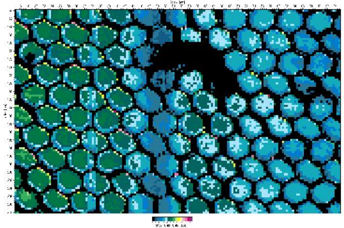
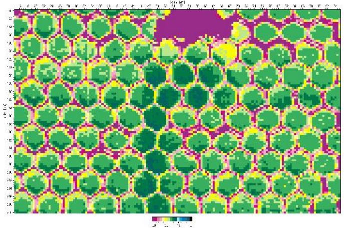
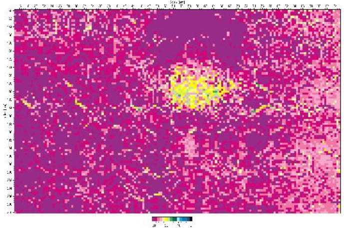
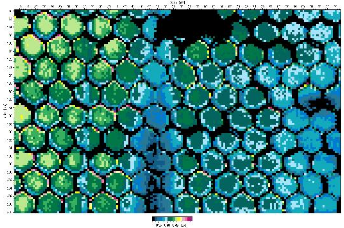
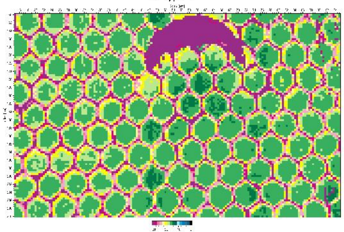
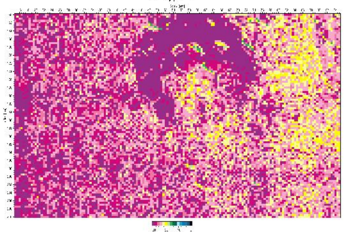
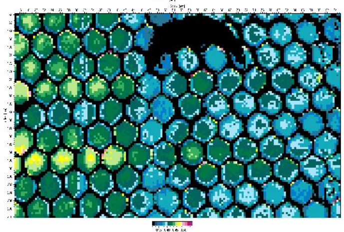
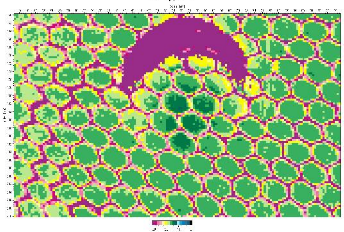
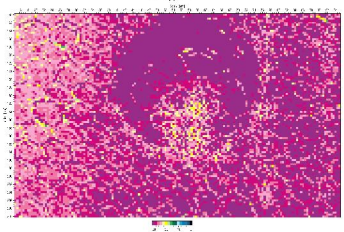
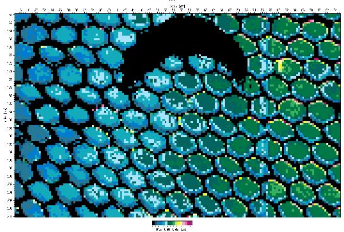
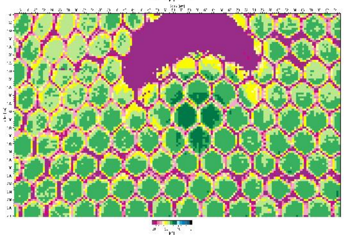
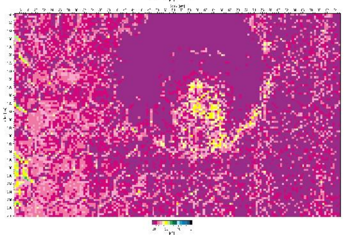
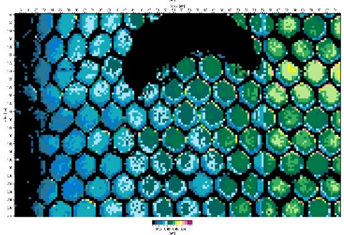
Panel ID	Backwall	Flaw echo	Thickness
ESA 039_1			
ESA 039_2			
ESA 039_3			
ESA 039_4			
ESA 039_5			

Table 5.10. After damage US test ESA_040 panel.

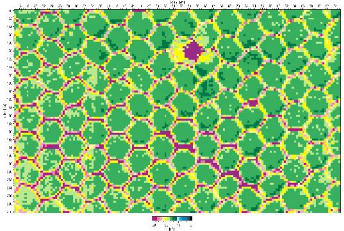
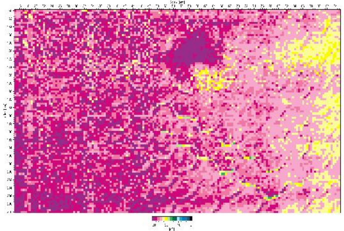
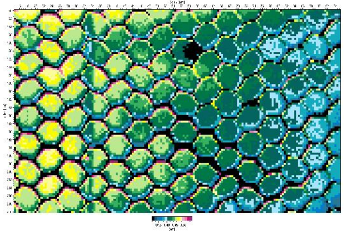
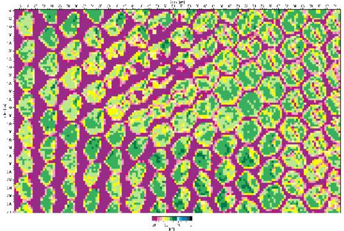
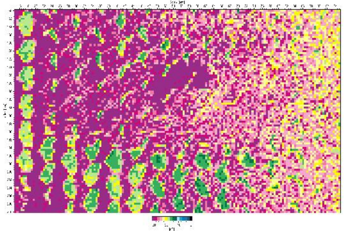
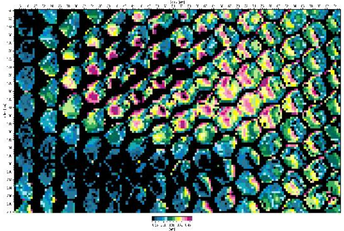
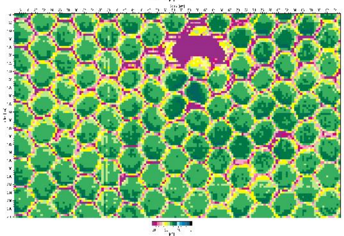
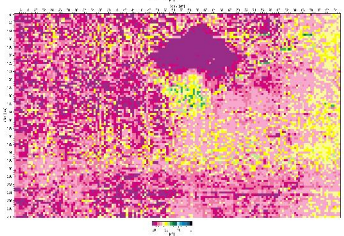
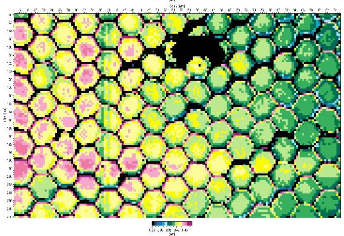
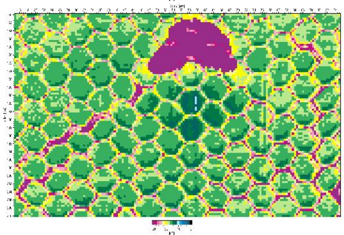
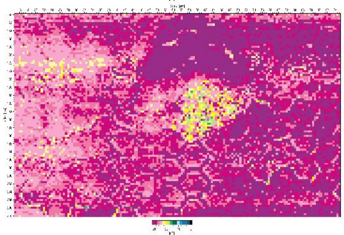
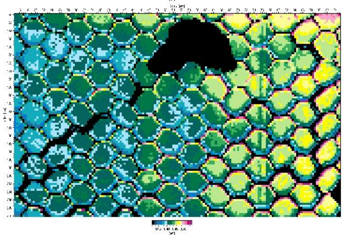
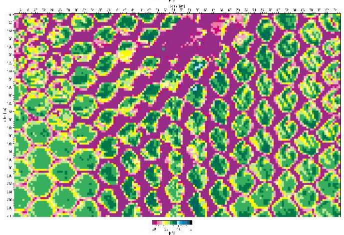
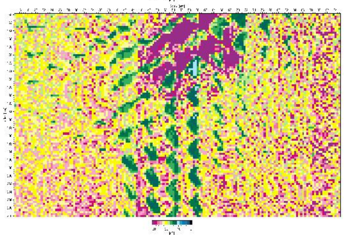
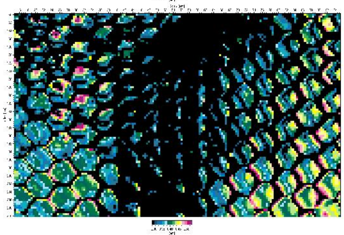
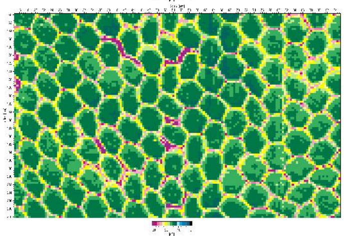
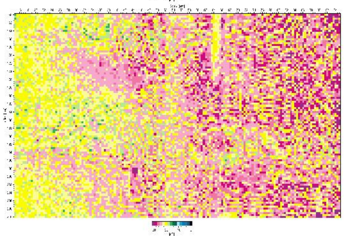
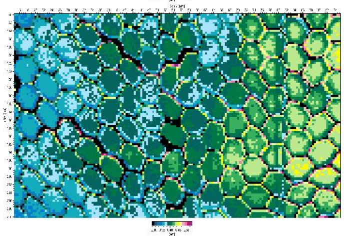
Panel ID	Backwall	Flaw echo	Thickness
ESA 040_1			
ESA 040_2			
ESA 040_3			
ESA 040_4			
ESA 040_5			
ESA 040_6			

