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SURFPREP FLASH-LAMP DEPAINT SYSTEM EVALUATION

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Abstract

The Surfprep machine is a flash-lamp device used for divesting surfaces of unwanted matter. It is believed that it can be used to clean gas turbine engine hardware and to strip corrosion and paints at a significant time and cost saving. The purpose of this program was to identify the potential uses of the standard paint stripper "Surfprep machine" and to verify that there is no negative effect to the substrates treated. The output power density from this machine is in the 15–30 J cm^{-2} range with short (4 μs) pulses. Areas of interest included: (A) cleaning and corrosive scale removal; (B) paint and varnish removal; (C) coating removal; (D) substrate effects; (E) geometry effects; (F) chemically assisted blasting. This program demonstrated that the Surfprep system can remove paints and varnishes in a controlled manner with reasonable removal rates, and provides optimism for what can be done with higher energy systems. It is also practical for cleaning engine parts of burnt-on oil and molybdenum disulfide, even though at a slower removal rate. We believe that it will not be detrimental to substrates. We have shown that geometry effects are not as severe as expected. Chemically assisted flashing has the potential to further improve the removal rates.

1. Background

The use of flash-lamps to divest unwanted matter was discovered early in the 1970s by John Asmus. Asmus, using lasers to clean diseased marble art works from Venice, Italy, was looking for a less expensive, safer and more rugged system, when he tried a flash-lamp. After several years of research, Asmus developed the flash-lamp as a divestment tool. In 1978 this system was used to selectively remove nine layers of paint from the California State Capitol Building, successfully exposing the colors and intricate design of murals over 100 years old [1].

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2. Introduction

The Surfprep family of high intensity light surface preparation (HILSP) flash-lamp systems produced by A & R Industries exhibits many advantages over the use of lasers for divestment and other surface preparation techniques. The initial cost of the Surfprep system coupled with the large area affected make the system more cost effective. The safety considerations of the non-coherent flash-lamp are much less stringent. Perhaps the most important consideration is that of the mechanics of application. Surfprep, with the flash-lamp being in a self-contained reflecting module, can be moved over the surface with simple positioning equipment. The use of sophisticated, computer-controlled focusing devices is not required. Therefore Surfprep may be used to divest a complicated three-dimensional surface such as an aircraft component in a considerably less complex manner than today's lasers.

The flash-lamp energy comprises broad spectrum, non-coherent, short pulses of intense light which is absorbed by a multiplicity of matter. The optical energy of the flash-lamp is deposited on the undesired matter in a very short pulse (up to a few milliseconds) at an energy density of several to tens of $J\ cm^{-2}$. The material illuminated absorbs energy and experiences a rapid temperature rise as a function of high energy per small unit volume. Keeping the pulse short limits the energy transfer into the bulk of the material and determines the depth of penetration. Divestment depths are typically a few micrometers and can be controlled within limits. The resultant temperature rise causes primary sublimation with pyrolysis and high energy chemical reactions, depending on the material divested and the surrounding atmosphere. These controls and characteristics make Surfprep ideal for paint removal from composite surfaces.

HILSP is not a panacea however. Materials that reflect, such as metals and marble, cannot be divested. With reflective materials as substrates, however, divestment becomes a self-quenching mechanism, since no further reaction is experienced once the substrate is bare. Surfprep is currently energy limited and will not attack metallic coatings on metals such as anodize on aluminum. Materials that are transparent or very thin so as to be transparent would also be non-candidates. However, there are tricks that can be applied in such instances. Dies or other absorbing materials may be added to enhance their removal. Chemicals can be used to enhance HILSP treatment of surfaces. Most chemical treatments are slow, require elevated temperatures and have drawbacks and undesirable side effects. In some cases HILSP can be used to enhance the chemical process to reduce the time required and to reduce or eliminate the undesirable side effects. Sometimes the side effect is advantageous, such as surface passivation on steel.

