SHOT PEENING WITH DRY ICE

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ABSTRACT

Dry ice blasting is a compressed air process, which uses solid carbon dioxide CO_2 at a temperature of -78.5 °C as a one-way blast medium. The main advantages of dry ice blasting are the sublimation of the blast medium – there are no residues left to be disposed – and the possibility to machine even sensitive surfaces due to the low abrasiveness of the process. Commonly dry ice blasting is used for cleaning operations or for paint removal.

Recent investigations have shown that despite the low abrasiveness of the process it is possible to use dry ice blasting for shot peening applications. Depending on the material to be machined it is possible to roughen the surface and to insert residual stresses. Both effects may be used for preparation of adherence processes without the disadvantages of other blasting media e. g. doting surfaces with the media.

KEY WORDS

Dry ice, CO_2, surface modification, roughening

INTRODUCTION

Dry ice is the alias for carbon dioxide (CO_2) in its solid state. The name 'dry' is derived from the thermodynamic behavior of CO_2. At a pressure of 1 bar CO_2 has no liquid state, depending on the temperature it is either gaseous or solid or in other words 'dry'. The gas-solid equilibrium at 1 bar exists at a temperature of -78.5° C.

Dry ice is non-toxic, non-combustible, non-electrical conductive and according to German law a non-hazardous substance. The MAC value is 5000 ppm. Compared to other solid blasting and shot peening media the hardness of dry ice of about 2 Mohs is rather low.

For blasting operations the usage of preformed dry ice pellets is most common. The pellet geometry is comparable to rice and the density varies between 1.300 and 1.500 kg/m^3. The dry ice pellets are accelerated by compressed air and – depending on the parameters and nozzle shape – they can reach sonic speed.

On the basis of the thermodynamic characteristics of CO_2 there are three working mechanisms. Due to the high impact velocity there is a mechanical effect. The low temperature of dry ice cools the machined surface locally so that thermal tensions emerge. The third effect is a result of the sublimation when hitting the surface. Because of the sublimation the volume of the CO_2 increases by about 700 times; additionally, the abrupt pressure rise contributes to the process (Spur 1998).

In general dry ice blasting is used for cleaning or coating removal operations. The process has two main advantages which makes it different from other processes with other media. First, due to the sublimation there are no solid residues of the blast medium which have to be disposed of or may pollute the machined surface. Second, due to the low hardness of dry ice and the combination of three working mechanisms it is possible to machine even sensitive surfaces depending on the parameters. For shot peening applications only the first advantage contributes to the process whereas the second, especially the low hardness of the medium, is rather a disadvantage. In the following it is shown that despite the low hardness it is possible to modify surfaces for the preparation of adherence processes. The second part of the paper describes the possibility of inserting residual stresses and increasing the hardness of metals, which is in general the main aim of shot peening.

INFLUENCE OF DRY-ICE BLASTING ON SURFACE ROUGHNESS

Surface roughness and its systematic increase is an important part of industrial surface treatment. One aim of manipulating surface roughness is to increase the materials ability of mechanical adherence. This is important for every application where a welded structure can be replaced by an adherence process, e. g. gluing in the automotive industry. Although dry ice blasting is known as a 'smooth' blasting process it may have a strong influence on the surface characteristics, especially on soft materials, such as aluminum. Nearly all blasting parameters such as pellet mass flow, average pellet diameter, working distance and blasting time (or nozzle feed, respectively) have an influence on surface roughness. It is, however, not always necessary to vary all parameters to reach the result aimed for. Therefore the parameters blasting time and working distance are often varied, since both of them are easy to handle in most cases and surface roughness can be manipulated within a wide range. In figures 1-4 the surface characteristics R_a and R_z of AlMg3 versus blasting time are shown for different *working distances a.*

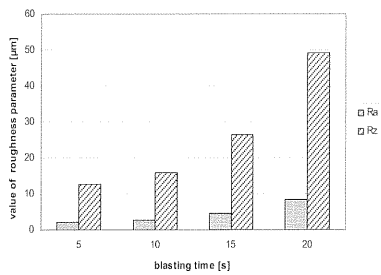

Figure 1: a=60 mm

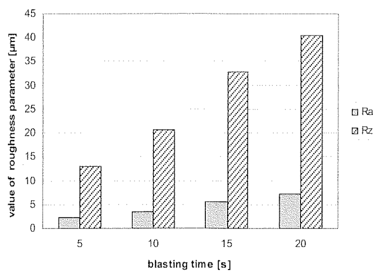

Figure 2: a=90 mm

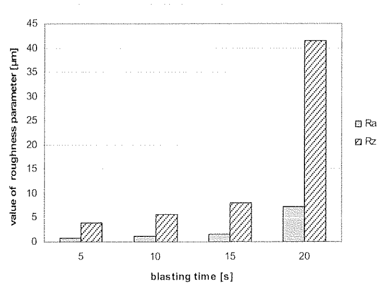

Figure 3: a=120 mm

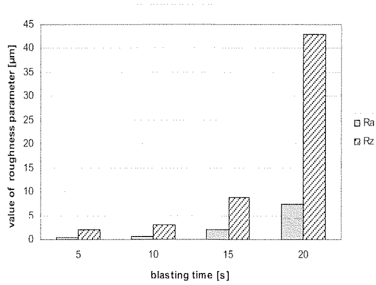

Figure 4: a=150 mm

Blasting pressure p = 10 bar and *mass-flow of dry ice pellets* $\dot{m}$ = 100 kg/h were constant parameters throughout all tests. For the tests on surface roughness, a dry ice blasting unit Cryonomic CAB-52, Artimpex nv, Belgium, was used. Moreover, the

test station includes a 6-axis industrial robot for nozzle handling and is encircled by a sound insulation. The compressed air is provided by a screw-type compressor.
It must be said that such results as shown above (figures 1-4) are typical of peening of aluminum, but you could get different results easily, e. g. just by using a different nozzle. Nevertheless the results show that the surface roughness can be manipulated within a wide range by varying one or two process parameters. Dry ice blasting can be used to increase the surface roughness of other materials as well, but especially for harder materials other processes are more adequate. Figure 5 shows the roughening of a punctual blasted aluminum surface.

