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2. Abstract

Paint removal is required in many different industries as aircraft-, marine-, railway- and automotive industries for repair during production line and during the service life of the products. The project "New techniques for paint removal" primarily concentrating on aircraft industry revealed the enormous potential of laser and plasma- etching techniques in order to substitute the available methods of paint stripping which are based on hazardous chemicals.

Basic experiments lead to the main laser and plasma etching parameters and the mechanisms which contribute to the ablation of highly resistant aircraft paintings. The optimum processing conditions for the different processes have been determined for application on different paint types and subtasks.The experiments were accompanied by analysis of the stripped surfaces. The key points considering the results of the applied paint stripping techniques were surface analysis and investigations of the mechanical behaviour.

Techniques for online process monitoring and -control have been developed and successfully implemented in the laboratory equipment.

The analysis of gaseous and solid waste materials evolving from the paint removal processes have been studied and identified. The studies lead to waste disposal concepts which can directly be transfered to real industrial application.

The process parameters were the initial point for a beam handling simulation. The dedicated software for simulation and off-line programming of laser paint stripping techniques has been developed. The obtained universal tool is not restricted to the demonstrator which could be realized containing the results of the parameter and process control investigations.

The simulation software states an effective tool for rapid deployment of laser paint stripping to industrial application.

The results of the performed investigations lead to an extensive study of upscaling containing technical and economical aspects as preparation and evaluation for industrial use.

3. Introduction

Every 5 to 8 years the paint of an aircraft has to be removed. Common aircraft paint strippers contain dichloromethane and phenol suspected carcinogens and are besides this very labor intensive. It takes 2,5 tons of the stripping agent to depaint an Airbus A300 and the waste disposal costs are 4 to 5 times higher than the jcosts for the stripping agents.

Besides the chemical stripping abrasive procedures (dry media blasting, aqua stripping) are applied. However, both groups are affected with individual problems such as economical disadvantages, environmental contamination or technical restriciton. Methods established up to now cannot solve all the problems because there are new substrate materials and further developed paint systems. For example the available methods are not applicable for fiber reinforced composites which are more and more common structure material not only in the aircraft industry. In case of reinforced composites, chemical strippers don’ t differ between paint resin and composite resin. Plastic and sand blating is far to severe for such substrates.

In other cases, where chemical methods do work, the environmental *regulations* (prohibition of CFC) and toxitiy of the material will not give the permission of application for the near future. Methylene chloride, phenols and chromate ions are severely restricted because of toxity and environmental contamination and “blast” removal of many of the older paints exposes workers to lead, cadmium and chromate containing dusts.

These facts lead to the necessity of developing new techniques for paint removal. The techniques of interest in this case laser paint stripping and plasma etching, result in a 90% reduction in toxic waste and disposal costs. The features of demanding no preparation before and no subsequent treatment after application and the high degree of automation promise the possibility of increasing the capabilities of competition against the international market in the field of aircraft maintenance.

The techniques are transferable to all branches of industry where paint stripping is necessary, because sensitive materials and highly chemical resistant paint systems are included in the investigations,

4. Technical description

The main objective of the project was to develop a reliable and environmentally safe paint removal method, for the chemical resistant aircraft paint schemes, which doesn` t affect the base materials negatively. By developing a process with a high degree of automation beside the environmental aspect, 50% of cost reduction compared to exisiting paint removal techniques has been aspired. The labor-consuming preparation and subsequent treatment of the surface before and after stripping will be omitted which represents a considerable contribution to the economy of laser paint stripping. The potential of automation will also make it possible to adapt the process to a lot of requirements for different industrial applications, To reach this goal the research has been focused on:

- basic research on stripping mechanisms of different laser types (CO_2, Nd:YAG, Excimer) and plasma etching.
- laser stripping and plasma etching or cleaning of painted metal and composite surfaces in order to provide a homogeneous, decontaminated surface with good adhesion properties for repainting.
- test and characterization of the interface properties (strippability, adhesion, repaintability, intermediate storage time e.g.).
- adaption of power and beam quality of industrially used excimer laser and mini TEA laser to the stripping process requirements.
- new beam shaping methods to approximate a homogeneous energy density of the focused laser radiation and adaption of beam transport systems to the process.
- integration of optical sensor systems to control the process.
- workcell design, programming and simulation of aircraft component stripping by a robot simulation program, to add derivation of the requirement imposed by the stripping process on the robot performance.
- simulation of overall process, operating with industrial robot integrating the end effecter with a laser, sensors and waste disposal device.

