Table 1: Selected materials and test methods agreed between TWI and the Topic manager

Item	Discussion/Agreement
Parts geometry	1. Sub-element demonstrator: flat plate with dimensions of 200mm by 150mm 2. Demonstrator component: Flat/tapered airfoil with dovetail root
Materials	1. The resin matrix is the MVK-14 Polyimide (PI) based resin. The material was purchased as a prepreg. 2. The metal for the leading and trailing edge is Ti64
Thermal environment	• Samples will be left at 360°C for 1000 hours • The temperature range of operation of the demonstrator is -55°C to 360°C. The Topic Manager identified three temperature spike ranges within the above limits: o T1 = -55°C to T2 = 75°C o T1 = 75°C to T2 = 195°C o T1 = 195°C to T2 = 360°C For the above ranges samples will be moved between two ovens/furnaces that will be set to the T1 and T2 temperatures. For achieving the sub-zero temperatures, dry ice will be used. The samples will be subjected to 20 cycles (T1 □ T2 □ T1) before subsequently tested.
Operational environment	For the tests in various operational environment scenarios, as detailed below, TWI will produce samples of various sizes. The sample geometry will be flat composite laminates. The coating area will range from 40mm by 40mm (preliminary tests) to 100 mm by 100 mm.
Moisture ingress	Moisture tests will be carried out on non-thermally cycled samples. The tests will follow ASTM D5229. The moisture uptake curves at 70°C and 85% RH will be measured. Care will be taken in the configuration of the experiments in order to avoid any moisture ingress from the side of the samples.
Erosion	Erosion tests will be conducted according to the E50TF121 test run supplied by the Topic Manager. Erosion tests will be conducted on flat samples before and after the thermal exposure (continuous and spike as described in §4.3.1.1 and §4.3.1.2 respectively).
Foreign Object Damage (FOD)	The tests will determine the damaged area and morphology the damaged area of the test samples. Also, the integrity of the surface protection system will be assessed. The test will be conducted using a hemi-spherical impact projectile with a diameter of 0.5 inches. The impact energy will be 1.667 J/mm. The exact test method of the FOD has not been provided by the Topic Manager.

