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Paint Stripping Techniques for Composite Aircraft Components

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Summary

For a Nato Research and Technology cooperation programme the NLR investigated the effects of PMB, Laser, Flashjet and Waterjet paint stripping on the surfaces of composites and fibre-metal laminates. The stripping methods were applied in different countries to specimens from an F-16 horizontal stabiliser made of carbon/epoxy composite material, and specimens of the fibre-metal laminate GLARE. The tests involved selective paint stripping down to the primer and complete stripping to the substrate surface. The abrasive paint stripping methods PMB V and PMB II enabled complete stripping without damaging the substrates, although for composite surfaces selective stripping is recommended. Laser and Flashjet stripping may damage the substrate surface, including the original surface treatment for metal surfaces. Therefore selective Laser and Flashjet stripping are recommended for both composite and aluminium surfaces. Finally, high pressure Waterjet stripping is not feasible for composite materials on aircraft structures. For metal surfaces (Glare) Waterjet stripping could be useful if the substrate is properly supported.

Keywords: paint stripping, environmentally friendly, composite, Laser, Flashjet, Plastic Media Blasting

Introduction

Paint stripping and recoating are required periodically for inspection, maintenance and repair of military aircraft. The current paint systems are usually epoxy primers and polyurethane topcoats, which are more difficult to remove by chemical stripping than the enamels and acrylics used before. Also, both military and commercial aircraft are increasingly built with composite components of reinforced organic matrix material. These have a different susceptibility to chemical attack than aluminium alloys, and the old paint system on composites is frequently not stripped but only sanded as pre-treatment before repainting.

Another aspect is that chemical paint strippers used to be based on methylene chloride and phenols. The attack on the polymeric coatings was quick and paint stripping was very effective. However, methylene chloride is toxic, and environmental regulations have forced the development of chemical strippers free of methylene chloride and phenols. A number of environmentally friendly paint strippers has come onto the market. A disadvantage for these new acid and H_2O_2 based strippers is the labour-intensive and time-consuming stripping process for conventional paint systems. However, simultaneously with the development of new chemical strippers, alternative non-hazardous methods for paint removal have come under investigation. These are:

- Plastic Media Blasting with different types of abrasive particles.
- Laser stripping with a carbon dioxide or photo-diode laser.
- Xenon Flashlamp/CO_2 stripping (Flashjet).
- Water jet stripping (for steel on marine vehicles and other equipment).

In the Netherlands the paint stripping of military aircraft is mainly chemical, except for the F-16 aircraft. In 1990 Plastic Media Blasting was introduced for RNLAF F-16s. The metal outer surface is PMB treated while the composite tail parts are partly sanded before repainting. Repetitive sanding and repainting causes significant weight increases of the composite tail. This, and the fact that sanding is a time consuming expensive procedure, made the RNLAF interested in new paint removal methods that can be applied on composite parts.

The need exists to verify these new processes for safe application to military vehicles, and the RTO[1] enabled formation of the Task Group AVT-052/018 "Shared test and joint qualification of advanced paint removal technology". In this task group NATO countries co-operated in the evaluation and selection of paint removal methods for specific types of NATO military vehicles. The participating countries in the co-operation programme were Canada, Germany, Italy, The Netherlands, United Kingdom and United States.

This paper concerns the results of the NLR investigation, which concentrated on the effectiveness of advanced paint stripping methods applied to an RNLAF F-16 composite horizontal stabiliser and to the fibre-metal laminate GLARE.

Experimental programme

An overview of the experimental programme is given below.

Materials	• Painted carbon/epoxy • Painted fibre-metal laminate (GLARE)
Stripping methods	• Plastic Media Blasting PMB V and PMB II • Laser stripping with a carbon dioxide laser • Xenon Flashlamp / CO_2 stripping (Flashjet) • Waterjet stripping
Evaluation	• Surface appearance • Surface roughness • C-scanning (composite) • Hardness/conductivity (GLARE) • Cross-sections (SEM)

Materials and specimen types

The RNLAF supplied a rejected horizontal stabiliser of an F-16 aircraft for paint stripping of a realistic component. The stabiliser consists of carbon-epoxy composite skins attached to a metal substructure. The skin is built up from prepreg layers of AS4/3501-6, thickness 0.125 mm, and the skin assembly, with the number of carbon/epoxy layers indicated, is shown in figure 1. On the outer surface a glass fabric layer (Type P5284-3) had been applied. The originally applied paint system was an S15/70 (MIL-P-85582) epoxy primer and an HF A 132 (MIL-C-83286) polyurethane topcoat from AKZO coatings. The paint thickness was determined from cross-sections and a primer + topcoat thickness of about 80-100 μm was measured.

