EVALUATION OF DECONTAMINATION PROCESSES ADAPTED TO LARGE OPTICAL COMPONENTS

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ABSTRACT

Due to the high sensitivity of large optical components embedded on satellites, a study has been carried out in order to evaluate some cleaning processes that could be applied easily in cleanroom, during assembly and integration phases. A methodology has been set up considering the two major pollutants: particulate and molecular contaminations. Small-size coupons of various materials representative of those used for large structures (ceramics, glass, metallic alloys, cables, isolation materials) have been intentionally contaminated. Three innovative cleaning techniques such as contact polymer, atmospheric ultrasonics and CO_2 blasting have been assessed by comparing the contamination level of the treated surface before vs after cleaning. The associated characterisation methods have been developed as well, adapted to the type and surface of samples. A summary of cleaning efficacy is presented in terms of particulate and molecular contaminations, according to the cleaning processes and the materials tested.

1. INTRODUCTION

The industrial cleaning solutions for batches of small or medium size parts are quite numerous. Indeed, the cleaning processes via bath immersion or tunnel spray are particularly adapted to those configurations. On the other hand, and especially for the space industry where the structures to be decontaminated are large and quite complex in terms of configuration and quantity of materials, those techniques become non applicable. The decontamination solutions are thus manual, with all the associated constraints (health and safety aspects, time-consuming operations…).
In addition, most of the time, the cleaning phases are divided into two steps. The first step for the molecular decontamination and the second one for the particulate removal. Finding a solution allowing to treat both types of contamination would be time-saving with regards to the cleaning cycles. This study, realised in the framework of a CNES R&T activities, allowed to identify the cleaning techniques that can be applied to large structures and evaluate their performances versus the particulate and molecular contaminations.

2. SPECIFICATIONS / CLEANING PROCESSES

2.1. Specifications

According to past studies on structures for optical satellites (Saverino et al., 2012) and taking into consideration the future perspectives in terms of materials and configurations for flight hardware (space standard ECSS-Q-ST-70-54C), various relevant samples have been selected showing relating applications and the expected specification levels, in terms of particulate and molecular contaminations (see table 1).

Table 1: Materials samples selected for the study

Optical structures concerned	
2 to 3 m size (even larger)	
Materials	**Examples**
Ceramics	Mirror and structure
Carbon/Carbon	Shell structure
Zerodur glass	Mirror and structure
Alodine Aluminium	Fittings, inserts
Kapton	Multi Layer Insulation = MLI
Overshielding braids, strands	Cables
Optical Solar Reflector = OSR	Thermo-optical elements
Expected specification levels	
Particles	< 50 ppm
Molecular contamination	$< 5.10^{-8}$ g/cm²

2.2 Selection of the cleaning processes for the study

In the framework of this study, decontamination assessments have been realized on 10 test pieces representative of the materials concerned (see figure 1).