As the use and disposal of toxic chemicals becomes more difficult, other methods of cleaning and stripping are being sought. Also, as military and civilian vehicles such as aircraft become more sophisticated, the use of composite materials is proliferating. These same chemicals cannot be used on composite surfaces because the substrates are of similar chemical species to the paint. Mechanical depainting such as plastic media blasting is not acceptable since it can damage the composite. It has been estimated that it takes 300 man hours to depaint an F-4 aircraft [2] using today's chemical depainting method, while the Surfprep method would only take 100 man hours. In addition to the environmental benefits, Surfprep is genuinely cost effective for metal aircraft and components, especially when one takes into account the capital investment of chemical waste disposal. For composite aircraft and components, Surfprep is the only presently available method with the exception of highly skilled hand sanding.

The United States Air Force evaluated the Surfprep equipment for stripping paint from composite aircraft structures [2]. They purchased two 9 in units, one of which was delivered to McClellan AFB in October 1985. Their program called for laboratory analysis, production validation and development of a fully robotized system to optimize production output.

3. Test program

Rolls Royce became interested in HILSP because of its potential to clean gas turbine engine hardware and strip corrosion and paints at a significant time and cost saving. It was further hoped to reduce the costs and to prevent the generation of large volumes of toxic chemical waste. Areas investigated include: (A) cleaning and corrosive scale removal; (B) paint and varnish removal; (C) coating removal; (D) substrate effects; (E) geometry effects; (F) chemically assisted blasting.

In addition to material tested in this test program, some other potential uses of this system are listed in Table 1. We are also interested in the potential of high energy variations of this concept. Similar devices with an output of 100–300 J cm^{-2} have the potential to do many of the things done today by lasers, but without some of the major disadvantages, such as the small footprint or plowing effect.

The testing was done at the University of California at San Diego. The materials evaluated are given in Table 2, and include the number of coupons tested for each material, their identification number and the approximate coupon size. A 229 mm (9 in) xenon tube was used along with an aluminum

TABLE 1

Additional HILSP potential uses (30 J cm^{-2})

(1) Local stripping of paint to effect a repair
(2) Cleaning ceramic materials prior to coating or ion implanting
(3) Paint removal of carbon ducts and thrusters
(4) Cleaning rubber parts
(5) Paint stripping of acoustical panels; current method traps fluid and is very easy
(6) Cleaning composite cases with oil leaks
(7) Stripping composite nosecone–outlet guide vane coating

TABLE 2

Surfprep coupon

Item	*Sequence no.*	*Coupon size* $W \times L$ (mm^2)
(A) Paint removal		
(1) PL205 heat-resistant paint on aluminum	A1-1–6	25.4 × 50.8
(2) Two-pack epoxy black paint on carbon fiber epoxy	A2-1–6	25.4 × 50.8
Two-pack epoxy black paint on siltemp	A2-7–12	25.4 × 50.8
(3) Gray enamel on magnesium	A3-1–5	76.2 × 25.4
(4) Rock-hard varnish as stoved	LK-17–20	50.8 × 101.6
Rock-hard varnish heat aged	LK-21–24	
(5) Thermal paint on YSZ	A5-1–4	76.2 × 38.1
(B) Cleaning and corrosive scale removal		
(6) Burnt-on oil on 12% chromium steel	B6-1–3	50.8 × 25.4
Burnt-on oil on nickel	B6-4–6	76.2 × 38.1
(7) Carbon–oil on TBC YSZ	B7-1–3	25.4 × 50.8
(8) Molybdenum disulfide lube on steel	B8-1–3	25.4 × 50.8
(9) Corrosion on nickel-base vane	B9-1–2	50.8 × 152.4
(C) Coating removal		
(10) Metco 443 on nickel	C10-1–3	25.4 × 50.8
(11) APS MCrAlY on nickel	C11-1–2	12.7 × 101.6
(12) SiC coating on carbon–carbon	C12-1–3	50.8 × 12.7
(13) YSZ on nickel	C13-1–3	38.1 × 38.1
(D) Substrate effects		
(14) 475 Nickel	D14-1–2	38.1 × 38.1
(15) Titanium	D15-1–2	25.4 × 50.8
(16) 12% chromium steel	D16-1–3	25.4 × 50.8
(17) Aluminum	D17-1–3	25.4 × 50.8
(18) Carbon–carbon	D18-1–3	12.7 × 12.7
(19) Metal–matrix (Ti–SiC)	D19-1–3	6.35 × 50.8
(E) Geometry effects		
(20) Painted PL205 hemispheres	E20-1–2	$D = 25.4$
	E20-3	$D = 12.7$
(21) PL205 aluminum compressor vane pair	LK82147	127 × 50.8
	LK82150	
(22) Steel disc with SermeTel W	E22-1–2	139.7 × 50.8
(F) Chemically assisted		
(23) Rock-hard varnish with sodium hydroxide	LK-19&23	50.8 × 101.6
(24) Molybdenum disulfide with nitric acid	F25-1–2	25.4 × 50.8