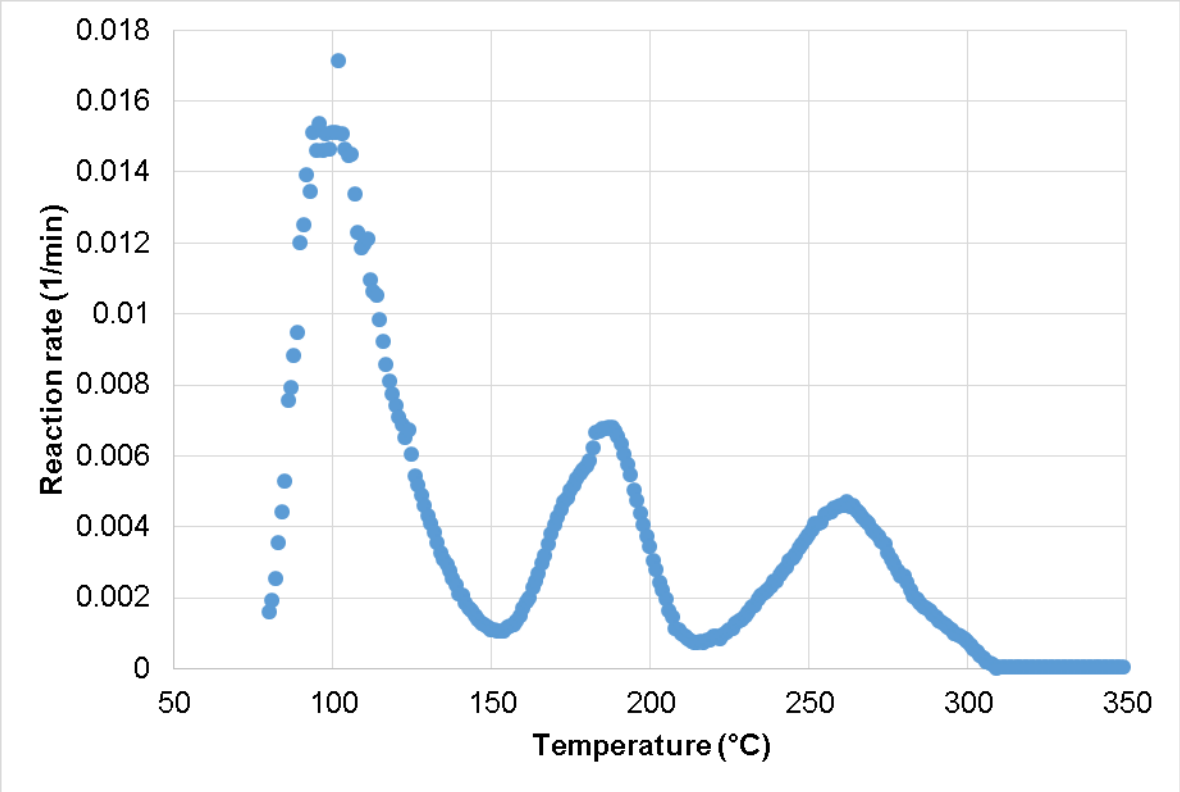


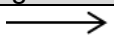
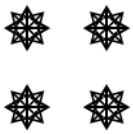
Figure 1: Representative thermogram from the cure of the MVK-14 system

Table 2: Summary of functional coating performances

Parameter	Functional top coat system		
	YSZ	Cr_2O_3	WCCoCr
Coatings thickness deposited per pass (µm/pass)	~12	~7	~7
As-deposited structure	Porous*, no cracking	Porous*, cracking	Dense**, no cracking
Average 3D Coating Roughness (Sa, µm)	15.26	3.75	6.40
Microhardness ($HV_{0.3}$)	Not measurable	Not measurable	1126
Cohesive strength	Very poor	Poor	High
Bond strength (MPa) (Al bond coat= 4.8-6.6MPa)	3.35 cohesive	3.11 (adhesive strength of Al/Cr_2O_3 to substrate)	5.17 (adhesive strength of Al/WCCoCr to substrate)
Residual stress	Medium	Low (relieved by cracking)	High
Adhesion under 4-point bending	Good	Medium	Very poor
Adhesion under fatigue loading	Good	Medium	Very poor (assumed)

* Characteristic of APS coatings
** Characteristic of HVOF coatings

Table 3: Surfi-Sculpt Nomenclature[1]

Term	Description	Image
Swipe	Movement of the EB deflection path line interacting with the material, to create a melt track	
Parent Material	Base material from which the feature is created	
Repeat	The number of times the power beam travels along the same swipe	
Leg	A swipe that contributes towards a feature, this can be one in the case of a simple feature or many in different places for a more complex feature eg a star feature	
Feature	A surface protrusion which made from a series of swipes and is often repeated over an area to create the Surfi-Sculpt treatment	
Array	Multiple features produced within the same software programme, usually produced in a rectangular field, eg, 2 x 2 or n x m. An array can consist of single legged or multi legged features	
Tile / tiling	Repeating arrays in a systematic manner, ie, tile 1 will be complete before commencing tile 2	
Treatment	A combination of beam deflection pattern and Surfi-Sculpt machine parameters required to generate an enhanced surface	