The composite stabiliser was sectioned into specimens of about 300 x 300 mm. Figure 2 shows the cutting scheme and indicates the paint stripping methods applied by each country. Although Belgium (B) was not an active member of AVT 052/TG 018, the Belgian aircraft maintenance company SABCA was willing to use the PMB II stripping process on the composite specimens.

Beside composite specimens, painted fibre-metal laminate specimens were investigated. The 2.35 mm thick substrate material was GLARE 3-4/3-0.4. This is a damage tolerant structural material consisting of alternating layers of 2024-T3 bare sheets and cross-ply glass/epoxy. The thickness of the aluminium sheet in the specific laminate was 0.4 mm and that of the cross-ply glass/epoxy 0.25 mm. The surface treatment condition of the outer aluminium surface consisted of a chromic acid anodic layer, a bond primer BR127 with a thickness of ~10 μm, Aerodur Primer S15/60 (30 μm), and Aerodur Finish C21/100 (40 μm).
The paint on the GLARE laminate was aged for 1 week at 70 °C, after which 300x300 mm specimens were distributed for paint removal.

[1] Research and Technology Organisation (of NATO).

Objective of the test programme

The painted composite and GLARE specimens were distributed with the objective of:
- Selective removal of the paint system up to the primer.
- Complete paint stripping up to the substrate surface.

Information on process conditions and stripping rate was compiled to enable comparing the effectiveness of the stripping methods.

Details on applied paint stripping methods (Ref. 1)

- Plastic Media Blast treatment
  Plastic Media Blasting (PMB) is a dry stripping process. It is abrasive, using small plastic plastic particles with a specific hardness to remove one or more layers of paint in each working cycle. The type of blasting medium, air pressure, mass flow, nozzle diameter, and distance and angle to the surface are the parameters that determine the effectiveness of the stripping process. MIL-P-85891 gives a specification for "Plastic Media for Removal of Organic Coatings". Of the seven types of media the most frequently used are:

Code	Material	Barcol hardness	Specific gravity
Type II	Urea formaldehyde (thermoset)	54 - 62	1.50
Type V	Acrylic (thermoplastic)	46 - 54	1.15
Type VII	Starch-g-acrylic	72 - 79	1.40

  The selection of the blast medium is determined by the type of substrate (metal or composite) and the *thickness* of the painted substrate to be treated. In general the low number type media enable a higher stripping rate.
  PMB is used mainly for paint stripping of the metal outer surface military aircraft. It has been shown that PMB is an excellent replacement for traditional chemical stripping. However, PMB is very time-consuming. A number of aircraft components have to be removed, and electronic units and hydraulic actuators have to be protected to prevent dust and media ingress.

  In the present paint stripping investigation on composite and GLARE, the plastic media Type II and Type V were used.

- CO_2 Laser Paint Stripping
  SLCR-Doreen (Germany) has developed the TEA CO_2-laser paint stripping process for removing paint from metallic and composite substrates. The laser is a pulsed adaptation of a continuous CO_2 industrial laser, operating at an output power of 2 kW and a pulse repetition frequency of 200 Hz. The pulse energy density used in the present programme was 8 J/cm^2.
  A spectrograph (an instrument that divides light into different colours) is used to examine the colour before the laser action starts. Coatings are selectively removed, based on the identification by colour of individual surface areas. The ablation rate is about 10 μm/pulse (at 8 J/cm^2). The laser pattern is rastered to minimise heat build up at the surface. Investigation programmes have shown that the substrate temperature will not exceed 80 °C (Ref. 2).

  By burning and filtering contaminants in the gases coming free during the process, the laser stripping is an environmentally clean process.

- Xenon flashlamp/CO_2 paint stripping (Flashjet)
  Flashjet stripping (high-intensity flashlamp exposure/CO_2 pellet blasting) reflects a synergistic coupling of two different approaches to aircraft paint removal. The flashlamp-induced coating volatilisation is followed by the sweeping motion of the low-pressure CO_2 particle stream that acts as a soot remover, lamp cleaner, and substrate cooler.

The coating absorbs photon energy, and its temperature rises rapidly to the point at which a thin layer is ablated (eroded). The resulting residue is swept from the surface by the low pressure dry ice particle stream. The CO_2 environment under the stripping head provides an atmosphere that suppresses combustion of flammable surface contaminates.
The amount of paint removed from an area of substrate is approximately proportional to the energy delivered to the area. A given energy can be delivered to an area by operating at high input voltage at a rapid traverse rate, or by using a lower input voltage and moving the head more slowly. A slower removal rate may provide finer control over the strip depth and minimise heating of delicate substrates.

