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Hibridno obstreljevanje s suhim ledom in laserjem

Hybrid Dry-Ice Blasting Laser Processing: Nd-YAG-Laser-assisted Dry-Ice Blasting for De-Coating

Eckart Uhlmann - Robert Hollan - Adil El Mernissi
(Technical University of Berlin, Germany)

V primeru visoko vrednih surovih materialov ali visokih obratovalnih stroškov se splača reciklirati izdelek, saj tako prihranimo denar in razpoložljiva sredstva. Recikliranje po navadi zahteva čiščenje oziroma odstranjevanje barve. Največkrat se za to uporabljajo običajni čistilni postopki. Obstreljevanje s suhim ledom in lasersko procesiranje sta dve naravno sprejemljivi alternativni tehniki čiščenja. Kljub vsemu imata tudi ti dve svoje tehnološke omejitve.

Obstreljevanje s suhim ledom temelji na mehanskem, toplotnem in sublimacijskem mehanizmu, ki omogoča mehko delaminacijo, čiščenje in predpripravo brez poškodb obdelovanca. Laserski postopek pa ponuja možnost definiranega odstranjevanja prevlek in obdelavo površin samega obdelovanca. Obe tehnologiji ne povečujeta odpadkov. Zelo vezivni in trdi zaščitni sloji se zelo težko odstranijo z uporabo obstreljevanja s suhim ledom. Laserskemu postopku pa delajo preglavice debele prevleke.

Da bi povečali njun učinek, jih združimo in izvedemo hibridni postopek. Odvzem materiala se je pri obstreljevanju s suhim ledom v hibridni kombinaciji z laserskim postopkom izkazal bolj učinkovit kar za 49 odstotkov. Rezultati kažejo, da je treba pazljivo načrtovati obratovalne razmere. Le v takem primeru je hibridna tehnologija konkurenčna običajnim čistilnim tehnologijam.

(Ključne besede: obstreljevanje, suhi led, procesiranje lasersko, čiščenje, postopki hibridni)

In the case of high-value raw materials or high manufacturing costs, the recycling of products is reasonable because it helps to save money and resources. However, recycling usually makes a cleaning or de-coating process necessary. Normally, these processes are based on conventional cleaning and de-coating methods. Dry-ice blasting and laser processing are two environmentally friendly alternatives that have different advantages over the conventional methods. However, both have technological and economic limitations.

The effect of dry-ice blasting is based upon a mechanical, a thermal and a sublimation mechanism that allow a soft de-lamination, cleaning and pre-treatment while the workpiece remains undamaged. Laser processing offers the possibility of a defined removal of the coating/contamination and a treatment of the surface of the workpiece itself. Both technologies do not increase the amount of waste. Strongly adhering or hard contaminations and protective or functional coatings are difficult to remove with dry-ice blasting, while laser processing is unsuitable for removing thick coatings or contaminations. The combination of both technologies offers different strategies for machining. On the one hand the laser can be applied in de-focused mode for heating up the surface of the workpiece, thereby increasing the thermal mechanism of dry-ice blasting. On the other hand a focused laser application makes a defined surface structuring or smoothing possible. In addition, both methods can be applied at the same focal point.

In order to measure the area-related cleaning efficiency a PUR-2 component varnish-substrate combination was chosen as a standard among the multitude of materials, coatings and contaminations available. The material removal rate achievable with dry-ice blasting was increased using the hybrid technology by up to 49%. The results show that an individual optimization of the parameters for the application is a pre-condition. Only then is the hybrid technology competitive in relation to conventional cleaning technologies.

(Keywords: dry ice blasting, laser processing, cleaning, de-coating, hybrid systems)

0 INTRODUCTION

In the case of high-value raw materials or high costs for manufacturing the recycling of products is reasonable. This implies, as well as used products, faulty coatings of products within the manufacturing process. Recycling saves money and resources. Therefore, it is economically and ecologically favourable. Usually for recycling a cleaning or also a decoating process is necessary, using mechanical, chemical or aqueous methods. But these conventional technologies are often time and energy consuming. Furthermore, they involve high costs for waste disposal and personnel, while offering only low flexibility [1]. Dry-ice blasting and laser processing are two environmentally friendly alternatives to these conventional technologies [2]. With regard to special cases of applications and to the economic point of view, both technologies have their respective limits.

The objective of hybrid dry-ice-blasting laser processing is to increase the area-related cleaning and de-coating ratio. The combination of both technologies will expand their economic and technological limits. An easily replicable substrate-varnish combination was chosen from the variety of materials, coatings and contaminations. With this standard substrate-varnish combination the process parameters of each stand-alone technology have been optimized. Thereafter, the results of these investigations were compared with the results of the hybrid experiments.