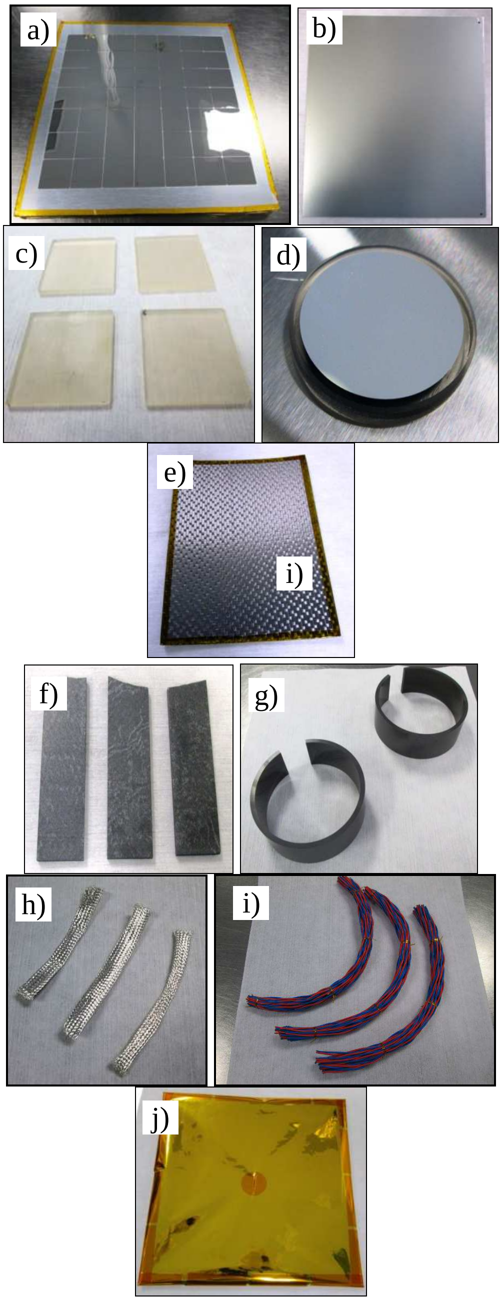

Fig. 1. Test pieces chosen for the tests : a) OSR panel ; b) Alodine aluminum plate ; c) Zerodur plates ; d) coated Zerodur ; e) Carbon-Carbon (C-C) plate ; f) silicon carbide (CeSiC) blades ; g) silicon nitride (Si_3N_4) rings ; h) Forissier braids ; i) strands ; j) MLI sheet

Considering the various state-of-the-art cleaning processes currently used in the industry, three techniques potentially applicable to large structures have been selected for the study, in order to evaluate their efficacy in terms of particulate and/or molecular decontamination.

a) Cleaning via contact with an adhesive polymer

The cleaning process consists in applying an adhesive polymer directly onto the surface to clean (see example of application in figure 2). Regarding its properties, that specific polymer delivers electrostatic forces enabling to remove the particles present on the surface. Easy to use, the process is essentially adapted to flat surfaces. However, as the operation is manual, its reproducibility is quite low. The targeted contaminants are mainly particles, and an automation of the method is poorly feasible.

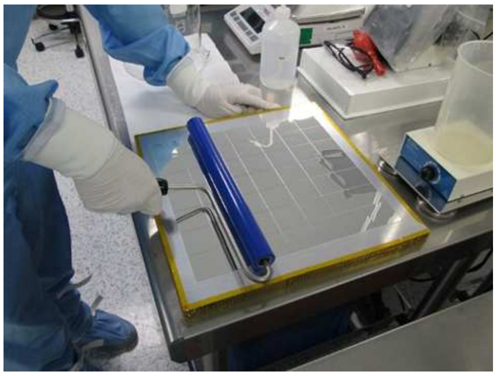

Fig.2. Example of decontamination via polymer contact

b) Cleaning via CO_2 spray

The cleaning method via CO_2 spray (also called CO_2 blasting) consists in a projection of CO_2 pellets at a temperature of – 80°C under high pressure, on the part to be cleaned. By sublimation effect, the pellets are directly transformed in gaseous phase at the impact on the surface. The main targeted pollutants are particulate and molecular contaminations. In addition, that technique is particularly effective to remove oily organic residues and as deburring process (see example of application in figure 3). One of the major advantages of that method lies in the fact that it is a dry process, and it can be used as mobile application under some specific conditions. Another positive asset is the possibility to automate the process thanks to a robot arm, enabling more repeatability of the cleaning results. However, the main consumables are the pellets of solid CO_2 that need to be managed in terms of supply and storage. The generation of gaseous CO_2 requires a dedicated attention to control the ambient air of the working room, in order to avoid any risk of gas suffocation. When the operation is manual (not automated), the reproducibility may be low. Finally, that technique is not well adapted to soft materials, as potentially damaging.