Through adjustment of the operating parameters (i.e., light-energy density, traverse rate, etc.) varying degrees of coating removal are possible, including complete coating system (topcoat and primer) removal or topcoat only removal. This selective coating removal is extremely attractive for composite substrates, whereby leaving the primer intact precludes any possible substrate damage.
An extensive qualification testing programme was performed with 0.5 mm thick 2024-T3 and 7075-T6 aluminium sheet, reference 3, representing helicopter fuselage skins. In the present investigation the Boeing Co Flashjet system was used.

- High-pressure Water jet stripping
  High pressure Waterjet stripping is currently under investigation as an environmentally compliant paint removal method for steel on marine vehicles and other equipment. Earlier investigations into the use of high pressure water jetting (Aquastripping) for paint removal from thin aluminium aircraft skin are described in reference 4. Aquastripping was applied on paint systems after softening the paint previously with a softener compatible with respect to environmental and health regulations. The actual stripping process occurred at a pressure of 500 bar maximum. Despite the extensive investigation programmes, this new paint removal technique has never been implemented in the aircraft maintenance industry. A point of concern is the likelihood of water penetration in e.g. structural joints of which the faying surfaces are not properly sealed or hot-bonded.

  The Water jet paint stripping technique, developed by the Italian P.T.C. company, operates at a pressure of 1200 to 1800 bar and was developed for paint removal for steel on marine vehicles. In the present investigation the Water jet technique was applied on composite basically to show its unsuitability for aircraft components.

- An overview of the applied paint stripping processes and the process conditions is given in table 1. The last column indicates the paint strip rate to enable mutual comparisons of the effectiveness of paint removal techniques. However, it has to be mentioned that a straight comparison is obscured by time-consuming preparations for certain stripping methods.

Results

- Surface appearances after paint stripping
  Figures 3 to 5 show the surface appearances of a number of stripped specimens. For the composite specimens the ultrasonic C-scan plot has been added. The experiences with the advanced stripping techniques on composite specimens can be summarised as follows:
  - The abrasive methods PMB V and PMB II enable selective and complete paint stripping without damaging the composite laminate.
  - With the thermal paint removal methods (Laser and Flashjet) selective and complete paint stripping is possible. However, with complete paint stripping stringent requirements for process control must prevent the occurrence of overheating of the composite surface. For Flashjet stripping local overheating had occurred, resulting in C-scan damage indications (Fig. 3c).
  - Waterjet paint stripping is disastrous for composite structures (Fig. 4b).

- Roughness measurements (Tab. 2)
  The PMB process resulted in the largest roughness for the composite substrate. The large roughness due to Flashjet stripping up to the interface can be attributed to the delamination damage that occurred near the outer surface, figure 3c. Selective paint stripping by Flashjet gave the smoothest composite surface. For the GLARE surface all paint stripping methods resulted in low roughness.
- Conductivity and hardness measurements
  Laser and Flashjet paint stripping may increase the substrate temperature. If the temperature becomes too high, the conductivity and hardness of the aluminium substrate could change. The GLARE laminates used for Laser and Flashjet paint stripping were checked for change in conductivity (Sigma tester) and hardness (micro Vickers). No changes were observed.
- Microscopic cross-sections and SEM investigation
  Cross-sections after the PMB V and PMB II treatment showed the carbon/epoxy layers, together with the top protecting glass/epoxy layer. Selective PMB stripping left a thin layer of primer on the glass/epoxy layer. Complete paint stripping cleaned the surface up to the glass layer. No signs of delamination due to the blasting processes were observed.

  Cross-sections after Flashjet and Laser stripping showed that selective stripping resulted in a similar surface appearance to that observed after PMB stripping. Complete paint stripping by Flashjet destroyed the glass/epoxy layer, which delaminated from the carbon/epoxy surface. Complete paint stripping by Laser resulted in a reduction of the glass/epoxy layer thickness without damaging the carbon/epoxy substrate.

  Cross-sections of treated GLARE laminates did not show internal delamination due to the paint removal processes even after the Water jet paint stripping.
  For paint stripping of aluminium surfaces it is important to examine the effect of paint stripping methods on the original surface treatment. Therefore a number of cross-sections were investigated in the SEM.
  After the PMB V treatment for complete paint removal, the paint system including the bondprimer had been removed but no damage to the anodic layer was observed.

  However, for Laser stripping down to the substrate the anodic layer can be attacked, as shown in figure 6. The intensive laser treatment with the surface appearance as shown in figure 5 resulted at some locations in a thickness reduction of the anodic layer to 0.3 μm, see figure 6. Cross-sections after complete paint stripping by the Flashjet and Water jet methods revealed no attack of the anodic layer.

Evaluation and recommendations

Advanced paint stripping methods were applied to composite specimens from an F-16 horizontal stabiliser and fibre-metal laminate (GLARE) specimens. The requirements for candidate technologies (for replacement of toxic chemical strippers and sanding of composites) are:
- Non-damaging to aircraft metallic materials and composite surfaces.
- Environmentally safe.
- Cost effective.