1 APPLIED CLEANING TECHNOLOGIES

1.1 Dry-Ice Blasting

Dry-ice blasting is a blasting technology that uses solid carbon dioxide – so-called dry ice – as a one-way blasting medium. The pressurized (57 bar) liquid carbon dioxide is expanded quickly to atmospheric pressure. Because of the Joule-Thomson effect it is cooled down to -78.5° C and solid carbon-dioxide snow is generated. A hydraulic stamp presses the carbon dioxide snow through the conical holes of a mould and finally forms the cylindrical dry-ice pellets. The pellet parameters (density, hardness, shape) are influenced by the conditions during their production (i.e., degree of compaction). For the blasting process the dry-ice pellets are injected into the blasting air stream by a dosing device and are then accelerated.

Dry-ice blasting is based on a mechanical, a thermal and a sublimation mechanism. The temperature of -78.5° C of the dry-ice pellets leads to a local cooling down at the point where the dry-ice particles hit the surface. Due to this, elasticity is lost and the coating embrittles and shrinks. Different thermal expansion coefficients of the substrate and the coating produce cracks in the coating. The kinetic energy of the particles and the air stream contribute to the removal. The sublimation of the dry ice leads to a sudden increase in volume by a factor of 700, which supports the process [3]. When the adhesive energy is exceeded by this combined thermo-mechanical effect the coating chips off [2].

A fundamental advantage of dry-ice blasting is that there are no residues left due to the sublimation of the dry ice. While other cleaning processes require complex processing or increased disposal costs, no media remains in the structure of the workpiece (i.e., boreholes and cavities) [2]. No special cleaning equipment is needed for the exhausted air due to the non-toxic blasting medium, carbon dioxide. Except for the removed coating-particles, which might have to be filtered off. Because of the non-corrosive and non-abrasive behaviour no post-treatment is needed for the workpiece. Dry-ice blasting allows a flexible soft de-lamination and cleaning, even of sensitive or structured surfaces. Contaminations and protective films (i.e., the paint of metal components) can be removed by dry-ice blasting. Strongly adhering or hard contaminations and protective or functional coatings are difficult to remove. The complete removal of rust using dry-ice blasting is, e.g., impossible.

1.2 Laser Processing

Laser processing has become a field of increasing significance in recent years. Surfaces can be cleaned, structured or modified flexibly and precisely by laser processing due to specific parameters. The controlled application of energy allows a melting or sublimating of the surface material, depending on the composition and thickness of the contamination or coating, as well as on the parameters of the laser process. Further fields of application are the removal of paint from metal components (i.e., exchange engines) [4], the removal of scale from welding seams [5], as well as the cleaning of railroads, memorials and pylons.

Cleaning and de-coating with laser processing offers significant advantages. It combines contact- and force-free processing of high precision with a low thermal and mechanical influence that can be applied to sensitive surfaces. By offering a selective cleaning, the depth of removal of consistent material is easy to control. Therefore, a high degree of automation, especially an online control, is possible. The removal of thick contaminations and coatings are the economic, and sometimes even the technological limits of the application. The more abrasive the parameters of laser processing are, the higher is the risk of damaging the surface of the substrate below an inconsistent coating or contamination.

1.3 Hybrid Dry-Ice-Blasting Laser Processing

The combination of both technologies offers different strategies for machining. While the laser can be applied de-focused for heating up the surface, a focused laser application enables a defined processing of the surface. The de-focused laser prevents a cooling down of the workpiece. The higher temperature increases the thermal shock when the dry-ice particles hit the surface and the efficiency is improved. Therefore, the wavelength has to be chosen according to the absorptance of the surface of the substrate. A focused laser application enables a defined surface structuring or smoothing of the workpiece. Thus, a preliminary purification by dry-ice blasting can be followed by a final laser-processing cleaning step. It, furthermore, makes it possible to combine the cleaning process with a potential following pre-treatment process (i.e., to realize a defined roughness). Both technologies can be applied at the same focal point or at different focal points. Two different focal points allows a repeatable quick change of separate processing by each single technology while using the same focal point for both technology is easier to realize.

2 EXPERIMENTAL SETUP

An easy-to-replicate standard was used to analyze the removal of highly adhesive coatings from incorrectly coated workpieces within the manufacturing process or the removal of partly remaining coatings from used products. A coating of PUR-2 component varnish with a thickness of 100 μm and 200 μm was defined as the standard and applied in two layers, one white primer and a black finishing varnish. The plates of hot-dip galvanized steal with dimensions of 150 mm x 50 mm were used as a substrate.

For dry-ice blasting the Artimpex device “Cryonomic Cab 52” was used. This device is based on the injection principle. For laser processing the “Sv10” of Bauer & Mück GmbH, Berlin was used. The Nd:YAG laser has a wavelength of 1064 nm, a cw output of 100 W in multi-mode and 18 W in basic mode. The laser beam was focused by a 1D scanner, which was moved by a robot together with the dry-ice blasting nozzle.

