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Advancing sustainable and efficient industrial cleaning: CO_2 snow jet blasting for residue-free surface cleaning

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Abstract

Through the increase in importance of environmental consciousness due to legislature and social awareness, efficient though sustainable manufacturing processes are gaining in popularity. CO_2 snow jet blasting is a widely used technology for industrial cleaning and allows for sustainable cleaning in comparison to established traditional methods which often necessitate the use of water, chemicals or abrasive material leading to hazardous waste products. In contrast CO_2 snow jet blasting is a dry and residue-free cleaning process. The presented investigations examine the efficacy of CO_2 snow jet blasting in removing a reference contamination consisting of a mixture of grinding oil and abrasive borcarbide particles from 316L stainless steel and tungsten carbide surfaces. The influence of three process parameters was investigated, stand off distance s, jet angle α and traversing speed v_f. The cleaning performance was evaluated based on residual filmic and particulate contamination.The results show the capability of CO_2 snow jet blasting for industrial cleaning applications by removing of up to 99 % of contaminations.

Keywords: cleaning, CO_2, snow jet blasting, residue-free, sustainable cleaning,

1. Introduction

As a process variant of blasting with solid CO_2, CO_2 snow jet blasting is a dry and residue-free cleaning method. Currently only approximately 6 % of blast cleaning method users utilize CO_2 snow jet blasting, despite it being viewed, by users and suppliers, as a process with clear future potential. Furthermore many blast cleaning applications require a substrate drying process which is considered to be an important technological and economical aspect. This drying step can be entirely circumvented by CO_2 snow jet blasting [1]. During CO_2 snow jet blasting, liquid carbon dioxide is released from a nozzle at high pressure p and room temperature θ. The sudden drop in pressure Δp when exiting the nozzle causes a phase transition in which the liquid CO_2 converts into a mixture of gaseous CO_2 and solid CO_2 snow particles [2]. To increase the cleaning effect the CO_2 snow particles are further accelerated by a pressurised air stream with higher pressures equating to increased cleaning capabilities [3]. Some current cleaning methods necessitate the usage of various chemicals including ecologically harmful ammoniac solutions [4]. By reusing the CO_2 produced as a waste product in the chemical industry for the purpose of a cleaning medium and utilizing the resulting cascade, no new CO_2 is produced [5]. For a more environmentally friendly cleaning process the removal of a mixture of grinding oil and borcarbide abrasive from differing metal surfaces using CO_2 snow jet blasting was tested under experimental conditions. Generally cleanliness results should be evaluated regarding the necessary technical cleanliness of components or assemblies rather than cleaning as clean as possible, in order to reduce resource usage [6]. CO_2 snow jet blasting is often used to clean bonding and functional surfaces. Due to the low abrasiveness of the CO_2 snow particles, it is also suitable for cleaning finely structured and highly sensitive components in microelectronics and optics [7]. This paper presents the initial findings using CO_2 snow jet blasting for the cleaning of a reference contamination of a grinding process from 316L stainless steel and tungsten carbide metal surfaces. The used reference contamination consisted of a mixture of grinding oil and borcarbide particles of the size F320 and F1200. A cobalt bonded tungsten carbide was used within this paper with a cobalt content of w_{CO} = 10 wt. % and a grain size of 0.5 µm ≤ d_K ≤ 0.8 µm. The influences of various process parameters are presented and their implications discussed based on the experimental data.

2. Methodology

Both examined materials were cleaned simultaneously to avoid possible errors and random influences. A consistent and defined movement of the nozzle was achieved by using a robot. The design and analysis of the experiments were done in Minitab.

2.1. Devices and setup

The CO_2 snow jet blasting was carried out using a single two-component concentric nozzle supplied with blasting media by the JetWorker system of the firm acp systems AG, Zimmern ob Rottweil, Germany, mounted to a six-axis robotic arm for routing purposes of the firm KUKA AG, Augsburg, Germany, of the type KR 10 R900-2. For the detection of residual surface contaminations, a fluorescence detector of the firm SITA Messtechnik GmbH, Dresden, Germany, of the type SITA CleanoSpector was used to detect filmic residues. Furthermore, a grazing light system of the firm PMT Partikel Messtechnik GmbH, Heimsheim, Germany, of the type PartSense 2.0 was used to detect particles left over after the cleaning process. The cleanliness of the substrate is classified based on two variables: the removed filmic contamination f_r and the removed particles p_r. The removed filmic contamination f_r is given in comparison to samples cleaned in an ethanol ultrasonic bath. The removed particles p_r are calculated in relation to the initial contaminated state. On average the contaminated samples showed a Component Cleanliness Code (CCC) according to ISO 16232 of A(B18/C18/D19/E16/F11/G9/H10/I9/J9) for stainless steel and A(B19/C19/D19/E15/F12/G11/H12/I10/J9) for tungsten carbide before cleaning.