Table 5.11. After damage US test ESA_041 panel.

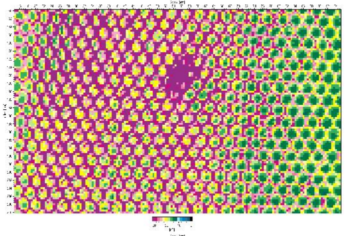
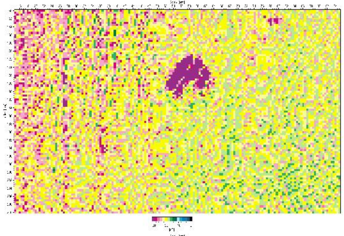
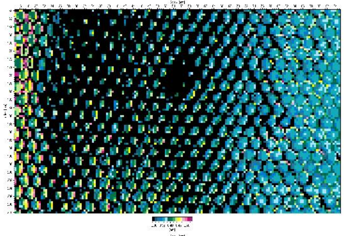
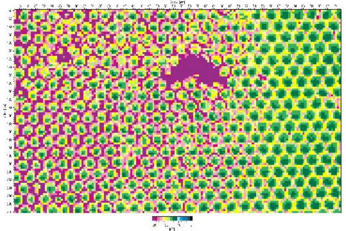
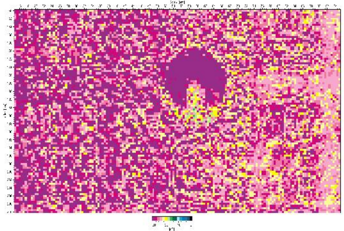
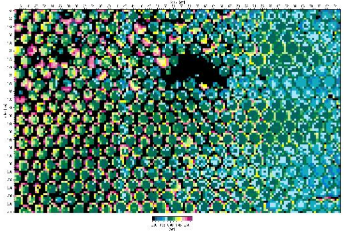
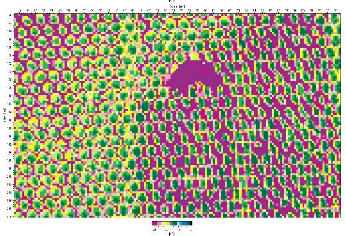
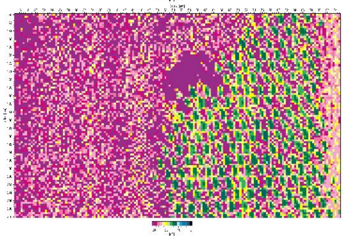
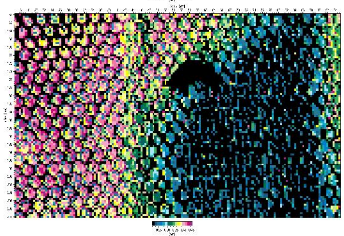
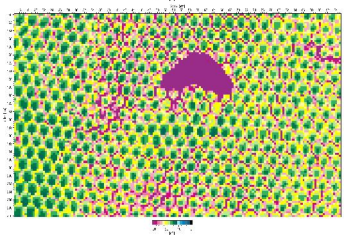
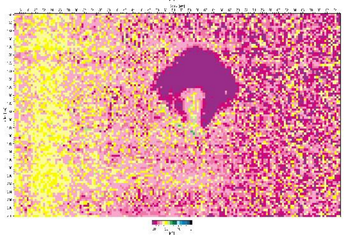
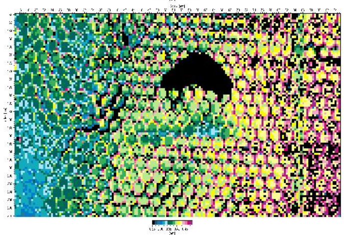
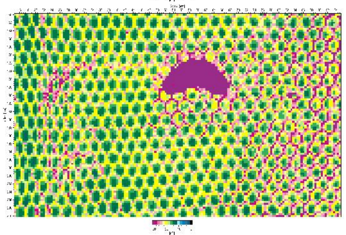
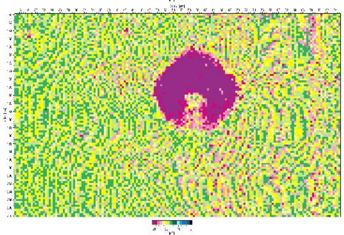
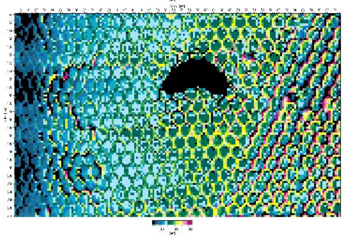
Panel ID	Backwall	Flaw echo	Thickness
ESA 041_1			
ESA 041_2			
ESA 041_3			
ESA 041_4			
ESA 041_5			

Table 5.12. After damage US test ESA_042 panel.