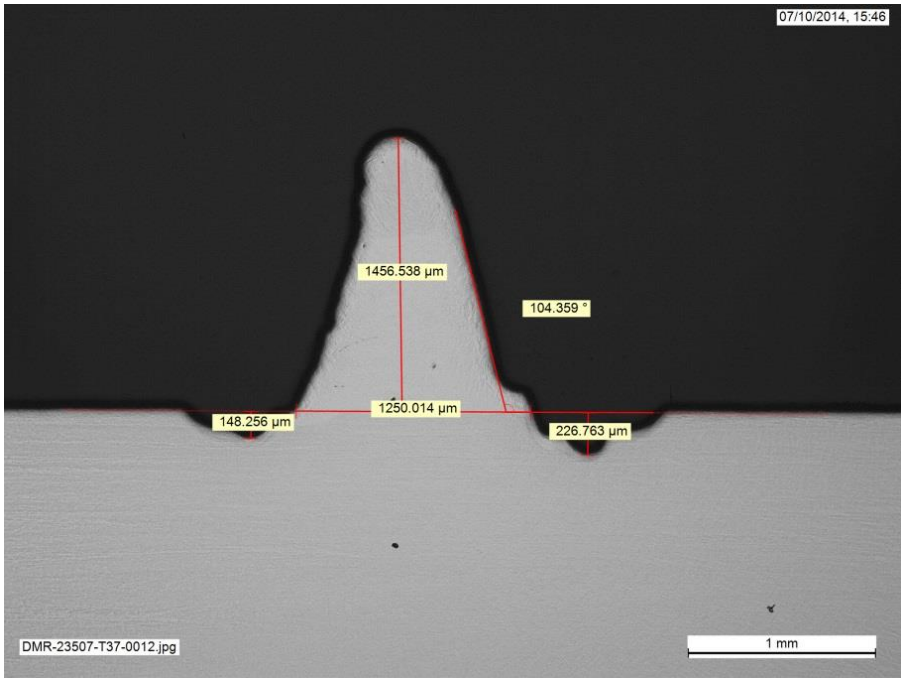
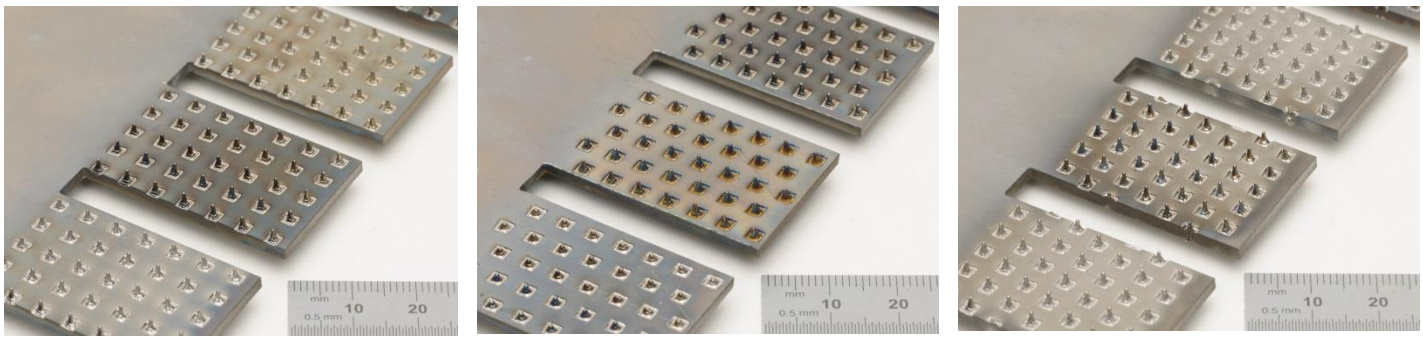


Figure 2 Cross section of single Surfi-Sculpt feature from T37 sample

[1] Earl, C. & Hilton, P., 2012. Optimisation and Observation of the Laser Surfi-Sculpt Process. TWI Report 19837.01/2012/1499.2, Great Abington: TWI Ltd



a) b) c)

Figure 3 Image of the three different Surfi-Sculpt arrays on panel samples
a) Square array
b) 0.50 offset array
c) 0.33 offset array

Figure 4 Example panel with 5 specimens

Table 4: Laser parameters

Parameter	Range investigated
Beam power (kW)	2 – 5
Processing speed (m/mmin)	1 – 6
Focus position (at workpiece surface), mm	-2, -1 and 0

Figure 5: Laser welding trials

Figure 6: Coated composite panels inside oven during long exposure testing (200°C for 750hr)

Table 5: Erosion resistance and erosivity of coated coupons before and after thermal processing (method based on GE Specification E50TF121, Class B). All coupons were coated with HVOF WCCoCr on TWAS Al bond coat, CFRP substrate (TWI Spray Sheet Reference 15-021)

Condition	Mass before (g)	Mass after (g)	Mass loss (g)	E_w	Average E_w
AS As sprayed	19.7306	19.5979	0.1327	221	219
	20.0888	19.9563	0.1325	220	
	19.8574	19.726	0.1314	219	
	19.4253	19.296	0.1293	216	
TC Thermally cycled (250°C, 10 cycles, water quench)	18.2357	18.1185	0.1172	195	195
	18.9247	18.8076	0.1171	195	
	18.1507	18.0324	0.1183	197	
	19.2152	19.1003	0.1149	192	
TE Thermally exposed (200°C, 750h)	19.4394	19.3357	0.1037	173	176
	20.2991	20.1911	0.108	180	
	19.9892	19.8815	0.1077	180	
	18.9772	18.874	0.1032	172	
Lexan reference material	7.4131	7.3452	0.0679	113	124
	7.7931	7.7126	0.0805	134	