elliptical reflector. The reflector was designed to be an ellipse in cross-section with flat end walls. In cross-section it is a truncated ellipse such that the focus is at the second major axis, or about 12 mm outside the reflector. The rig with a stator vane in place is shown in Fig. 1.

The weight loss as a function of the number of pulses is given for the different tests later in this paper. In most cases the area of removal was the footprint width (about 12 mm) by the width of the specimen. To compensate for a width variation between specimens, the weight loss is given for a 25 mm width. Table 2 lists all the tests.

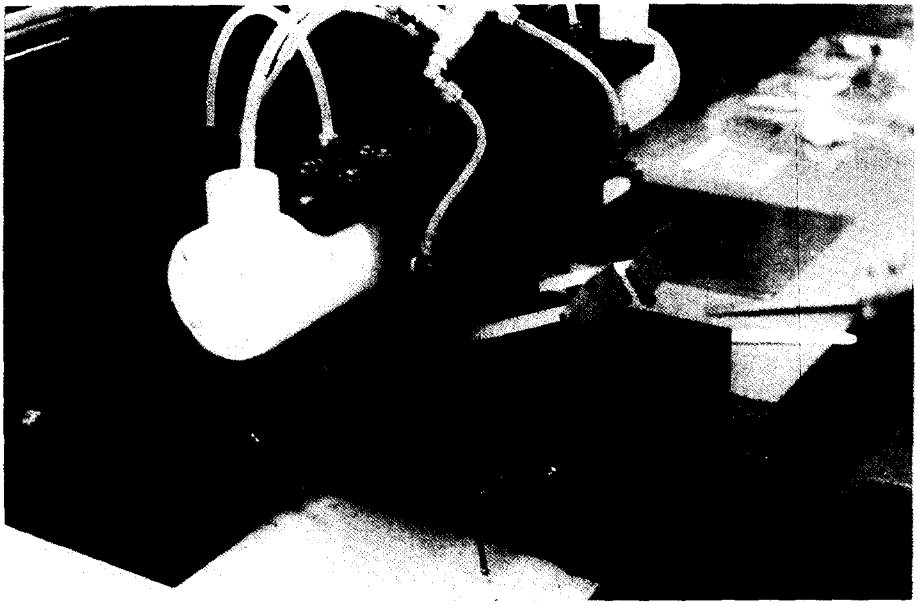

Fig. 1. Surfprep set-up with compressor vane in place.

4. Results

4.1. Paint removal

The first paint tested was a heat-resistant silicon epoxy (PL205) for use on engine components operating up to 250 °C. It is used on aluminum compressor stators. Six specimens were processed with varying pulses between 1 and 12. The weight loss *vs.* pulses is given in Fig. 2. The removal rate is slightly over 2 mg per pulse. It took 12 pulses to remove the paint. Even after 1 pulse it was not noticeable that some paint had been removed. Figure 3 shows the 25 mm × 50 mm plates with 1, 3, 5, 7, 10 and 13 pulses.