To measure the removal rate the surface profile was detected perpendicular to the movement of the robot. Therefore, the tactile measurement equipment “Talysurf-120L” of Taylor Hobson GmbH, Wiesbaden was used. The cone point of the applied sensing device had a radius of 2 μm and an angle of 60°. The cross-sectional area (CSA) of the removed material was calculated based on the detected profile. For the calculation the software “Talymap Univ. 2.0.10” was used. Compared to a gravimetric measurement the applied method has the advantage of additional information about the material removal perpendicular to the direction of the robot’s movement.

First, the individual technologies were optimized to reach the maximum material removal rate. The blasting pressure, the distance between the blasting nozzle and the surface, the blasting angle and the dry-ice mass flow rate were optimized. For laser processing the focus, the pulse rate, the distance of the single pulses on the surface of the workpiece and the period between the single pulses were varied. A suitable feed rate was chosen by an optical evaluation as well as from the tactile measurement.

3 RESULTS OF EXPERIMENTS

The optimized dry-ice blasting parameters, blasting pressure, blasting angle, dry-ice mass flow rate and blasting distance, were constant. The number of repetitions and the feed rate of the robot were varied for each test. For the shown results the laser pulse rate, the power output of the laser, the distance of the pulses on the surface and the laser feed rate (independent of the dry-ice blasting feed rate) were varied. The applied dry-ice blasting parameters are shown in Table 1; the laser processing parameters are shown in Table 2.

Table 1. *Dry ice blasting parameters*

Dry-Ice Blasting Parameters:	A	B	C	D	E
Number of repetitions of the test	1	2	3	4	6
Feed rate [cm/min.]	3	6	9	12	18
Constant Dry-Ice Blasting Parameters:					
Blasting pressure	12 bar				
Dry-ice mass flow rate	60 kg/h				
Blasting distance	10 mm				
Blasting angle	90°				

Table 2. *Laser processing parameters*

Laser Processing Parameters:	A	B	C	D	E
Pulse rate [kHz]	4	6	5	5	5
Power output [W]	91	91	85	85	85
Pulse distance [µm]	10	20	20	20	20
Feed rate [cm/min.]	20	20	20	50	50

Subsequently, the results for the PUR-2 components varnish standard with a thickness of 200 µm are shown exemplarily. The used standard consisted of a white primer and a black finishing varnish. A comparison of the material removal of single dry-ice blasting and a hybrid-laser-assisted dry-ice blasting is shown in Figure 1. The cross-sectional area (CSA) is used as an indicator.

Figure 1 shows the cross-sectional area (CSA) of the removed material of tests A to E, applying different parameters. The removed material was increased in each test by laser-assisted dry-ice blasting compared to the stand-alone dry-ice blasting. The best improvement of 49 % was obtained in test A, the parameters of test B resulted in the smallest improvement, of 28 %.

4 SUMMARY

Dry-ice blasting and laser processing are ecological alternatives to conventional mechanical, chemical or aqueous cleaning and de-coating methods. However, neither technology is suitable for highly adhesive or hard coatings and contaminations. By combining both technologies the material removal of a defined testing standard was increased up to 49% compared to the optimized stand-alone technology. The optimized parameters of the stand-alone methods are not the ideal parameters of the hybrid combination.

It is planned to optimize the processing strategy of the focused laser application for the hybrid combination of both technologies. Further tests are planned to research the strategy of de-focused laser application to increase the thermal mechanism of dry-ice blasting. Finally, a combination of both strategies will be investigated by applying two lasers of different wavelengths.

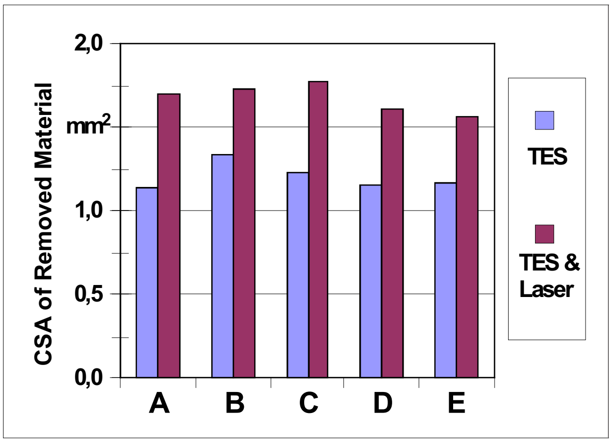

Fig. 1. *Cross-sectional area (CSA) of the removed material by dry-ice blasting and laser-assisted dry-ice blasting*

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Authors' Address: Prof. Dr. Eckart Uhlmann
Robert Hollan
Adeil El Mernissi
Technical University of Berlin
Institute for Machine Tools
and Factory Management
Pascalstr. 8-9
10587 Berlin, Germany

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