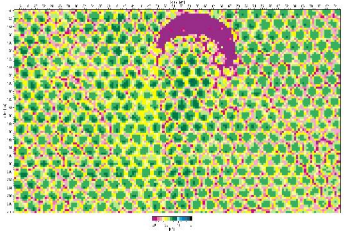
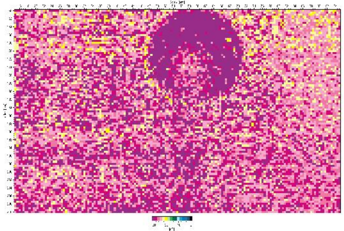
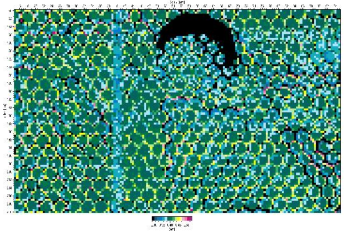
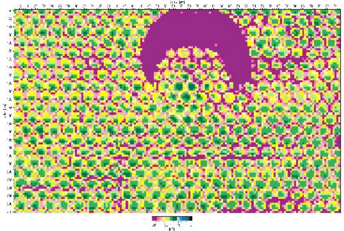
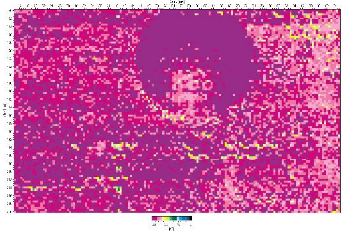
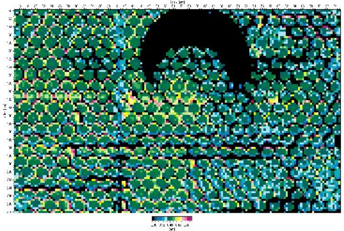
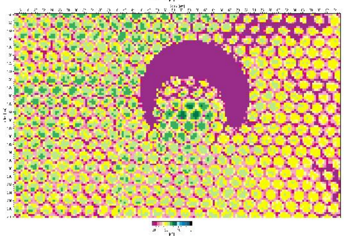
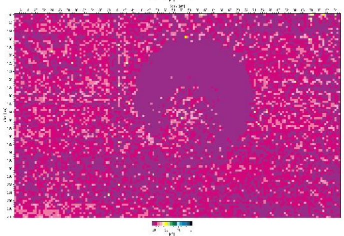
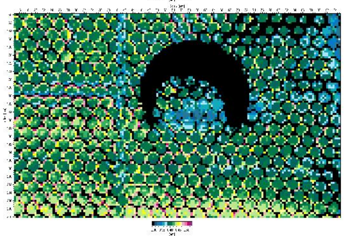
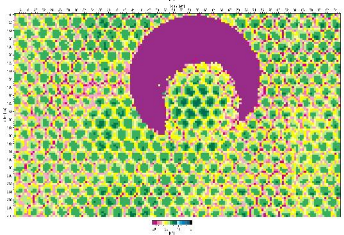
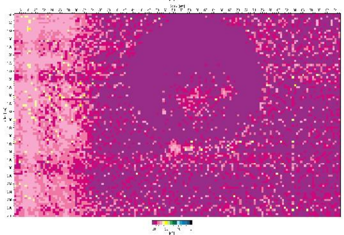
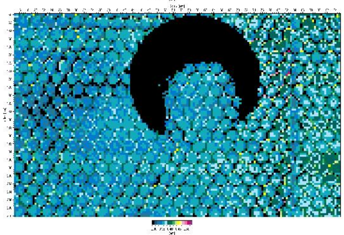
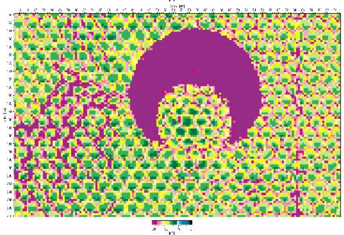
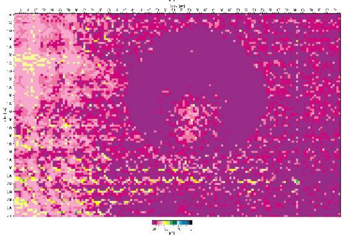
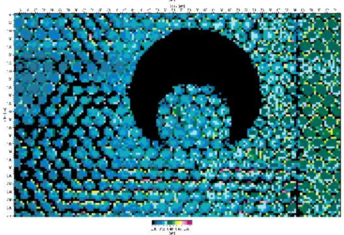
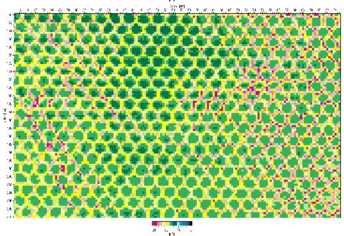
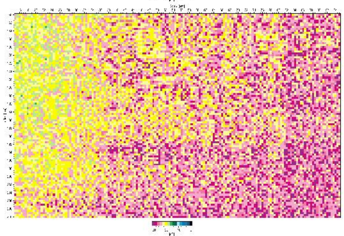
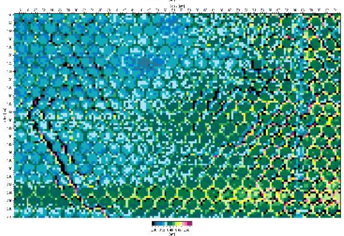
Panel ID	Backwall	Flaw echo	Thickness
ESA 042_1			
ESA 042_2			
ESA 042_3			
ESA 042_4			
ESA 042_5			
ESA 042_6			

Table 5.13. After damage US test ESA_043 panel.