The second paint tested was a two-pack epoxy paint on carbon fiber epoxy and on carbon fiber epoxy siltemp. Six samples of each material were tested with 1–10 pulses each. The removal rate was about the same as for the PL205. The coating was gone by 7 pulses.

The third paint tested was gray enamel applied on magnesium casted flanges that had run in an engine. They had been repaired and recoated several times; the coating was very thick and went alternately gray and red (primer) during removal. Six samples were processed with up to 20 pulses per sample. The removal rate was again similar to PL205 and the epoxy paint.

Rock-hard varnish on aluminum was tested next. Three samples were as stoved and three were heat aged. The removal rate was lower than for the paints. The heat-aged varnish had a higher removal rate of about 1.5 mg per pulse compared to 1 mg per pulse for the as-stoved varnish.

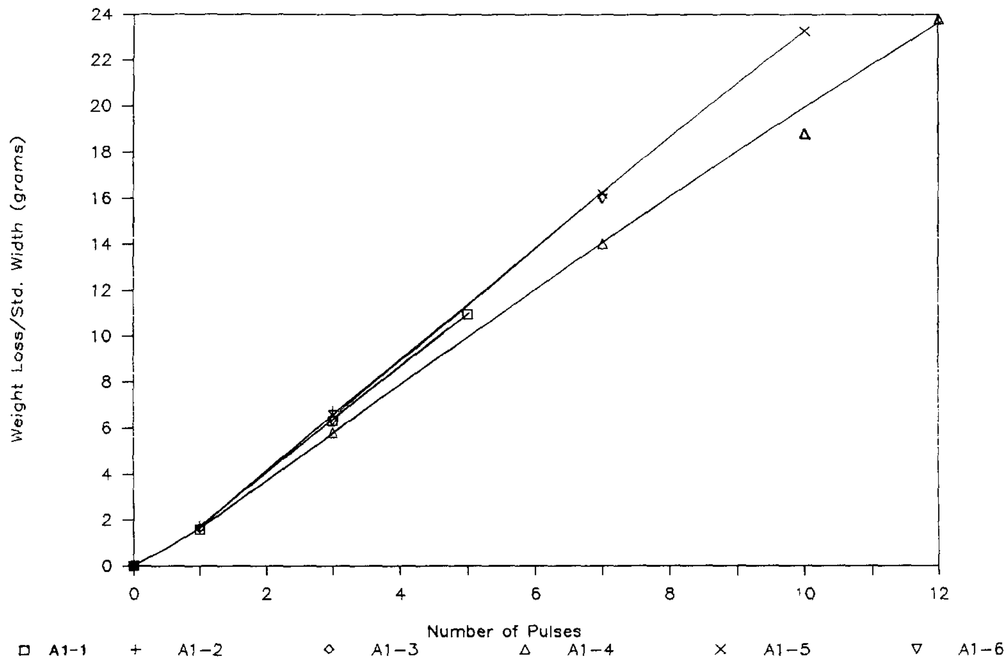

Fig. 2. Weight loss of heat-resistant paint per pulse.