The performed investigation concentrated on the first aspect.

The results for the abrasive methods PMB V and PMB II have shown that selective and complete paint stripping on composite surfaces is possible without damaging the composite laminate. After stripping, a relatively rough surface is obtained for composites and a smooth surface for GLARE. In the present investigation only one strip cycle was performed. A life cycle use of PMB will involve at least 5 stripping cycles. Therefore it is recommended to use PMB for selective stripping down to the primer for composite substrates. Complete paint stripping on aluminium surfaces can be performed without damaging the anodic layer.

For the thermal stripping methods Laser and Flashjet, complete stripping down to the composite surface is not recommended. Local overheating due to non-optimum process control may cause delamination or attack of the protective glass layer. Although no effects of thermal stripping on aluminium properties (conductivity and hardness) were observed, the original surface treatment (anodic layer) can be damaged. Therefore for both Laser and for Flashjet stripping the selective paint removal process is recommended for composite and aluminium surfaces.

Finally, the high pressure Waterjet paint stripping method is totally unsuitable for composite aircraft structures. For fully supported metal parts (Glare) the paint system can be removed without damaging the anodic layer. However, the high pressure at Waterjet stripping, the relatively thin skin materials and the likehood of water penetration in structural joints, make this stripping process unsuitable for aircraft outer surfaces.

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Table 1 Applied paint stripping techniques and process conditions

Process	Substrate		Process parameters			Selective = to primer complete = to substrate	Strip rate m^2/h
	Composite	GLARE	Pressure (bar)	Distance (mm)	Angle^o		
PMB V	•		0.84	300	45	complete	1
	•		0.84	300	45	selective	1.5
		•	1.05	450	45	complete	0.5
		•	1.05	450	45	selective	1.5
PMB II	•		2.1-2.45	>300	40	selective	
	•		2.1-2.45	>300	40	complete	
Laser (2 kW TEA CO_2	•		2 kW 200 Hz	>10	90	selective	5
	•		8 J			complete	3.5
		•				selective	4
		•				complete	7
Flashjet/ CO_2 cleaning	•		2 passes (2300 V) to primer at 55 mm			selective	11-22 to primer*
	•		3+4+1 passes at 2300, 2100 and 1800 V			complete	9-15 to substrate
		•	3 passes 2300 V			selective	
		•	10 passes 2300 V			complete	
Waterjet	•		1800	100	90	**	
		•					
		•	1200	100	90	complete	15

* Strongly depends on paint surface reflectivity
Figures concern grey top coats
** Destruction of composite

Table 2 Surface roughness after paint stripping

Method	Roughness (µm) after stripping of composite		Roughness (µm) after stripping of GLARE	
	up to primer	up to interface	up to primer	up to interface
PMB V	7.2 7.3	6.7 7.8	1.2 1.2	2.1 1.8
PMB II	6.4 7.3	6.1 6.4	-	-
Laser	3.3 3.2	4.1 3.7	1.8 1.2	0.3 0.3
Flashjet	1.9 1.8	6.2 6.0	-	0.7 0.6
Waterjet	-	-	-	0.5 0.6