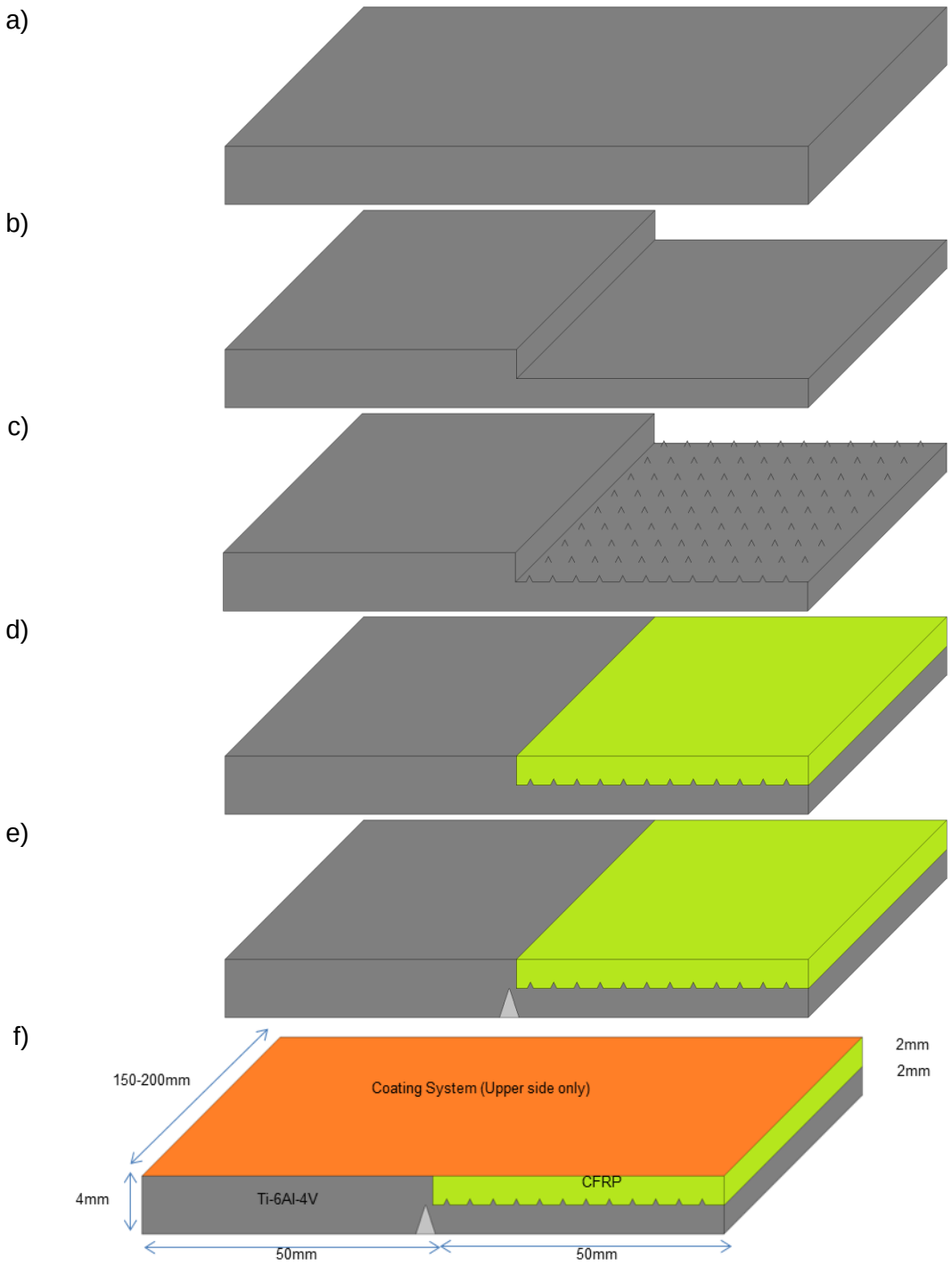


Figure 7: Primary sub-element demonstrator design, showing manufacturing steps: a) Preparation of initial Ti-6Al-4V sheet, b) Machining of 2mm deep groove on one side to accommodate CFRP, c) Surfisculpt of machined surface, d) Layup and curing of CFRP, e) Laser welding in vicinity of Ti-6Al-4V to CFRP interface (1.5mm offset), f) Application of surface protection system to one side. Diagrams are not to scale