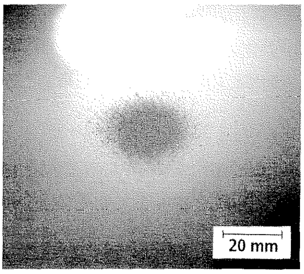

Figure 5: Roughened aluminum surface

INFLUENCE OF DRY-ICE BLASTING ON HARDENING AND RESIDUAL STRESS

Compared to 'classical' blasting media used for surface treatments, dry ice is comparatively soft. Therefore its influence on the mechanical properties of metallic materials is often supposed to be small. The effect of dry ice being shot on a surface, as described above, is not only a mechanical one and yet it is not sure which consequence each of the mechanism has on the material characteristics. In order to find out what kind of materials can be treated by using dry ice and in which way the mechanical characteristics can be manipulated, there have been basic investigations on three different metals: Aluminum alloy AlMg3, brass alloy CuZn37 and austenitic steel X5CrNi18.9. For all materials measurements of Vickers hardness und residual stress have been conducted before peening with dry ice and afterwards. Throughout, only the nozzle feed has been varied, while all other blasting parameters like blasting distance, pressure, angle and mass flow of dry ice pellets, have been adjusted to values, which are generally used for cleaning applications.
The testing unit for these experiments was a blasting unit CryoMax II, provided by Linde AG, Germany. The Vickers hardness has been measured by a low-load hardness test device, the residual stress has been measured by using an X-ray diffractometer. All test specimens have been grinded and polished to provide the same initial state for all tests.
The test results show that hardening as well as inserting of residual stress is possible for all tested materials. For the hardness tests the nozzle feed has been varied for all materials at the levels 0.01, 0.03, 0.10, 0.50 and 1.00 m/min. The highest increase of hardness is reached with the lowest feed of 0.01 m/min, afterwards the reachable hardening falls hyperbolic with higher nozzle feeds. For AlMg3, the increase of hardness below a nozzle feed of 0.10 m/min is not measurable by means of the used hardness test device, because the Vickers impression could not be determined

optically, since the blasting process produced very high values for surface roughness.

Regarding to the residual stress, each material shows different behavior. For AlMg3 the highest residual stress of approximately 130 MPa was reached with a nozzle feed of 1.0 m/min while for lower speed the value of the residual stress falls quickly to a lower level. This behavior is due to the over-peening of AlMg3, which means that the critical blasting intensity with the purpose of increasing the residual stress is exceeded. CuZn37 shows similar behavior, but the critical nozzle feed here is 0.1 m/min. For the austenitic steel X5CrNi18.9 the critical blasting intensity could not be reached by means of the applied blasting parameters, the highest level of residual stress was measured for a nozzle speed of 0.01 m/min. Table 1 shows the "best" results for hardness and residual stress values.

The measurement of residual stress for untreated AlMg3 was not possible due to its coarse-grained structure.

Table 1: Hardness and residual stress resulting from dry ice blasting

Material	Vickers Hardness HV		Residual Stress [MPa]	
	untreated	after blasting	untreated	after blasting
AlMg3	82,8	97,3	n/a	-131 ±12
CuZn37	145	210	-110 ± 9	-290 ± 9
X5CrNi18.9	201	335	-230 ± 20	-324 ± 16

The tests show that high blasting intensities, realized with lower nozzle feed, cause an increase of hardness for all materials that are not too soft in untreated condition. Measurements of the surface roughness for the test specimen showed that for high blasting intensities the roughening outbalances the increase of surface hardness. This is a relevant fact for soft materials, where dry ice blasting causes a strong plastic deformation of the materials surface. Moreover, the test results show that in general, harder materials have a higher potential of hardening (Elbing, 2003; Spur, 2002).

DISCUSSION

The test results demonstrate that dry ice blasting can be used as a peening process with great potential for industrial applications. The main difference between dry ice and other blasting media is that it sublimates at room temperature so that no residues of blasting media have to be removed after the process. This is of importance for all applications where complex structures have to be shot peened and therefore the effort is very high in order to clean them afterwards. Moreover dry ice blasting could be used for a wide spectrum of materials hard ones like steel as well as softer ones like aluminum. The results of the peening process differ from material to material so that dry ice blasting is a custom-designed process. In general it could be said that an increase of residual stress, hardness and surface roughness are reachable, but that there is a correlation between these effects. Increasing surface roughness often means that the values of surface hardness fall at the same time.

One disadvantage of the dry-ice blasting process are the requirements to the working environment: During the process sound pressure levels of up to 125 dB(A) could emerge and the CO_2-concentration in the surrounding air may be elevated. Moreover, process automation is often difficult to realize (Spur, 1998).

OUTLOOK

Further investigations on dry ice blasting head for increasing the effects of the process. Particulary the mechanical, the thermal und the effect due to the sublimation will be analyzed separately. The tests have shown that there is an urgent need for research as it is not known which influence each effect has on the blasting result. It is assumed that harder pellets as well as heating of the workpiece before peening with dry ice may have a strong influence on the blasting result.

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