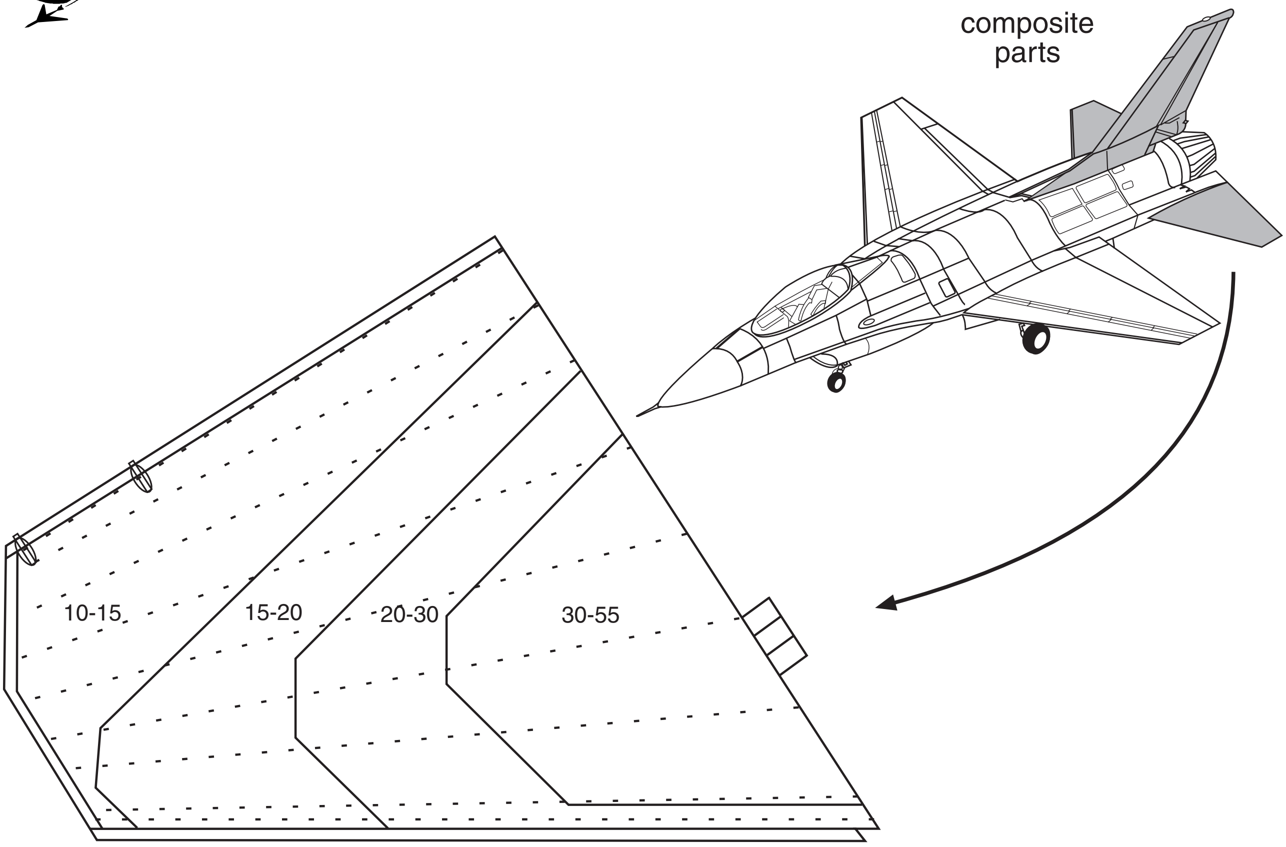

Figure 1   Skin assembly in number of carbon/ epoxy layers of the horizontal stabiliser used for paint stripping tests

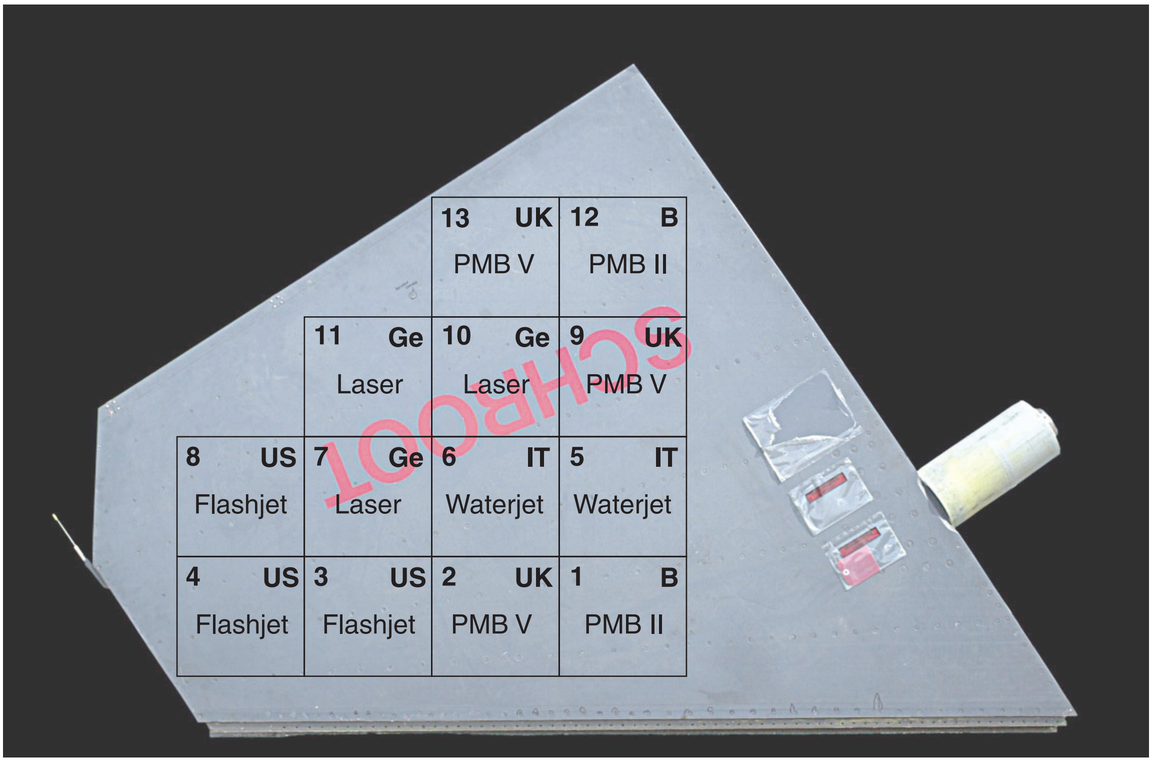

Figure 2   Overview of the cutting scheme for F-16 composite horizontal stabilizer and the applied paint stripping techniques in the different participating countries