Table 6: Erosion resistance and erosivity of coated coupons extracted from SEDs as shown in Figure 10. Erosion testing method based on GE Specification E50TF121, Class B. All coupons were coated with HVOF WCCoCr on TWAS Al bond coat, CFRP substrate (TWI Spray S

Specimen set	Mass before (g)	Mass after (g)	Mass loss (g)	E_w	Average E_w
WCCoCr on SED Ti alloy TWI/20870/13 D4	31.8639	31.745	-0.1189	198.2	201
	32.4928	32.3691	-0.1237	206.2	
	32.5769	32.4583	-0.1186	197.7	
	31.9609	31.8406	-0.1203	200.5	
WCCoCr on SED CFRP TWI/20870/13 D4	22.9635	22.9432	-0.0203	33.8	44
	23.1946	23.1579	-0.0367	61.2	
	23.0795	23.0706	-0.0089	14.8	
	23.2669	23.2273	-0.0396	66.0	
WCCoCr on SED Ti-CFRP interface TWI/20870/55 D18	29.0579	28.9483	-0.1096	182.7	175
	29.5035	29.4169	-0.0866	144.3	
	28.0383	27.9248	-0.1135	189.2	
	28.8737	28.7644	-0.1093	182.2	
Lexan reference material	8.1078	7.6955	-0.4123	687.2	458
	8.0218	7.8844	-0.1374	229	

a)

b)

Figure 8: Coated SEDs after impact testing using a method based on ASTM D2794. a) SED TWI/20870/11 D2 after impact testing. One impact per area was applied to the coated Ti alloy, 2 impacts per area were applied to the CFRP. b) SED TWI/20870/18 D5 after impact testing of the CFRP. One impact per area was applied to the coated CFRP. All impacts had energy of 17.64J