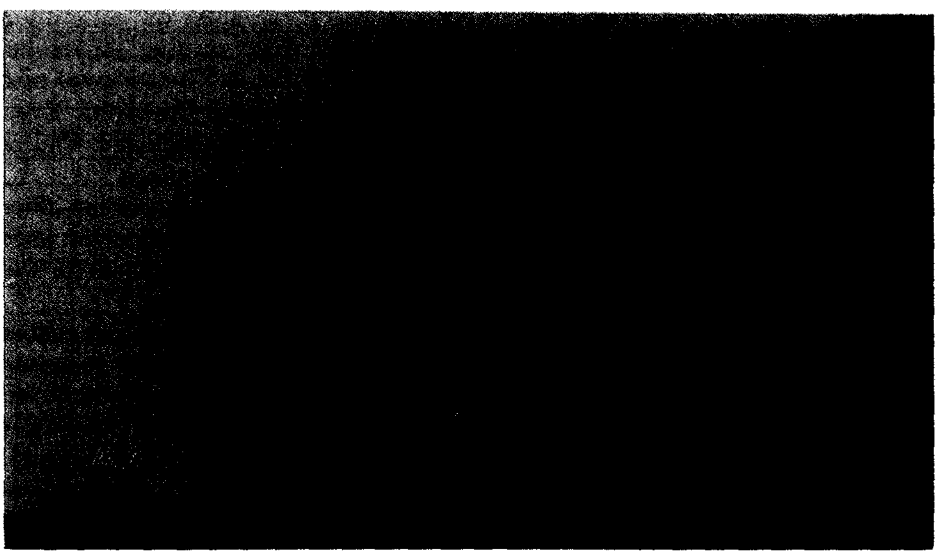

Fig. 3. Heat-resistant paint on aluminum after 1–13 pulses.

The last paint evaluated in this test program was temperature-sensitive thermal paint (TP5) on yttria-partially-stabilized zirconia (YSZ). Four samples were supplied, each cured at a different temperature and therefore of a different color. The flashes had only a minor effect on the coloration of the paint cured at 1000 and 1100 °C and the weight loss caused was hidden by chipping of the ceramic. The sample cured at 800 °C, however, showed significant color change (affected width 23 mm) and had no chipping. The weight loss was minor; 1 mg per pulse up to 2 pulses, then little loss, indicating perhaps that the paint was removed at the surface at that location. The sample cured at 600 °C had the most color change (affected width 28 mm) but the least weight loss.

4.2. Cleaning and corrosive scale removal

The first attempt at cleaning was of burnt-on oil from 12% chrome steel and nickel plates. The oil was not distributed uniformly on the six coupons tested, so the results were a bit scattered. The average removal rate was 1 mg per pulse up to 4 pulses. The removal pattern was not very distinctive.

Next we tried to clean some YSZ coupons with burnt-on oil. The removal pattern was more distinctive than on the metal plates, but the weight loss was less. The average weight loss rate was less than 0.5 mg per pulse.

We were more successful at removing molybdenum disulfide from 12% chrome steel. Three samples had an average removal rate of about 1 mg per pulse up to 5 pulses, as shown in Fig. 4. The removal pattern was not very distinctive.

The next attempt was more ambitious; we tried to remove corrosive scale from a turbine nozzle guide vane that had had about 10 000 h flight in an RB211-22B. This was from our program on service evaluation of thermal barrier coatings (TBCs) [3]. Because the vane weight exceeded the limit of our scale (240 mg), weight measurements were not taken; however, there was a noticeable discoloration of the olive green corrosion. With the use of a wooden spatula it came off fairly easily in the irradiated area, but would not come off in the non-treated areas.

4.3. Coating removal

The effect on plasma-sprayed coatings was minimal; after 20 pulses the weight loss was less than 1 mg. The CoNiCrAlY lost the most, perhaps a thin oxide film on the surface being removed. With the porous coating one might suspect water vapor to be removed, but the weight loss was less with the porous coating and approached the accuracy of the analytical scale ($\pm$0.1 mg).

4.4. Substrate effects

The substrates evaluated were Ti–SiC metal–matrix, 12% chromium steel, titanium IMI 829, carbon–carbon (C–C), 475 nickel and aluminum. The effects on five of the six were negligible; however, the C–C lost close to 3.5 mg