2.2. Design of experiments

To achieve an efficient cleaning process, multiple process parameters were held constant, including air pressure p, capillary diameter d_k, and path spacing a. The air pressure p and capillary diameter d_k were set to the corresponding maximum settings to achieve a strong cleaning effect, increasing both the mechanical and thermal influence of the CO_2 snow jet blasting on the contamination and substrate [2]. The path spacing was set to a = 3.5 mm. The varied process parameters include the nozzles stand off distance s, the jet angle α and the traversing speed v_f. The process parameters and routing of the cleaning nozzle are shown in figure 1. Based on the different settings, a full factorial design was created encompassing a total of 18 runs for each material. The experiments were repeated 2 times leading to 108 runs.

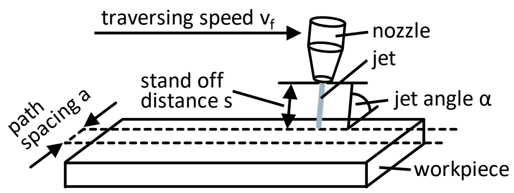

Figure 1. Experimental setup and procedure

3. Results and discussion

Figure 2 shows the removed filmic contamination f_r in correlation with the jet angle α. The results indicate a significant increase in cleanliness by up to 10 % through adjustment of the jet angle from α = 90° to α = 45°. It is important to note that the jet angle is not tilted along the path, pushing contamination ahead but rather perpendicular to the path line, as displayed in figure 1. The disparities in results between carbide and stainless steel might be due to differing surface structures or adhesion capabilities of the substrate.

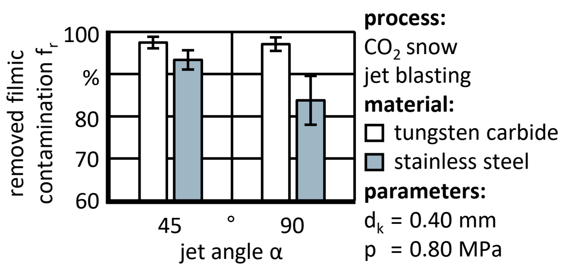

Figure 2. Results of the removed filmic contamination f_r in correlation with the jet angle α

Figure 3 shows the removed filmic contamination f_r corresponding to the the stand off distance s. A matching correlation between the filmic contamination f_r and the stand off distance s is not apparent for the investigated materials.

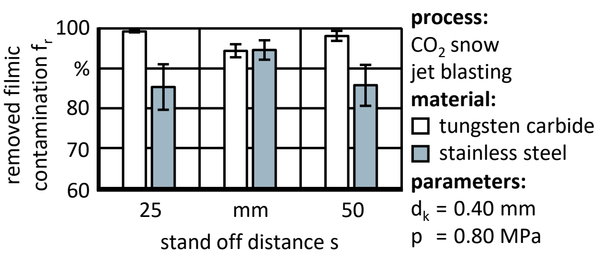

Figure 3. Results of the removed filmic contamination f_r in correlation with the stand off distance s

Figure 3 shows a convex curve of the removed filmic contamination f_r over the stand off distance s for carbide and a concave curve for stainless steel. The correlation between the removed particles p_r and the traversing speed v_f, shown in figure 4, indicates an increase in cleaning capabilities through decreasing the traversing speed v_f. Lower traversing speeds v_f equate to extended exposure durations of substrate and contamination to the CO_2 snow jet. While the averaged measured data between maximal and minimal settings only varies by approximately 2 % a trend is observable. Through increasing the step size between settings of the traversing speed v_f larger influences should become apparent.

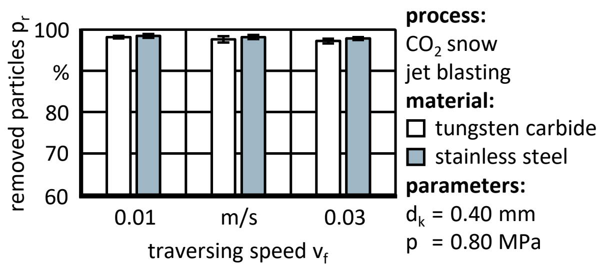

Figure 4. Results of the removed particulate contamination p_r in correlation with the traversing speed v_f

4. Conclusion

For all parameter combinations, 83 % - 99 % of filmic and particulate contaminants were removed. When only considering the parameter combinations with v_f = 0.01 m/s and α = 45° an averaged CCC for particulate contaminations according to ISO 16232 of CCC = A(B14/C13/D12/E7) was achieved for stainless steel and CCC = A(B12/C12/D12/E10/F6/G5/H7) for tungsten carbide surfaces. The investigations show that CO_2 snow jet blasting is suitable for the different material/contaminant combinations, although the process parameters must be adjusted according to the combination. The influence and interaction of contaminant and material need to be analysed in further studies. Many machining processes lead to grease, oil and particulate residues on the substrate surface. This necessitates cleaning steps after machining to not influence further manufacturing steps or the functionality of the final product. For this CO_2 snow jet blasting can be a valid alternative to common chemical cleaning methods, as shown in this paper. The cleaning of other surface level filmic and particulate machining residues should be further investigated, to provide functional alternatives to common, environmentally harmful, cleaning methods.

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