Figure 9: 4-point bending test of sub-element demonstrator

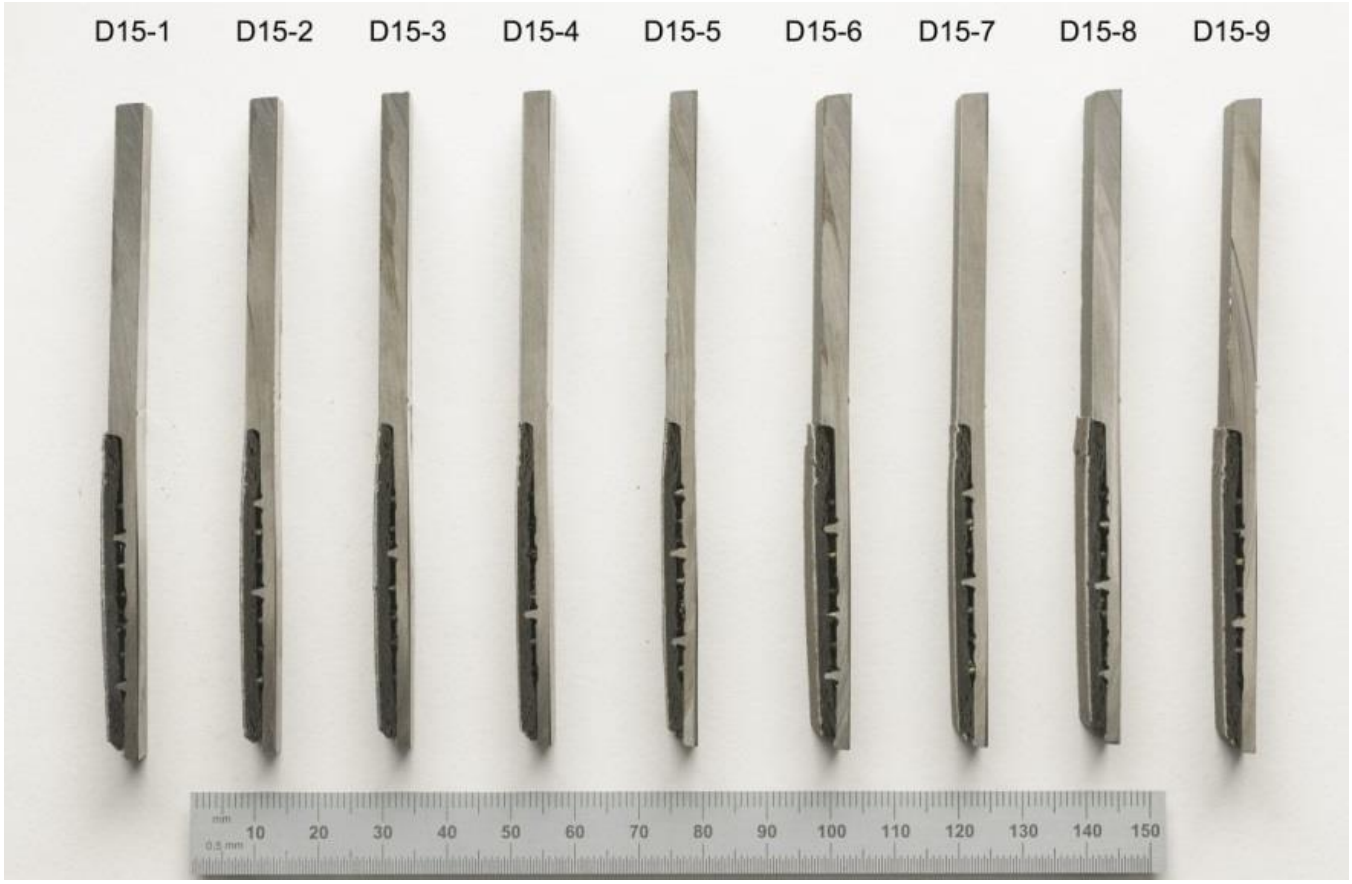


Figure 10: Representative visual examination of the SEDs after mechanically tested

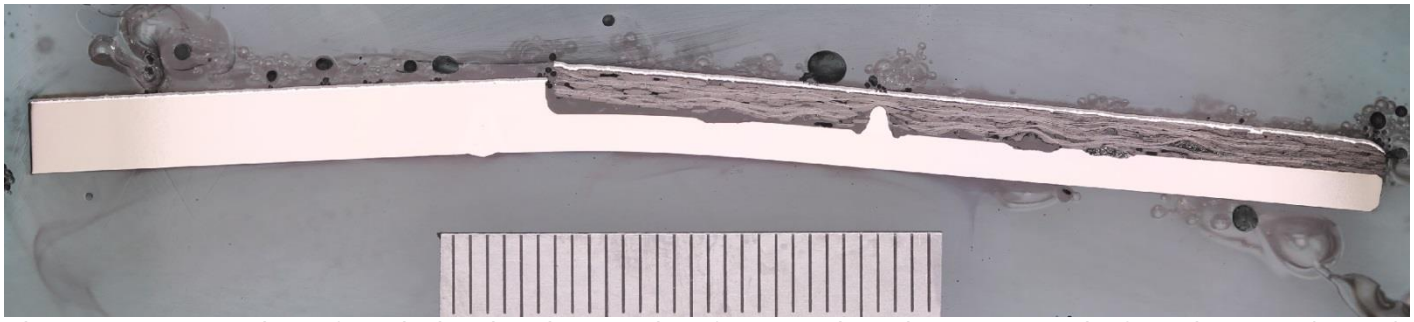


Figure 11: Cross-sections of 4-point bend testing samples after extraction. Photomacrograph of specimen TWI/20870/4 D11-1 (6mm displacement) after extraction and cross-sectioning showing detachment

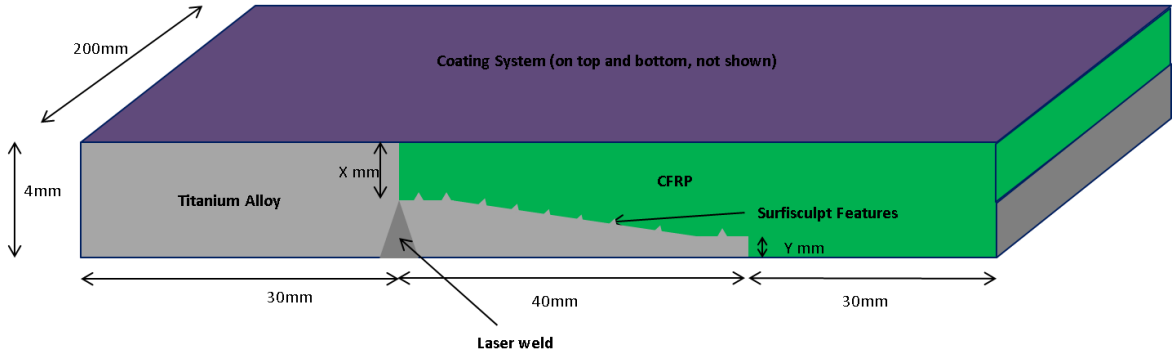


Figure 12: Component demonstrator (diagram not to scale)