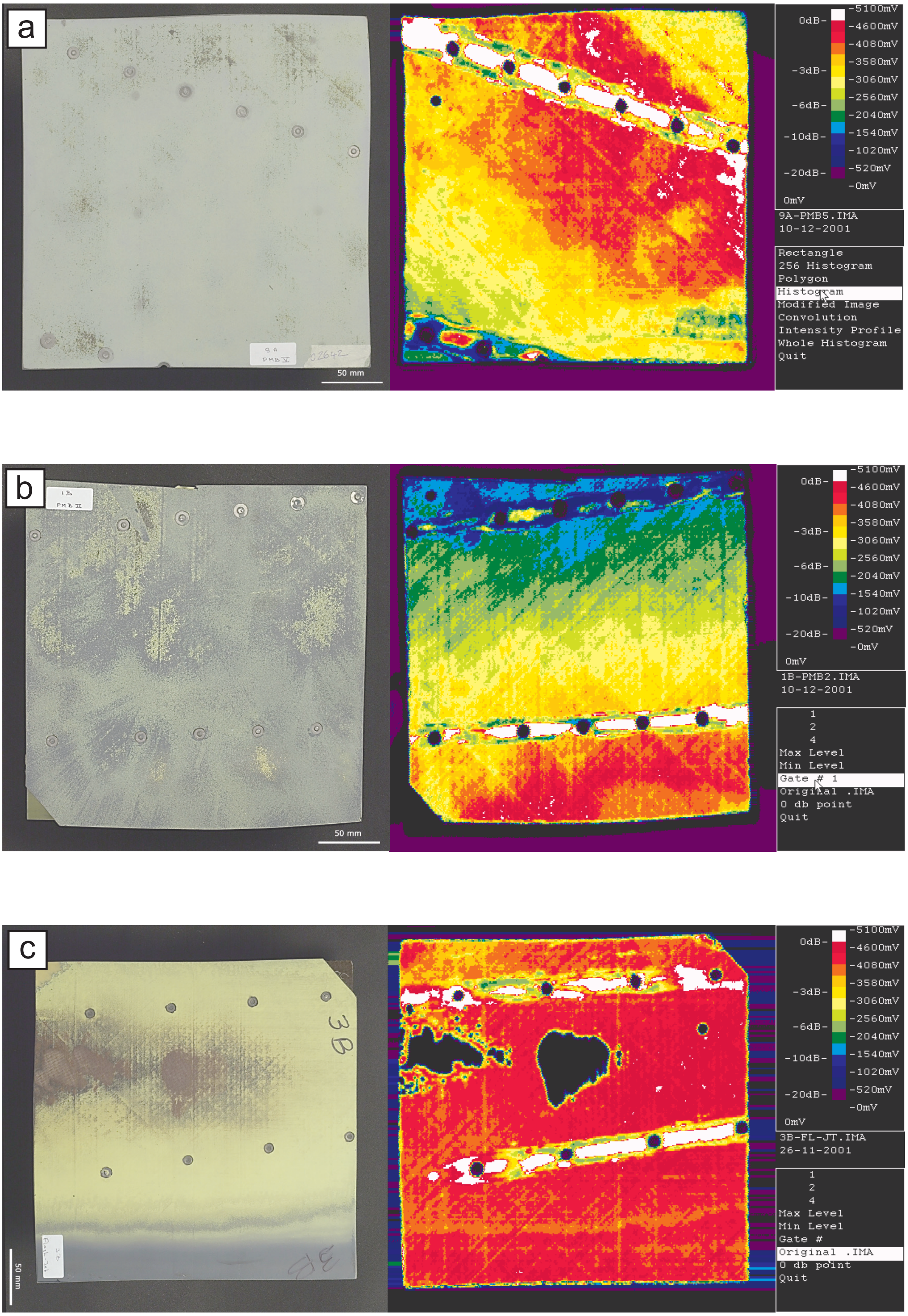

Figure 3 Surface appearances and C-scans after paint stripping of composite components
a) Selective stripping with PMB V
b) Complete stripping with PMB II
c) Complete stripping with Flashjet