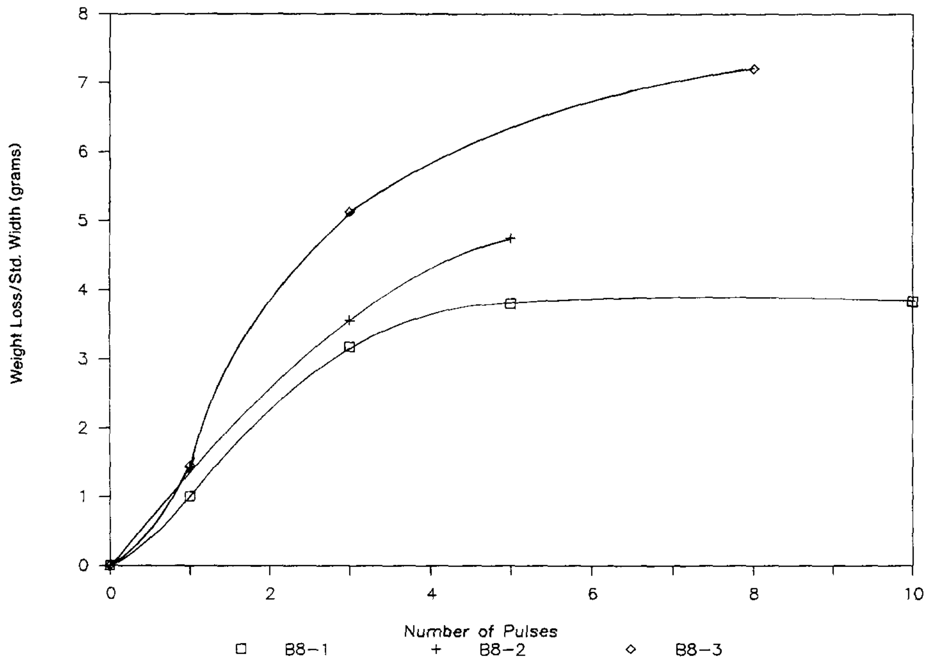

Fig. 4. Weight loss of molybdenum disulfide lube per pulse.

after 24 pulses and the average removal rate for the first 5 pulses was about 0.4 mg per pulse. The weight loss of the C–C could be due to removal of some carbon matrix. An Air Force study [2] showed that Surfprep does not damage composite structures such as C–C during coating removal. This is probably because such thin layers are removed per pulse and the substrate sees only a few pulses after the coating is gone.

4.5. Geometry effects

To evaluate the severity of Surfprep being a line-of-sight process, several more complicated geometries were tested. First we tested two steel spheres of different diameter (25 and 13 mm) coated with PL205 paint. As expected, the weight loss of the bigger sphere was greater; however, when normalized by the width (diameter), the removal plots are almost identical, as seen in Fig. 5. It is also interesting to note that there is discoloration (therefore removal) for the full 180°; see Fig. 6. This would indicate that the problem is not as bad as anticipated and perhaps a reflector can be designed to minimize the geometry effects.

Next, two compressor stator vanes coated with PL205 were irradiated. One vane was pulsed spanwise on the pressure-side airfoil. Both were done chordwise at the fillet radius convex-side airfoil, tilted at about 40° to the lamp as shown in Fig. 1. Again the spanwise loss per pulse was larger; however, when divided by the width, the plots (Fig. 5) are very similar. From