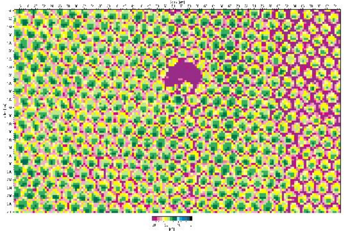
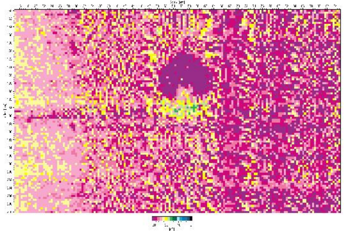
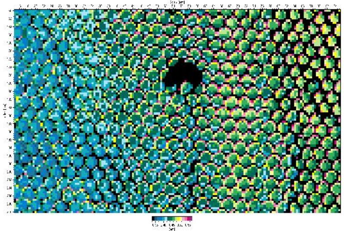
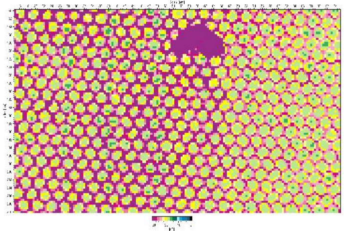
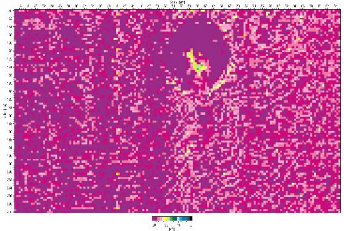
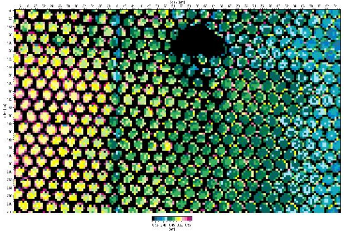
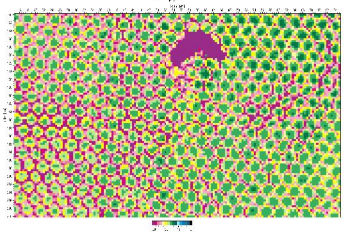
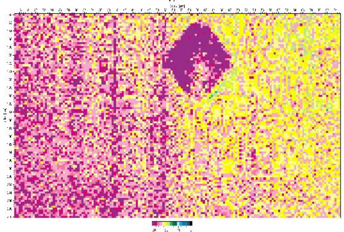
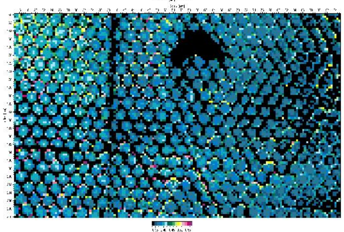
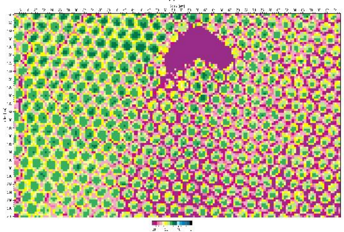
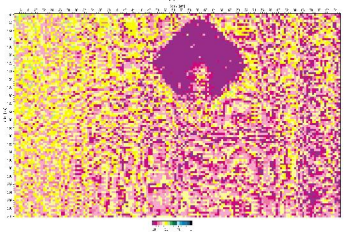
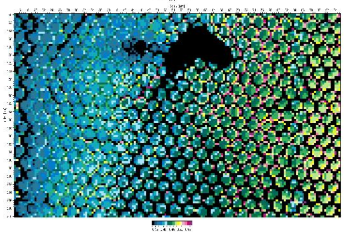
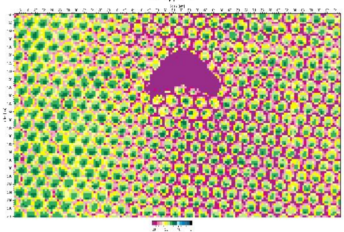
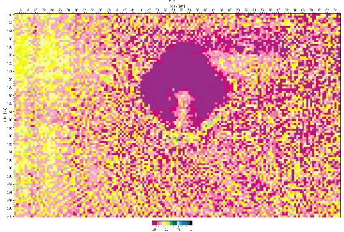
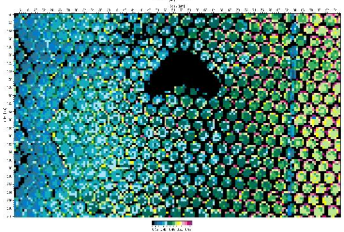
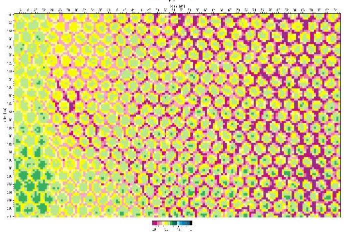
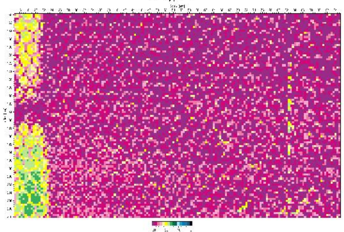
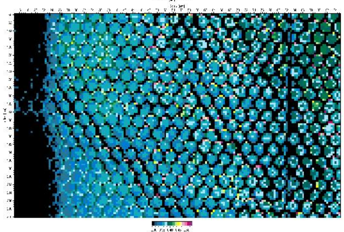
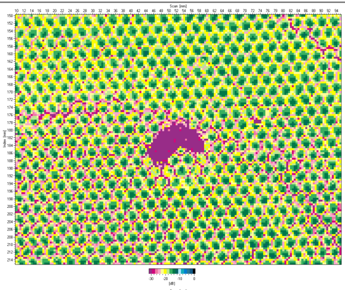
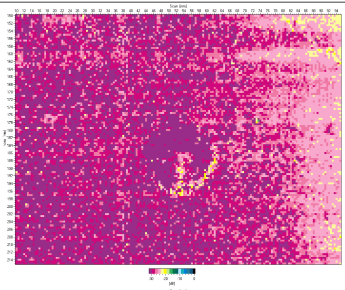
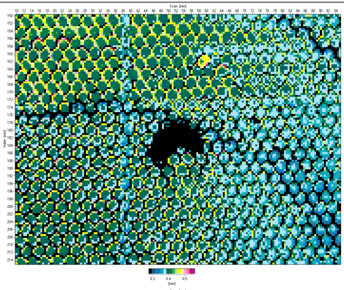
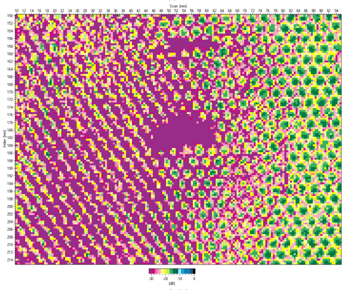
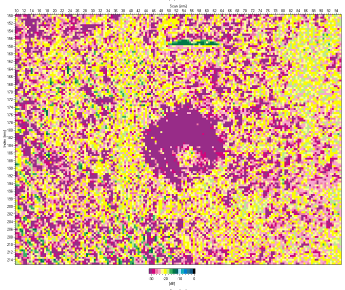
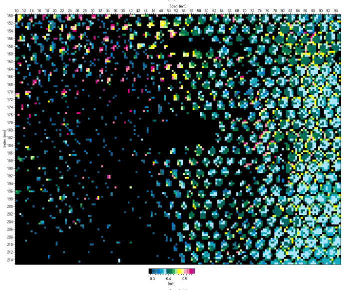
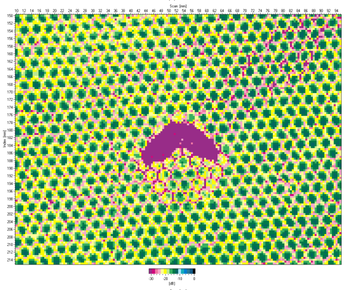
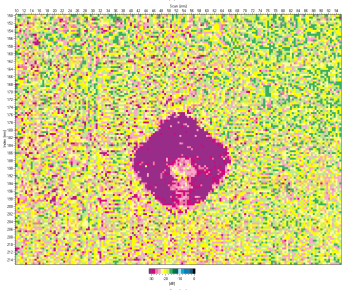
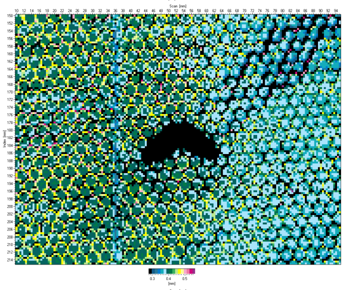
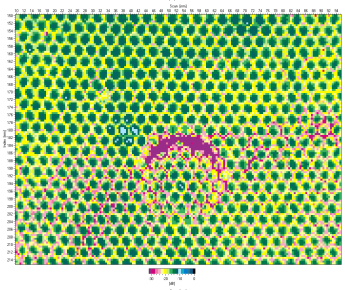
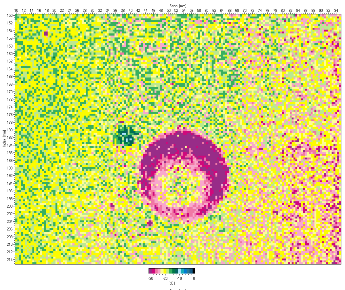
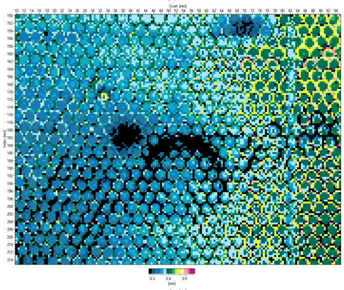
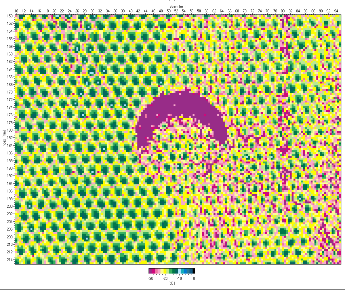
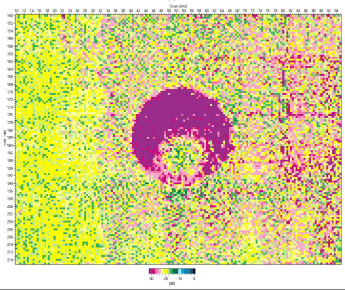
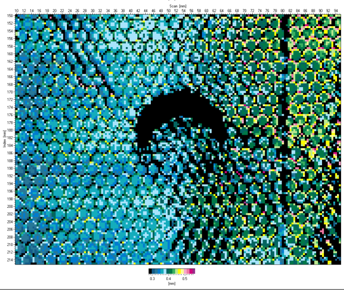
Panel ID	Backwall	Flaw echo	Thickness
ESA 043_1			
ESA 043_2			
ESA 043_3			
ESA 043_4			
ESA 043_5			
ESA 043_6			

Table 5.14. After damage US test ESA_044 panel.

Panel ID	Backwall	Flaw echo	Thickness
ESA 044_1			
ESA 044_2			
ESA 044_3			
ESA 044_4			
ESA 044_5			

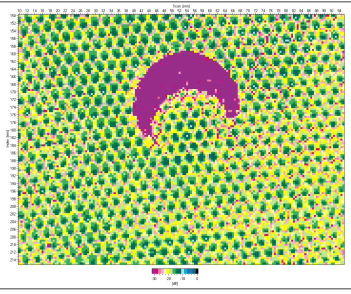
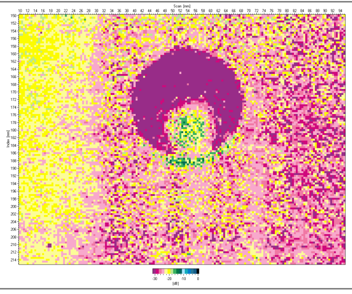
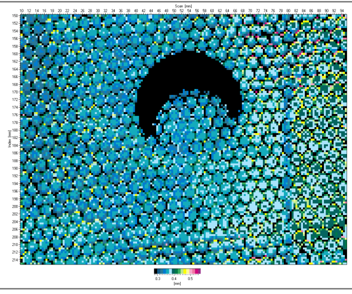
ESA 044_6			

Table 5.15. After damage US test ESA_046 panel.