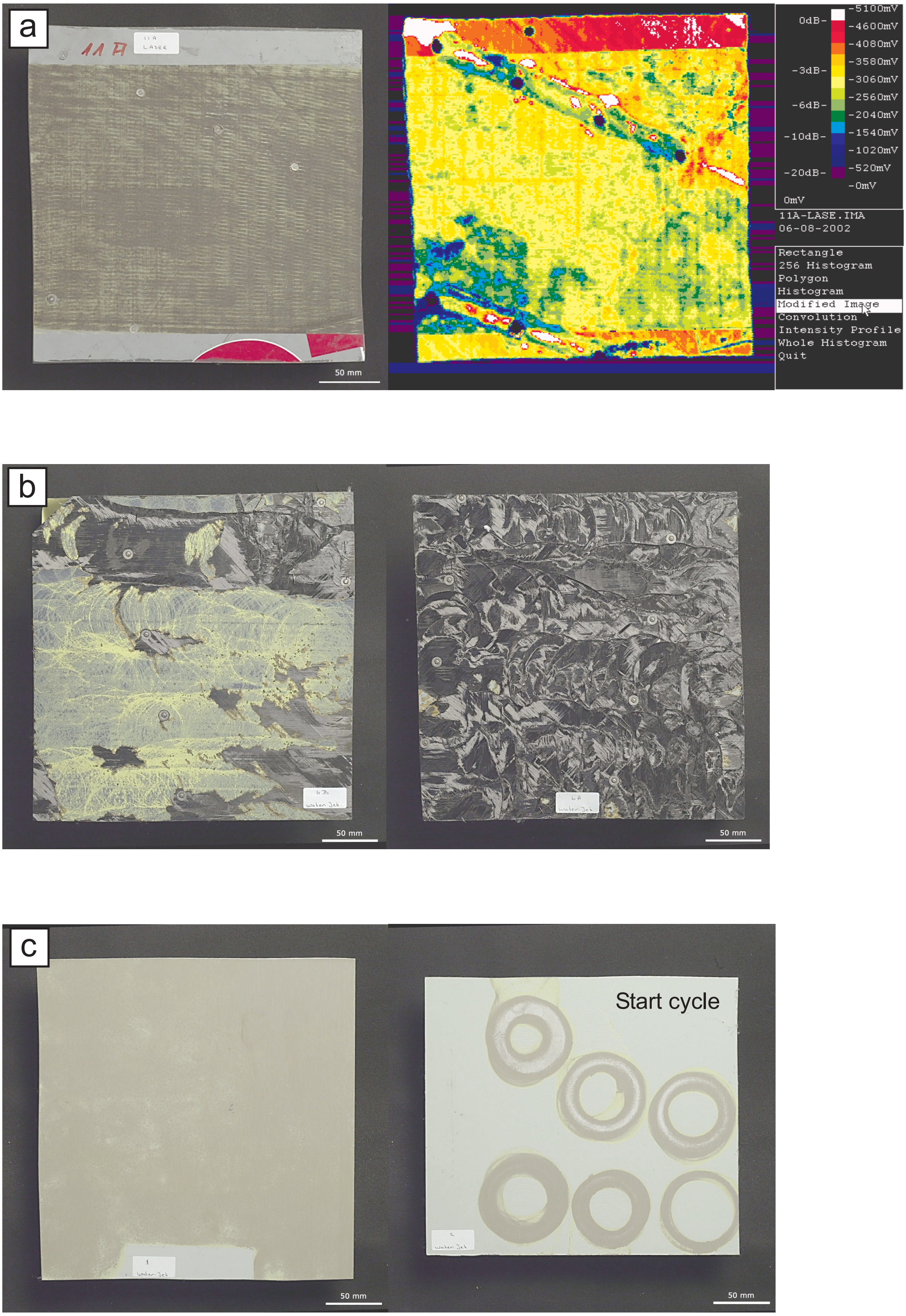

Figure 4   Surface appearances after paint stripping
a) Complete stripping of composite with Laser
b) Waterjet stripping of composite
c) Waterjet stripping of GLARE