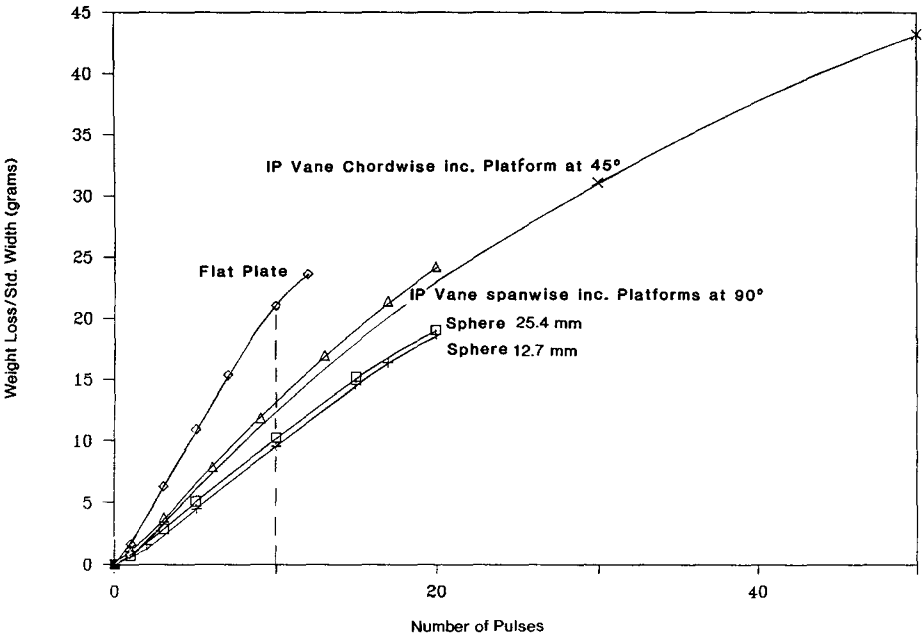

Fig. 5. Geometry effect on weight loss of paint per pulse.

Fig. 6. One-inch spheres with paint removed after 20 pulses.

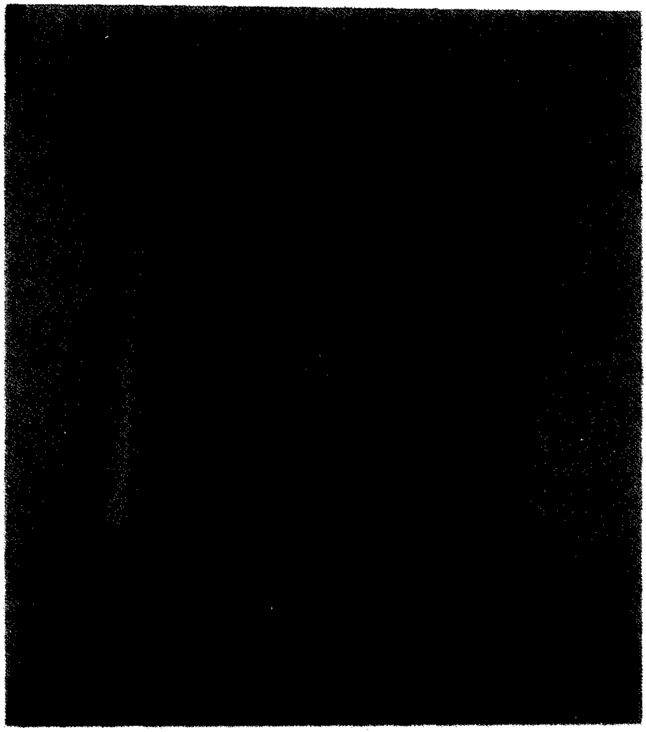

Fig. 7. Compressor stator vanes with paint removed.

Fig. 7 one can see that the paint was removed in the vane fillet radius and that the discoloration on the platform is similar to that on the airfoil just beyond the removed zone. Figure 5 summarizes the geometry effects. At 10 pulses, 22 mg of paint were removed from a flat plate, while about 13 mg were removed from a curved airfoil and only 10 mg were removed from spheres. This indicates about a 55% reduction in removal rate due to geometry.

4.6. Chemically assisted removal and cleaning

Since most of the stripping and cleaning is currently done chemically, it was of interest to see if a combination of the two would be faster. Nitric acid was swabbed on the varnished plates and then flashed. There was a slight improvement to both the as-stoved and heat-aged varnishes. Perhaps a short soaking would be better. In the removal of molybdenum disulfide, the swabbed nitric acid was more effective and the removal rate was more than doubled, which would indicate that chemically assisted cleaning is a viable concept. Also, the inventor showed that steel surfaces flashed with citric acid had enhanced corrosion resistance [4].