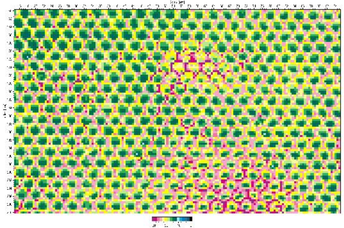
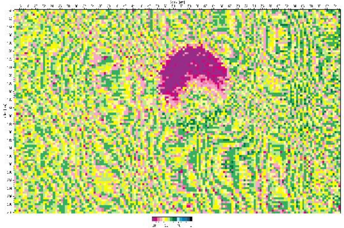
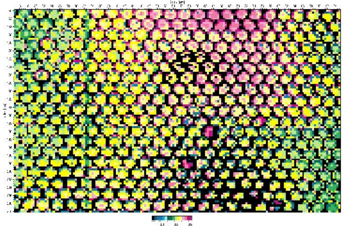
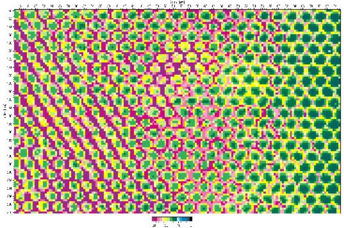
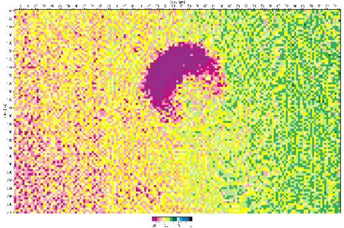
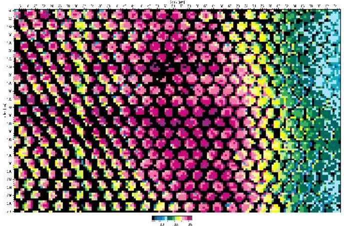
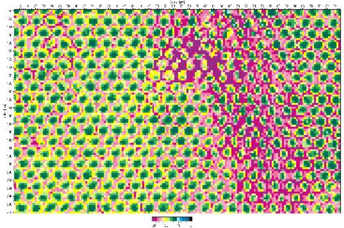
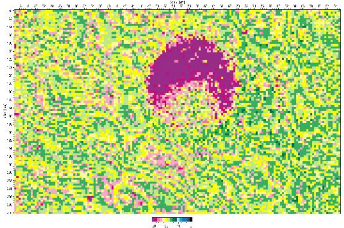
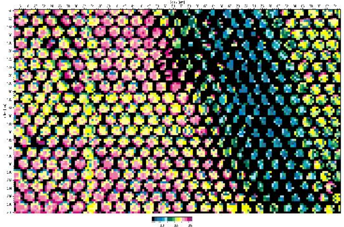
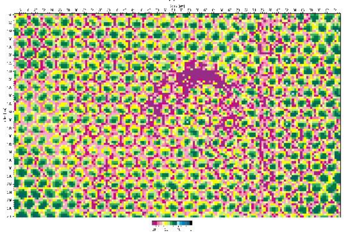
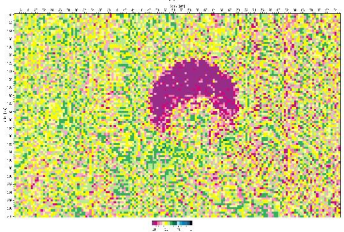
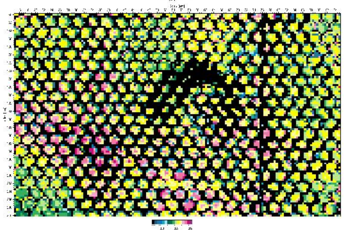
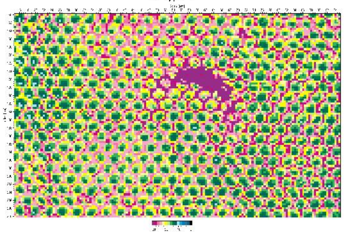
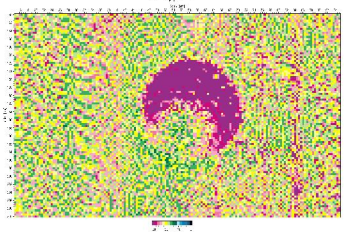
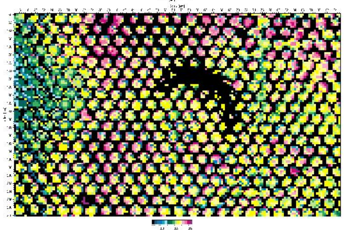
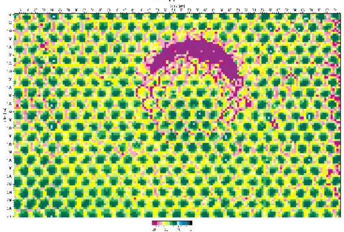
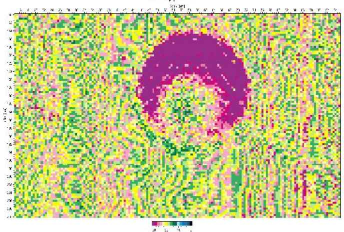
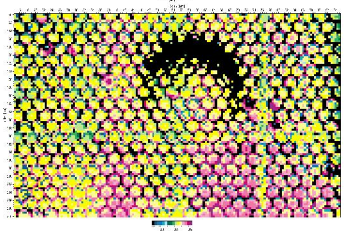
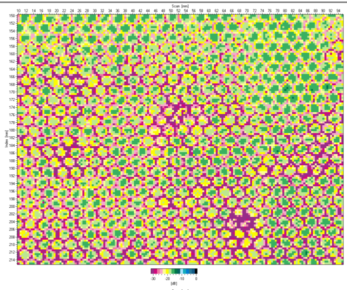
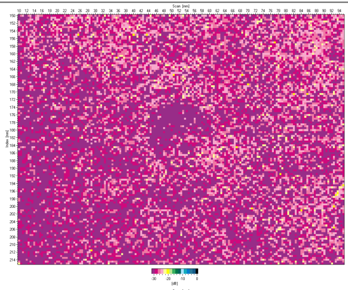
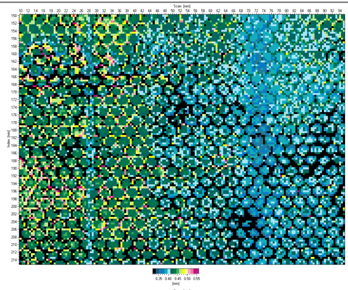
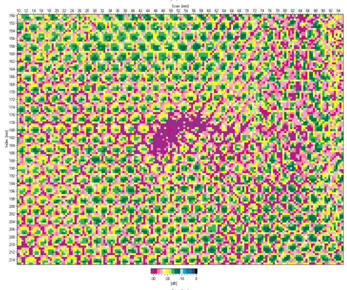
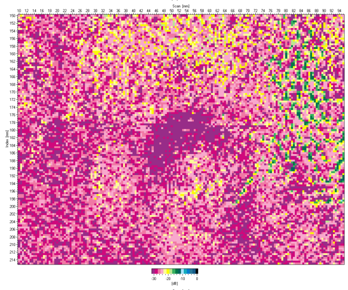
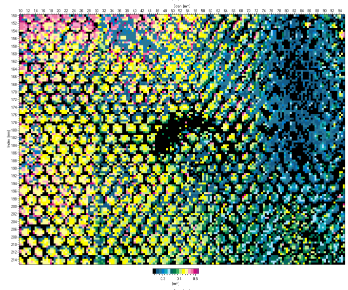
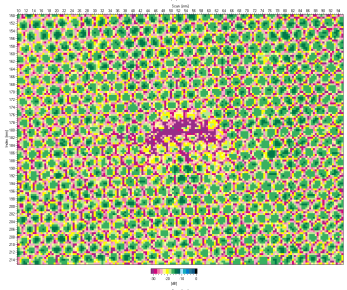
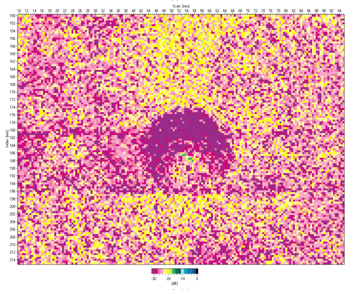
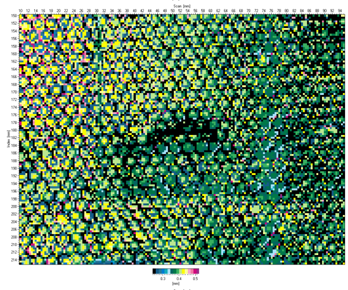
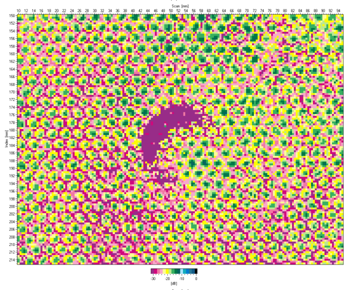
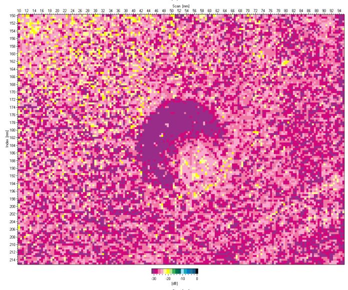
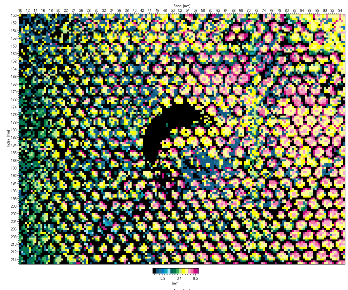
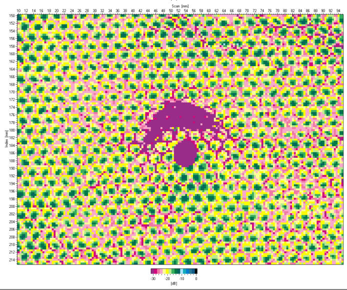
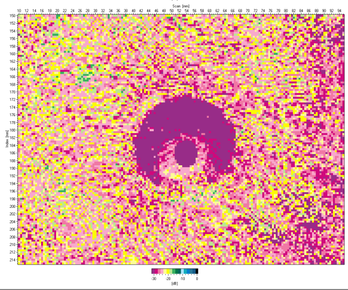
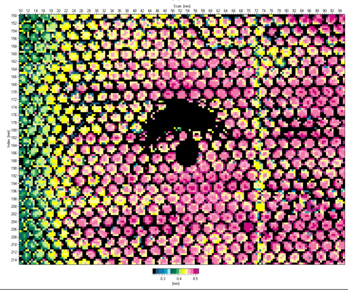
Panel ID	Backwall	Flaw echo	Thickness
ESA 046_1			
ESA 046_2			
ESA 046_3			
ESA 046_4			
ESA 046_5			
ESA 046_6			