- optimizing the plasma etching parameters with respect to the treatment of thick and stuffed plastic materials.

- adaption of a plasma etching system for treating aerospace components with good stripping, repainting and repairing behaviour.

- basic research on waste products and waste disposal.

In order to achieve the results which are summarized in chapter 5 several interactions between the different subtasks were necessary. The following flow diagram gives an overview about the main items.

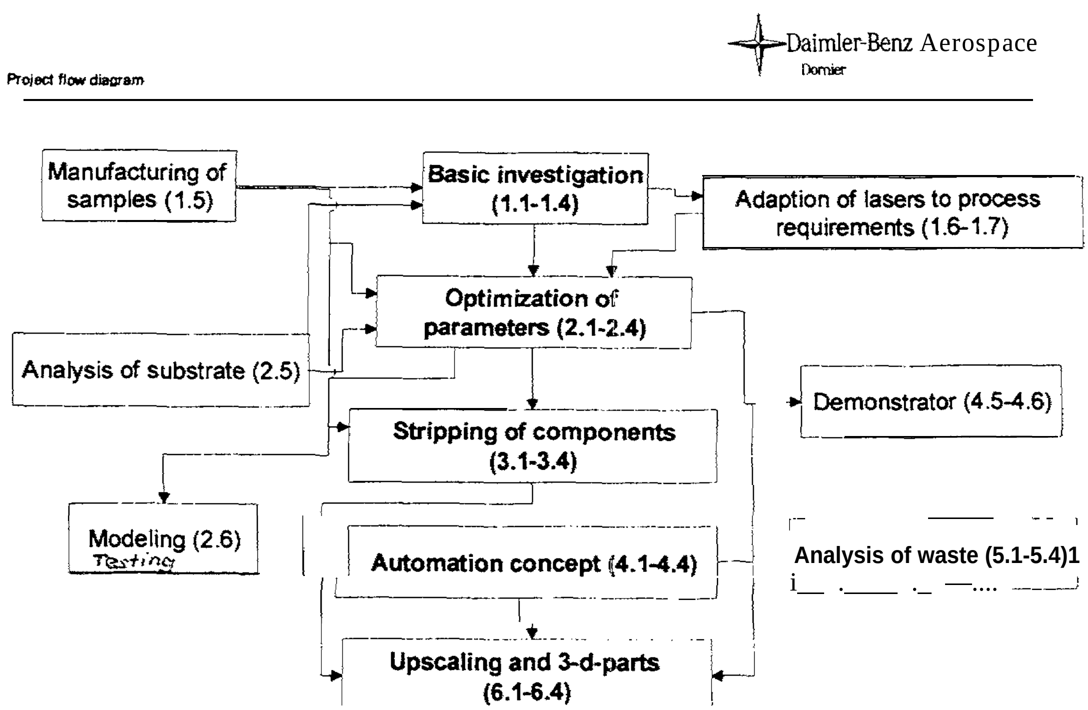

Fig. 4-1: *Project flow diagram*

5. Results

The different processes developed and investigated within the project can be devided into the two groups: laser paint stripping and plasma etching which are not directly comparable.

The lasers applied cover the wide band of the electromagnetic spectrum from UV to IR-radiation. However, they reveal similar ablation behaviour dominated by a combustion process. The mean ablation per pulse is the main differing parameter due to absorption and pulse duration characteristics. The analysis of ablation rates show further that the Nd:YAG laser with the radiation of 1,06 μm wavelength leads to a dependency on the colors of the paint which could not be observed for the excimer and CO_2 lasers.