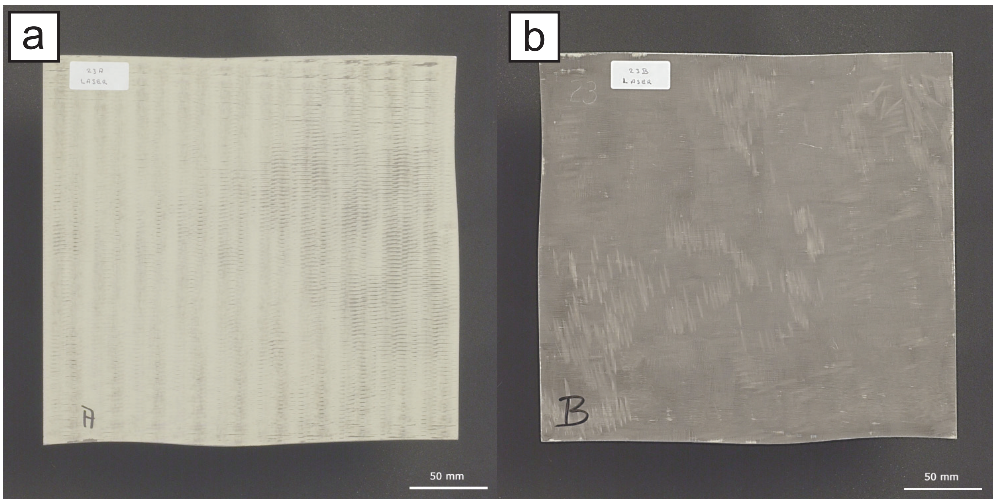

Figure 5   Selective (left) and complete Laser stripping of GLARE

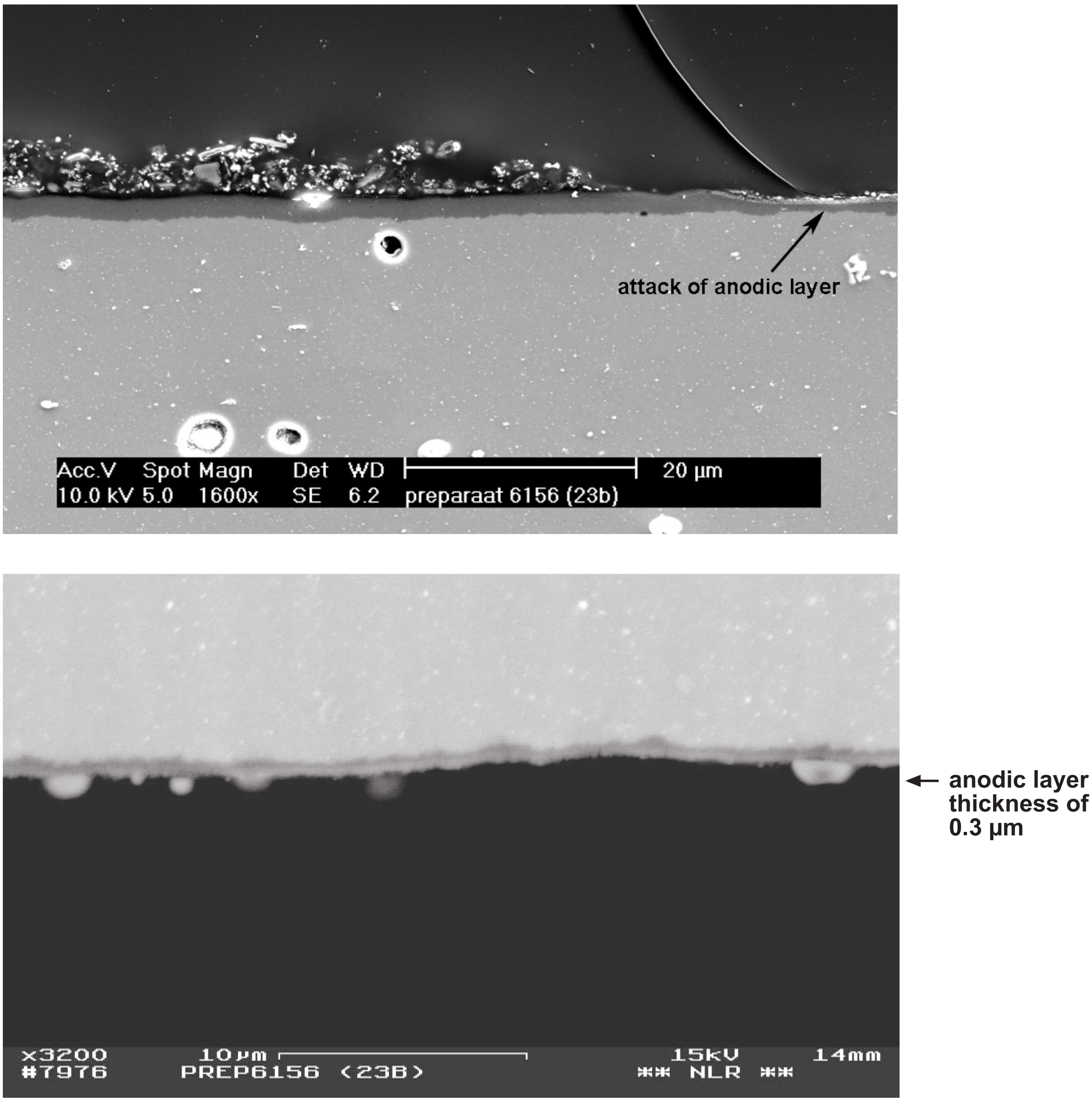

Figure 6   Cross-sections of GLARE after complete Laser stripping showing attack of the anodic layer