Table 5.16. After damage US test ESA_047 panel.

Panel ID	Backwall	Flaw echo	Thickness
ESA 047_1			
ESA 047_2			
ESA 047_3			
ESA 047_4			
ESA 047_5			

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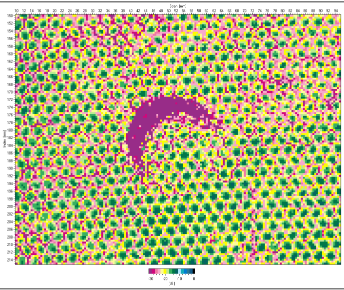
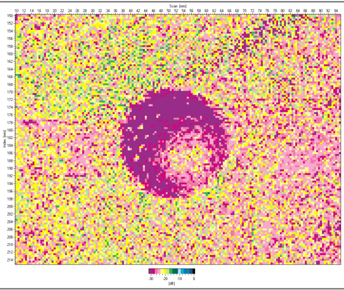
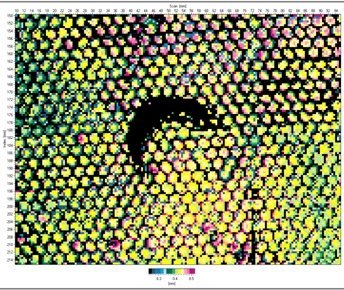
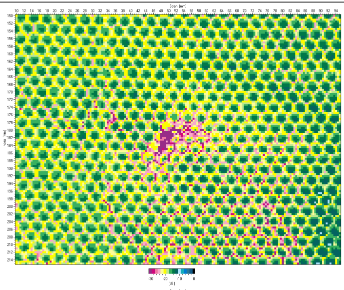
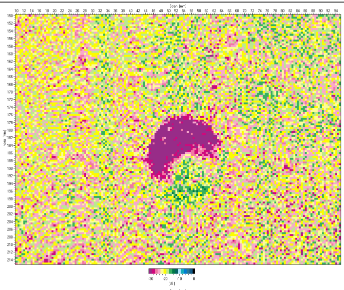
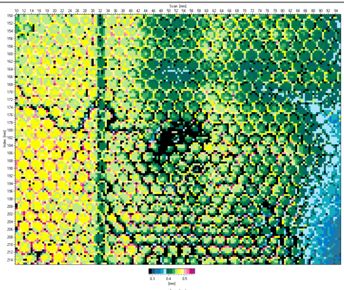
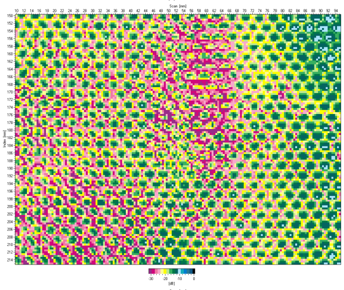
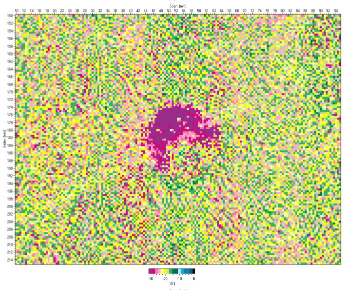
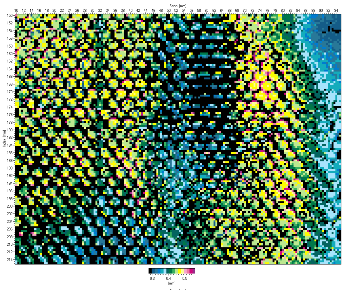
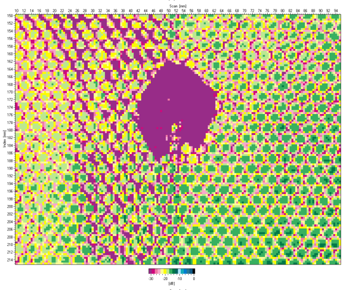
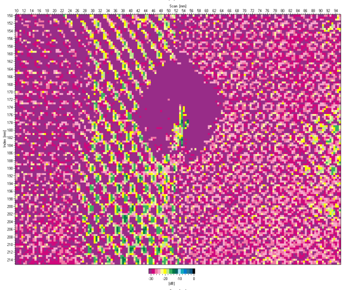
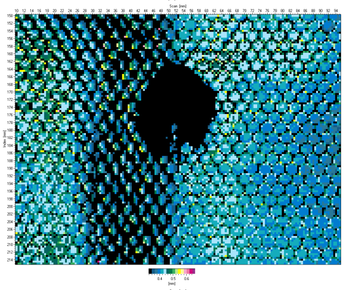
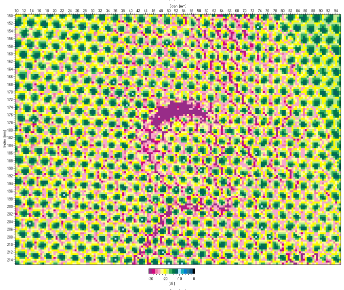
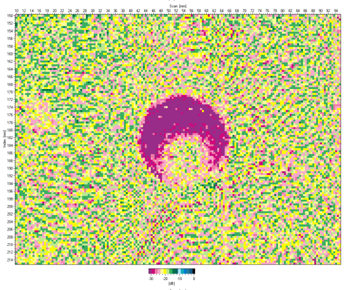
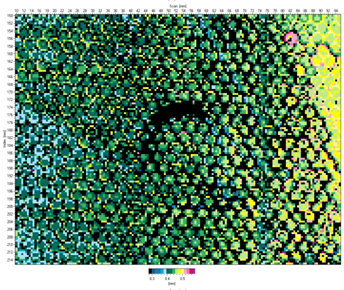
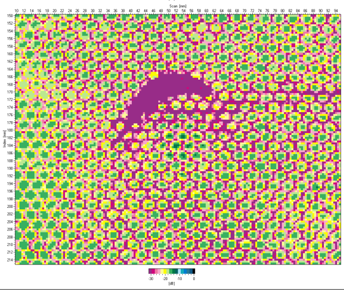
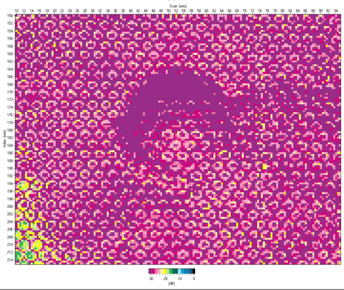
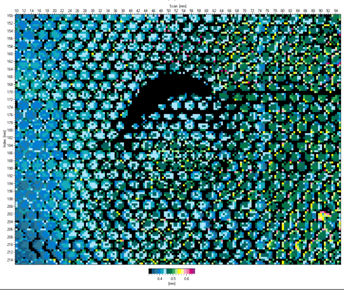
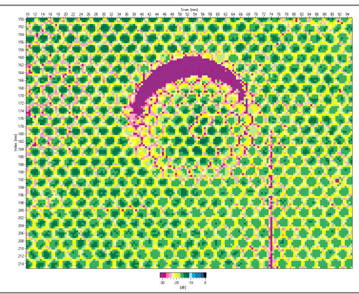
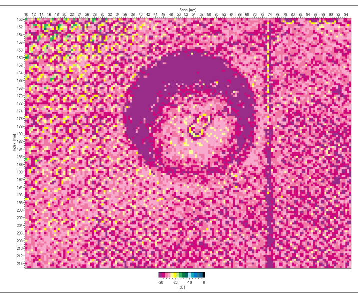
ESA 047_6			