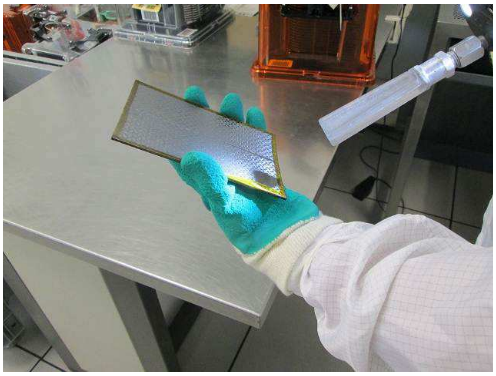

Fig.3. Example of decontamination via CO_2 spray

c) Cleaning via atmospheric ultrasonics

The decontamination via atmospheric ultrasonics is an innovative technique combining the generation of cavitation by air pressure through a specific nozzle, coupled with a vacuum system. Initially adapted to clean rolls of films, that technique enabled to remove particulate contamination is also compatible to flat surfaces other than films. It can also be applied to irregular surfaces by using a specific nozzle-type cleaning head (see example of application in figure 4).

It appears to be a dry process, adapted to most of materials. It can be used as mobile version, depending on the working space conditions. The main drawbacks of that decontamination method are the requirement to respect the distance between the cleaning head and the surface to clean, and the low reproducibility due to manual operation.

Fig.4. Example of decontamination via atmospheric ultrasonics

3. METHODOLOGY AND ASSOCIATED ANALYTICAL TECHNIQUES

3.1. Methodology

In order to evaluate the decontamination efficacy of the tested processes, an intentional pollution of the test pieces was realized according to the type of contaminant, followed by the application of the selected cleaning techniques. The measurement of the residual contamination after treatment, compared to the initial contamination of the test piece, defines then the removal ratio of each method.

3.2. Analysis of particulate contamination

The extraction protocol for particulate contamination is performed via aqueous immersion or spray of the part to control, as presented in figure 5. The extraction solution is then filtered on a membrane, by using a vacuum ramp or a filtration flask. The membrane is dried, and placed under translucent film in order to be digitized via a high resolution scanner. The resulting image is then analyzed via an automatic counting software, in order to have a complete overview of all the particles recovered on the membrane, and enabling the amount of particles according to their sizes.

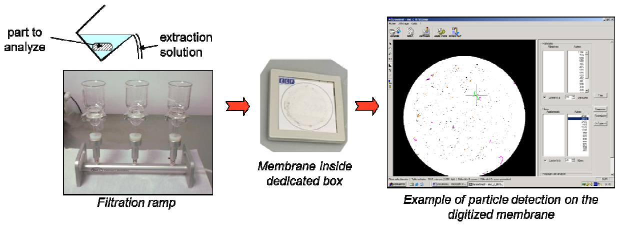

Fig.5. Protocol for the extraction and analysis of particulate contamination

3.3. Analysis of molecular contamination

As the contaminants to detect are of organic nature, the Gas Chromatography coupled with Mass Spectrometry (GC/MS) technique was chosen for the identification and quantification of the various molecular compounds. The extraction protocol is performed via leaching or swabbing of the part, by using an appropriate solvent. That solvent is then sampled and directly analyzed via GCMS (see figure 6).

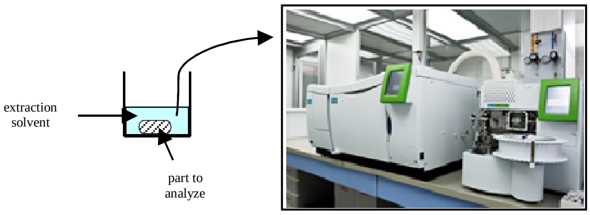

Fig.6. Protocol for the extraction of molecular contamination and analysis via GC/MS

4. RESULTS

4.1. Results from the particulate decontamination tests

The table 2 summarizes the best efficacy values of the particulate contamination treatments, obtained from the various tests realized on the test pieces selected for the study, according to the type of process applied.