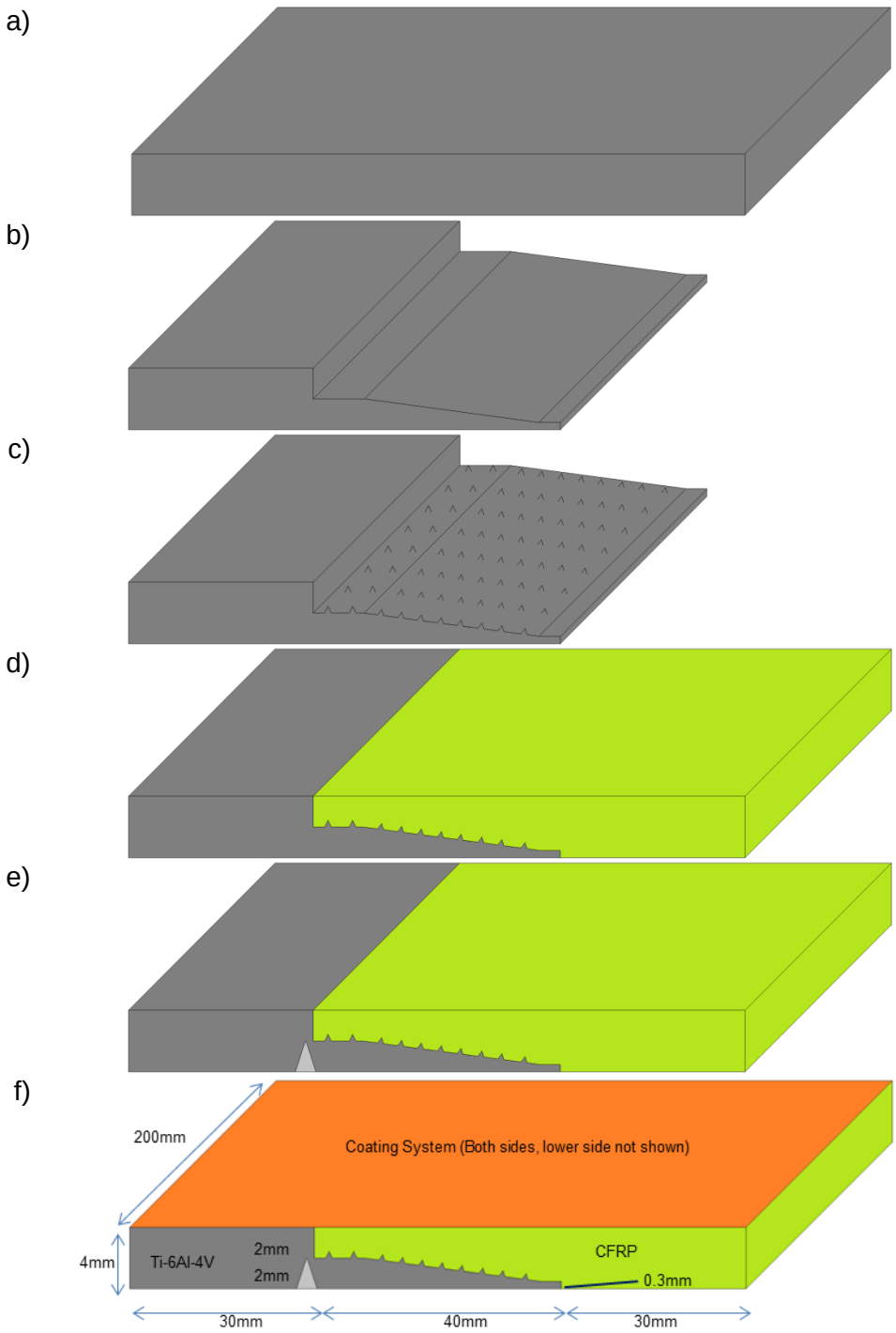


Figure 13: Component demonstrator: a) Preparation of initial Ti-6Al-4V sheet, b) Machining of stepped groove, geometry as shown., c) Surfisculpt® of machined surface, d) Layup and curing of CFRP, e) Laser welding in vicinity of Ti-6Al-4V to CFRP interface, f) Application of surface protection system to both sides.. Diagrams are not to scale.