Table 5.17. After damage US test ESA_048 panel.

Panel ID	Backwall	Flaw echo	Thickness
ESA 048_1			
ESA 048_2			
ESA 048_3			
ESA 048_4			
ESA 048_5			

ESA 048_6





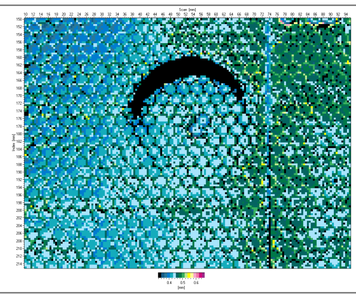
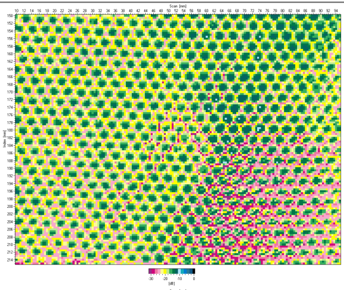
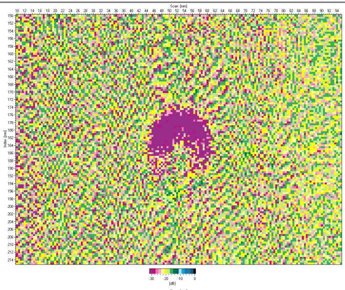
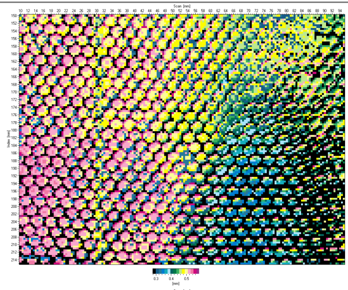
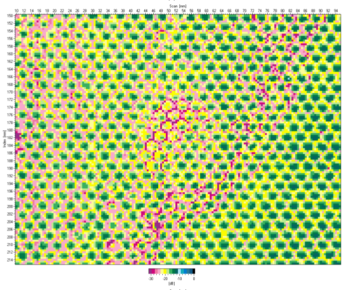
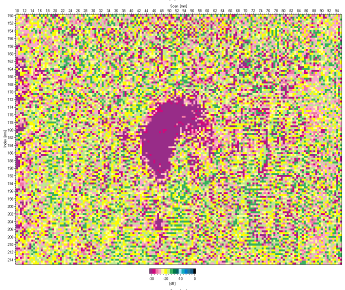
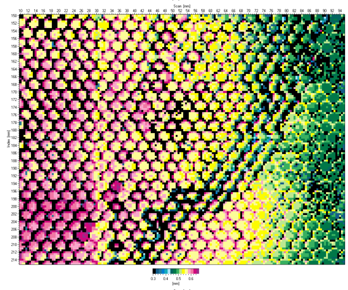
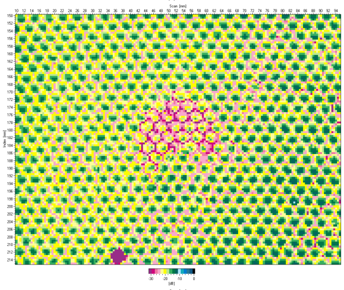
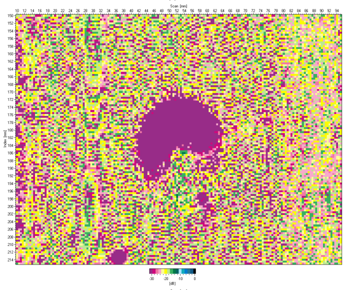
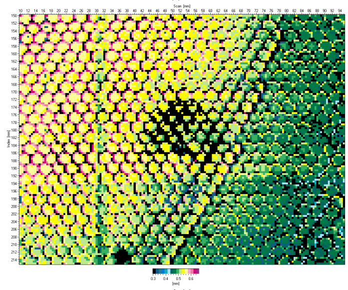
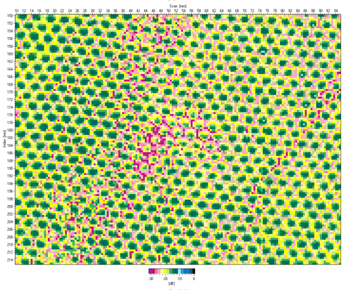
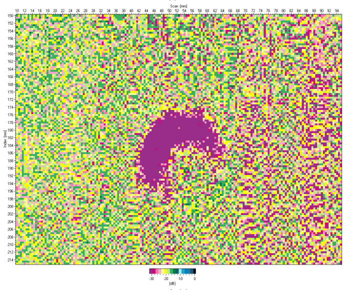
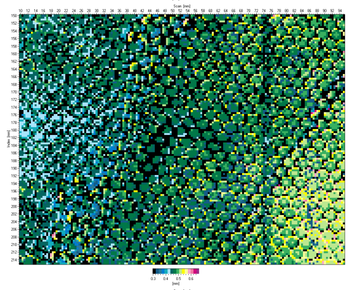
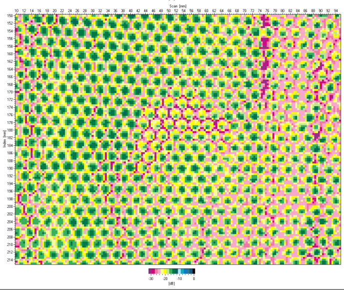
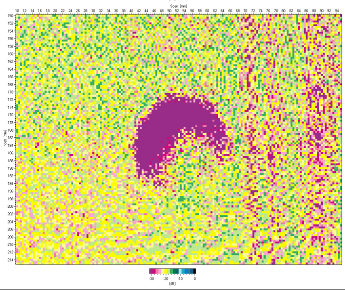
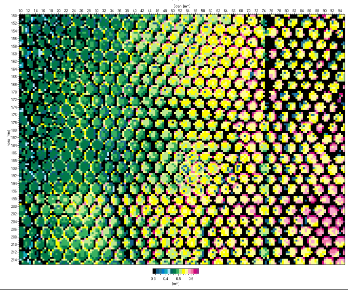


Table 5.18. After damage US test ESA_049 panel.