Table 2: Synthesis of particle decontamination efficacies of the three processes tested, according to the type of sample

	Type of sample	Contact polymer	CO_2 spray	Atmospheric ultrasonics
PARTICLE TESTS	OSR panel	76%	-	-
	Alodine aluminium plaque	89%	-	-
	Zerodur	-	95%	87%
	Coated Zerodur (mirror)	-	45%	70%
	Cesic blades	-	93%	98%
	Si_3N_4 rings	-	97%	44%
	Cable (Forissier braid)	-	97%	84%
	Cable (strand)	-	97%	96%
	MLI sheet	92%	-	96%
	C-C plaque	93%	-	81%
	Average	**88%**	**87%**	**82%**

The cleaning process via contact polymer gave very positive results of decontamination (between 76 and 93%), but stays limited to flat surfaces. In addition, the application on materials such as MLI can induce some adverse folds, leading to potential damage of the surface.
For the CO_2 spray process, very good efficacy results have been reached in terms of particulate decontamination (between 93 and 97%), except for the coated Zerodur samples (only 45%), as we noticed a degradation of a part of the mirror. Besides, a special care should be taken when using that process on sensitive parts, due to the fact that an alteration of more or less “soft” materials has been observed during the treatment.

The process via atmospheric ultrasonics has also led to good results regarding particulate decontamination (between 70 and 98%), except for the Si_3N_4 ceramic rings (only 44%), as the treatment was not optimal on the internal parts of the rings, due to a difficult access of the nozzle.
In terms of comparison between processes on the same type of sample, a slight advantage can be given to the CO_2 spray compared to atmospheric ultrasonics on most of common samples, except for the Cesic ceramics on which the atmospheric ultrasonics were more effective. In addition, the process via atmospheric ultrasonics has shown a better efficacy on the MLI sheets, which was not the case on the C-C plates.

4.2. Results from the molecular decontamination tests

Regarding the molecular decontamination, only the CO_2 spray process has been tested on the polluted samples. An intentional contamination protocol has been performed by using typical organic compounds (silicone, hydrocarbon, esters), but the conditions were not optimum in terms of concentrations. However, we succeeded in quantifying the efficacy of the CO_2 spray treatment by comparing the final and initial levels of the witness samples (see table 3).

Table 3: Synthesis of molecular decontamination efficacies of the CO_2 spray process according to the type of sample

	Type of sample	CO_2 spray
MOLECULAR TESTS	Zerodur	95-100%
	Coated Zerodur (mirror)	100%
	Si_3N_4 rings	98-100%
	Cable (Forissier braid)	98-100%
	Cable (strand)	48-93%

From all the samples tested, the molecular decontamination ratio ranged from 95 to 100%, except for the strands cables where the removal efficacy was ranging from 48 to 93%, according to the organic compound.

5. CONCLUSION

In the framework of this study, a few potential cleaning processes addressed to large structures for space parts have been identified and evaluated. The main purpose was to substitute the existing techniques, such as wiping with a solvent or the combination of ionizing air blowing with vacuum. According to the various assessments performed on representative small size samples, we succeeded in evaluating the cleaning efficacy of the tested processes, and showed that such cleaning techniques could be more powerful for some materials types.

Among the decontamination techniques used, the cleaning process via contact polymer appeared to be well adapted to flat geometry parts, such as OSR panels or Alodine aluminum plates. In addition, we had the opportunity to check that the adhesive polymer did not leave any trace amount of organic compounds after treatment.

We also noticed that the cleaning via atmospheric ultrasonics is a promising process that can be applied to the decontamination of large structures, since that technique showed a great cleaning efficacy with very few used consumables. However, the process showed some limits on parts having a complex design with hard-to-reach surfaces, due to constraints linked to the configuration of application.

Finally, very interesting results were obtained with the process via CO_2 spray on most of the samples tested, in terms of particulate or molecular contamination. However, the set-up of such process appears to be tricky if applied on large size parts, due to a non-negligible use of consumables and a significant volume of gaseous CO_2 released during the treatment.

As a further perspective of this study, it will be convenient to check and confirm those results on real size parts, in order to evaluate if a transfer of those cleaning techniques can be applied at a big scale. In terms of industrialization of the current processes, several automation possibilities (xyz table, robot arm) as well as the required adapted accessories will have to be investigated, in order to enhance the cost-effectiveness while keeping the performance.

6. REFERENCES

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