The plasma etch process shows a benefit which can not be achieved by the laser process. It is the independency from the geometry of the substrate in a wide range.

On the other hand laser paint stripping is able to be applied for large surfaces because there is no necessity of having a vacuum chamber.

Surface analysis results show that it is possible to consider the stripping of a whole aircraft structure by laser.

In each case of couple paint/substrate, at least one laser type is suitable to give good stripping results. Substrates based on metal alloys without non conducting conversion layers is not as critical to strip as composite materials, due to its high reflectivity especially for R-radiation (10,6 pm). Reinforced plastics reveal a critical behaviour because of the resin matrix of the substrate which is similar to the paint resin. Considering each laser type, excimer laser appears to be convenient with all kind of substrates followed by TEA-CO_2 laser and then Nd: YAG-laser. For all cases it has been shown that paint stripping should be performed down to the primer. Any risk of substrate degradation can be prevented in this case.

The mechanical investigation focused on the sensitivity of the material characteristics on the stripping parameters. The results of the tests showed that the mechanical characteristics of the composite materials are decreased; the degradation depends on the stripping process. As no damages in form of fiber damage - when applying the optimized paramters - are accumulated due to laser radiation it is believed that photo thermal attack occurs during the stripping process. The influence of the stripping process on the mechanical characteristics of the AA

2024 is impressive. The ductility and the fracture toughness of the substrate are generally decreased. The fatigue behaviour is significantly improved after stripping.

The improvement in fatigue life reaches high values for the selected base material and depends on the stripping process.

The laser stripping process has a potential for industrial application as a novel technique for paint removal. However, one should extend quality control evaluation to aspects other than those required by conventional regulations.

The considerations lead to say that on line monitoring is necessary to realize careful treatment of all kind of material.

From the studies carried out during the project it became obvious that there is no universal technique for the on-line monitoring and control of the paint stripping process. The plasma analysis and the short time photography of the plasma formation distinguish the next layer down (i.e. primer or substrate) after this layer is ablated by one laser pulse. These techniques cannot be applied when paint stripping down to the substrate is required.) For shock wave measurement as monitoring device additional research (beyond the context of this project) is necessary in order to determine what happens close to the transition from one layer to another. The plasma analysis is a technique which does not depend on the paint system since a chemical difference between top coat and primer is always given. This feature is similar to the one to observe when applying difference reflectometry. However, there are a few cases where the reflectivity of adjacent layers is almost the same. Plasma analysis, short time photography and shock wave measurement can be applied for short pulsed laser sources.

The combination of two techniques may give the best results.

Beside the monitoring of the ablation quality waste analysis plays an important role for qualification of such a new technique for paint removal. TOF- and LIBS-measurements show that the fragments produced during the laser ablation are basically small fractions of the macromolecular chains of the paint polymer, small inorganic compounds or atoms that come from inorganic additives in the paint system and in some cases, organic monomers (100 -1000 a.m.u.) that the large polymer molecules consist of. The LIBS spectra at average energy densities confirm the production of small organic radicals - diatomics - while at high energy fluence the atomic lines predominate owing to high sensitivity of LIBS in the detection of many elements. The gases analyzed using an infrared spectrometer could be identified as H_2O, CO_2,

NO_2, different aromates, benzene and toluene. The investigations of the solid particles generated during the laser paint stripping process were Ti, Zn, Cr, Cr and Ba with some potential risk for the employees and the environment. These results lead to the necessity of applying an exhaust system. Filters can be used for the partical size distribution (0,5µm). Due to the variety of gaseous components there is no general solution for the gas filtration. The investigations considering the amount of waste revealed that the disposal and the treatment don' t put the new technique applying lasers into questions. The results confirm the environmental benefit obtained by substitution of the chemical paint stripping.

The plasma etching process is not causing a high amount of waste as well. Hazardous substances like solvents are not used and the stripping residues are not particles but gases, As the process is performed in a closed system the safety requirements are comparably low.