Panel ID	Backwall	Flaw echo	Thickness
ESA 049_1			
ESA 049_2			
ESA 049_3			
ESA 049_4			
ESA 049_5			

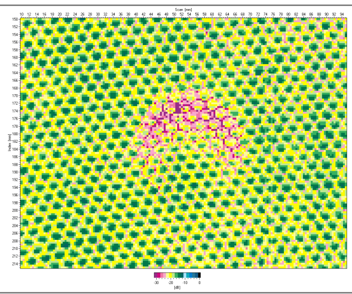
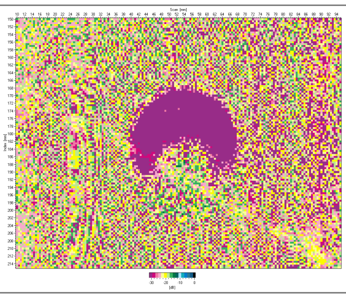
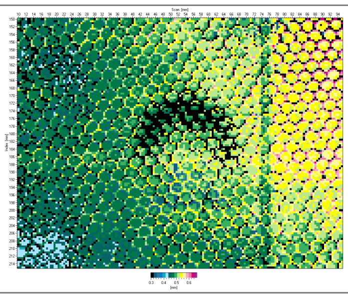
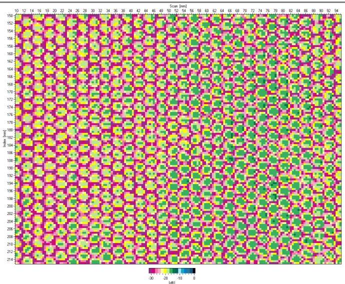
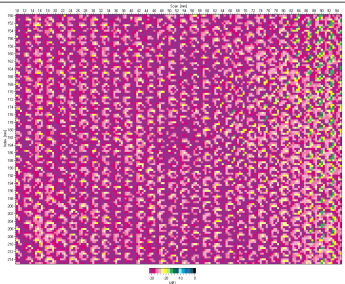
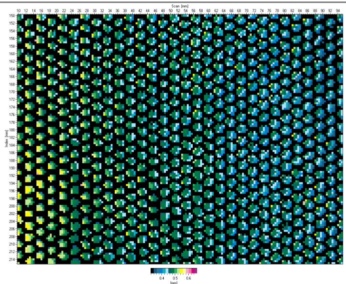
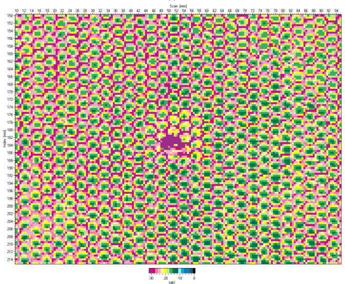
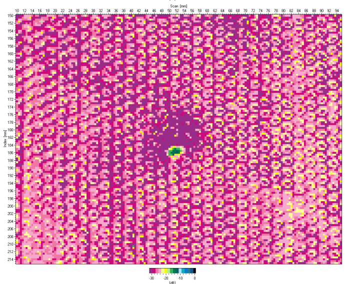
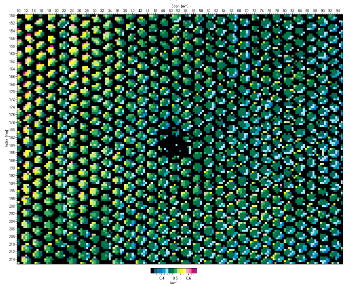
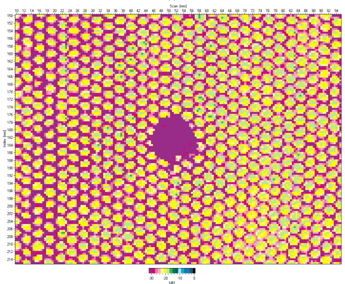
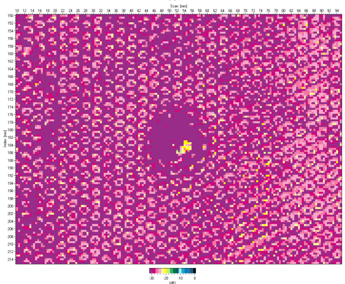
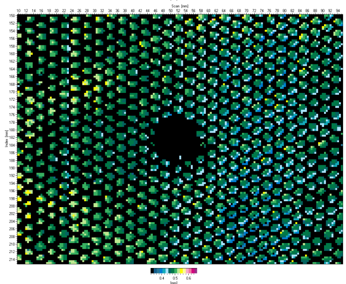
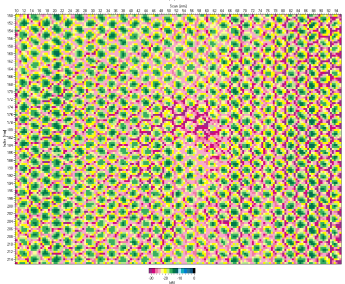
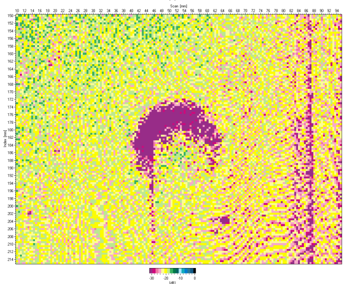
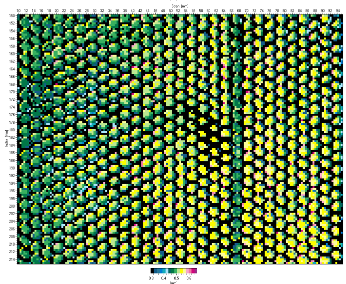
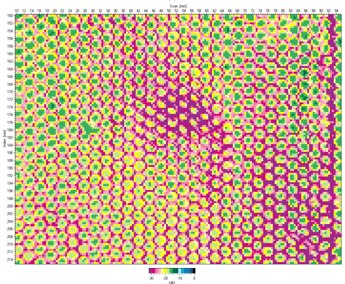
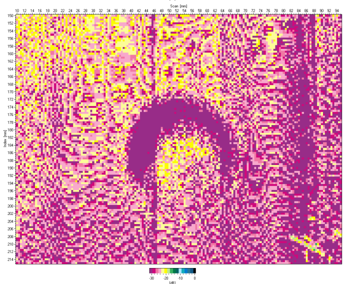
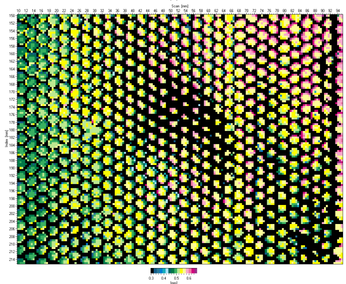
ESA 049_6			

Table 5.19. After damage US test ESA_050 panel.

Panel ID	Backwall	Flaw echo	Thickness
ESA 050_1			
ESA 050_2			
ESA 050_3			
ESA 050_4			
ESA 050_5			

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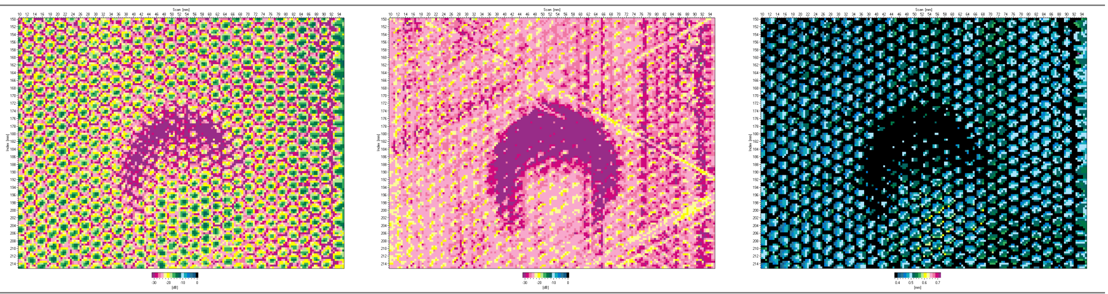

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