4.7. Summary

Figure 8 summarizes the removal rates for the different materials evaluated; paints had the highest removal rates, while substrates were not

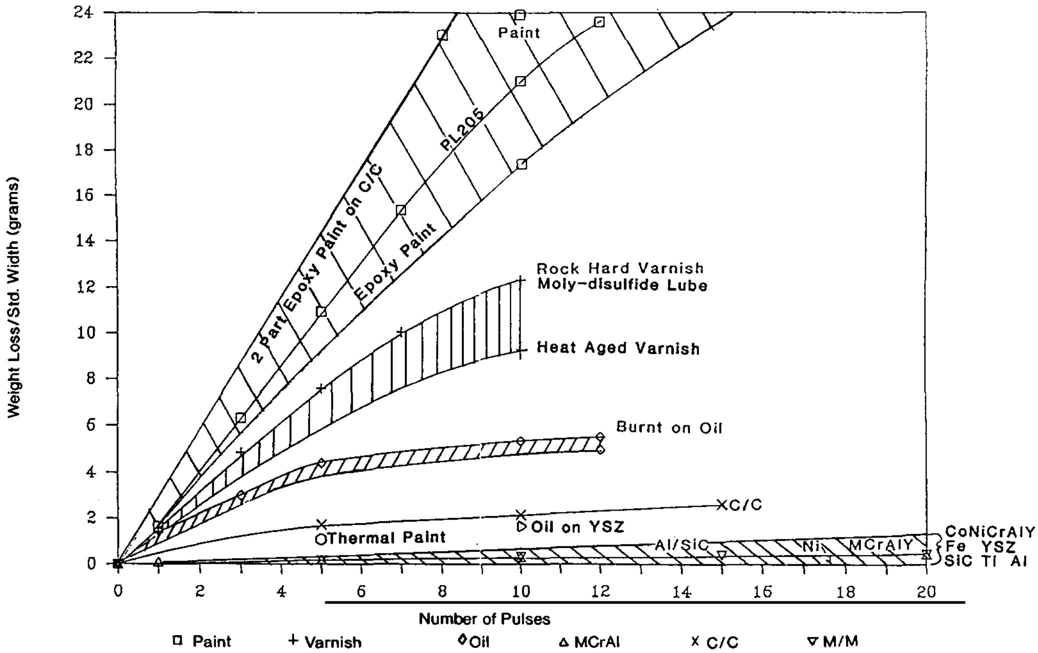

Fig. 8. Summary of removal rates.

affected at all. At 10 pulses the removal rates were: (1) paints, 18–24 mg per pulse; (2) varnish, 9–12 mg per pulse; (3) molybdenum disulfide, 4–8 mg per pulse; (4) burnt-on oil, 4–6 mg per pulse; (5) carbon–carbon, 2 mg per pulse; (6) substrates, less than 1 mg per pulse.

5. Air Force program

The Air Force is interested in Surfprep for the removal of paint from aircraft structures, particularly composite structures. They were looking for a system that would eliminate the generation of hazardous chemical waste and remove paint efficiently, economically, safely and without any damage to the aircraft surfaces. They evaluated the Surfprep system and in their report "Flashlamp depainting system" [2] they came to the following conclusions.

(1) It will strip paint from both metallic and composite structures without damage to the substrate.

(2) It can selectively strip by location or depth, *e.g.* to the primer and stop.

(3) Component temperature rises range from 38 to 49 °C.

(4) It is safe and cost effective.

(5) The process generates essentially no hazardous waste material.

(6) No preparation such as masking is required.

(7) Training of a flash-lamp operator is minimal.

(8) Specially designed reflector heads must be made to remove paint from corners and recessed areas.

6. Conclusions

(1) The Surfprep system in its present form provides a controllable way to remove paints and varnishes at reasonable rates; see the summary in Fig. 8.

(2) It is feasible for cleaning engine parts, *e.g.* removing burnt-on oil and molybdenum disulfide.

(3) There is not enough energy available to remove metallic coatings, but it did seem to loosen corrosion.

(4) It is not detrimental to metallic or composite substrates.

(5) Geometry constraints are not as severe as anticipated.

(6) Chemically assisted removal looks promisingly faster.

Acknowledgments

The testing was done at the University of California at San Diego by Roy Doxstader, President of A & R Industries. Roy is an associate of Dr. Asmus (now at the University of California at San Diego) who markets the Surfprep equipment.

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