The realization of a demonstrator covering the subjects process parameters, monitoring and robotics (atomization) under the application of different types of lasers lead to a complete paint stripping system containing the input of the first results on laser paint stripping which were achieved during the first half of the project. The distance sensor (Seampilot), ablation sensor (diffref.), Slave PC and Master PC have been integrated through several ways of communication.

Based on feasibility studies three different technical attachments have been investigated.

concept 1: stacker crane

concept 2: maintenance platforms

concept 3: floor-bounded platforms

The concepts contain filly automatic paint stripping plants.

Concept 1 and 2 are suitable realizations of the paint removal plant with regard to the economical aspects. A technical evaluation lead to concept 2 as the best solution, The advantages of this concept are:

* The applied platform is an industrial well proven component
* Common maintenance hangars are already equipped with these platforms
* The platforms can also be used for manual maintenance and other tasks
* The power supply and connectors for process air are integrated into the platform

Summarized it can be stated that the project „New Techniques for Paint Removal" revealed the enormous potential of the technologies (laser paint stripping and plasma etching) as a transfer preparation into the industrial market and applications although some additonal basic research is necessary in order to achieve the required reliabilities.

6. Conclusions

Although the main aim of the project was to develop replacements for the conventional chemical methods for paint stripping of aircrafts and aircraft components, there is a large number of potential other direct and indirect applications. This can easily be revealed by a functional analysis of the project. The basic investigation work demonstrated that all of the lasers used in the program as well as the plasma etching technique are fully suitable tools for paint removal. It therefore can easily be anticipated that the one or the other of these techniques may find its application not only in aircraft maintenance industry, but also for example in railcar maintenance, in restoration of historical objects, cars in spot repair in the paint shops of car manufactures, in removal of damaged fictional coatings, e.g. teflon coatings before replacement, in removal of "graffiti" from buildings etc.. Depending on the stripping job, each technique will have its specific advantages and disadvantages. For example, the very sensitive and easily controlled removal with the Excimer-laser would be a meaningful choice for spot repair on cars. Contrary, the powerful, but also somewhat "coarse" stripping with the cw-CO_2-laser may be prefered for stripping of complete railcars. Geometrical complex, smaller parts are ideal candidates for the plasma stripping process.

The on line-monitoring techniques developed in this project are very promising. They are suitable instruments not only for optimizing the material processing quality, but also for optimizing the process rate and thus the overall treatment efficiency. At least for aircraft application, it probably can be stated at this time that their availability will be a necessary prerequisite for industrial application. But also for other paint stripping applications, it can easily be foreseen that they will be part of any laser paint stripper - if not for processing quality, then for processing speed reasons (i.e. to adapt the process parameters to varying paint thicknesses and/or removal rates). Furthermore, most of the techniques under investigation have an additional potential to be used for other material treatments, e.g. micromachining of polymers and ceramics, cladding of metall alloys etc. The work on waste analysis and disposal is very important for the industrial realization of the new paint stripping techniques. Again it can be stated that its application will not be confined to aircraft maintenance, but will be as well necessary for any other “spin off” applications of the new stripping techniques. Moreover, many of the results can be of use for other techniques.

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8. References

Type of report	Reference period	Reference document no.
1st 6-monthly progress report	March 1st 1993 to August 31 st 1993	Do-Luft SY 21 -249/93
1st 12 monthly technical progress report	March 1st 1993 to February 28th 1994	Do-Luft LREK1 5-68/94
Mid term assessment report (technical annex), incl. 2nd 6-monthly progress report	March 1st 1993 to August 31st 1994	Do-Luft LREK1 5-214t94
Mid term assessment report		Do-Luft LREK15-289/94
2nd 12 monthly technical progress report	March 1st 1994 to February 26th 1995	Do-Luft LREK 15-17/95
3rd 6-monthly technical progress report	March 1st 1995 to August 31st 1995	Do-Luft LREK 15-32/95