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Cryogenic wet-ice blasting—Process conditions and possibilities

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ABSTRACT

In the present article frozen and deeply chilled water-ice particles, with a temperature of around −100 °C, act as a blasting abrasive. For accelerating cryogenic ice particles the process of injector blasting is used. The advantage of this abrasive at these low temperatures lies in the complete absence of residues after processing. Abrasive water-ice particles turn back to water by melting. Possible applications for this innovative process are especially complex components that can be easily deburred and cleaned. The production process of deep frozen ice particles will be described and first practical deburring test results will be shown.

1. Introduction

Deburring is a recurrent process step in manufacturing. Especially for complex and high-tech components costs are often high above average. Due to the fact that such components often have to be deburred by hand or reworked manually [1,2]. In order to keep up with requirements of modern manufacturing processes and component geometries the deburring technology has to seek new and advanced ways. The here described method of deeply chilled wet-ice blasting (WIB) tries to meet these requirements.

WIB is based on the use of a hard and solid abrasive for the deburring process via abrasive blasting. Therefore solid water ice in the form of small particles is used. The really innovative property of this abrasive is to leave no solid residue behind, which is a main reason for using the innovative WIB process for deburring of complex and difficult-to-clean parts, as exemplified in Fig. 1.

When using conventional abrasives for deburring blasting there are various difficulties in the subsequent removal and cleaning of the components after work. The hard and abrasive grains may not be completely removed out of the component. This is especially not feasible at complex component geometries with cross holes and undercuts. The use of water-ice particles as an abrasive eliminates this expensive cleaning work completely. The ice particles remain after the deburring abrasive blasting in form of water and easily flow out of the component. This is, particularly in case of complex components, a big advantage [3].

The objective is to realize the potential to implement the described procedure of abrasive blasting by use of deep frozen water-ice particles. In order to produce and provide water-ice in the form of fine cryogenic ice particles, a special equipment is required which is called "Cryo-Tank" and presented here [3].

The differences between the process described here and the one used in commercially available equipment [4–6] are first of all the method of ice particle production with all following particle parameters like defined size, form and hardness and second the working process- and particle temperature. The ice particles used here will be formed by fog in a cryogenic atmosphere and work with a temperature of round −100 °C to have more hardness and abrasiveness in blasting process. The other procedures operate with mechanical scraped ice particles and not in cryogenic temperature range. So the ice particles have an undefined form and size and are softer and much less abrasive.

Fig. 1. Acryl glass model of a complex workpiece with intersection boreholes, Co. HELLER.

To avoid any confusion; the process of cryogenic wet-ice blasting is not similar to dry ice blasting process working with frozen CO_2 which has a much lower hardness than cryogenic-temperature water-ice, and the mechanism of impact is also different [7].

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2. Theoretical backgrounds

2.1. Water-ice as a blasting abrasive

The hardness of CO_2 dry ice is comparable to that of gypsum, and is in a range of 2 Mohs. This is not sufficient for working or deburring harder materials such as metals. In contrary water-ice from liquid H_2O offers a great benefit. Frozen water increases its hardness as a function of temperature. With decreasing temperatures, the hardness is increased [8,9]. Thus the application of WIB is able to transfer more energy to a surface and therefore produce more erosion on it.

After impact and transmitting kinetic energy, the ice particle melts and leaves no solid residues, like CO_2. Cryogenic water-ice is a very abrasive blasting medium which leaves no solid residue, only water remains in addition to the removed material.

Another positive characteristic of the abrasive water-ice is the temperature-dependent hardness to be seen in Fig. 2. At a temperature of −10 °C water-ice has a hardness of 2 Mohs, exactly like gypsum. When the temperature decreases to −80 °C it has a Mohs hardness of 6–7 which is comparable to glass [8,9]. Water-ice is a material which, depending on the applied temperature, changes its hardness and thus can work both as a soft abrasive as well as a very hard and abrasive blasting medium.

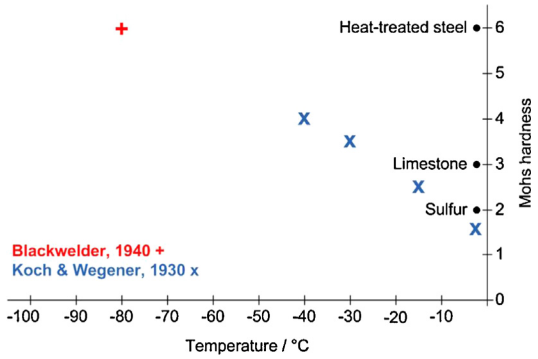

Fig. 2. Mohs hardness of water-ice [10].

"An ideal blasting abrasive should have an edged form, has a hardness of at least 6 Mohs and desintegrates into gas at room temperature completely" [7].

Comparing water-ice with the definition of a perfect abrasive [7] this is very close to ideal. It melts finally just to water and not to a gas, but otherwise the other attributes are largely fulfilled. To achieve this last requirement, a drying process after machining can be realized in the application of WIB. Furthermore, as already mentioned, the possibility of adjusting the hardness of the abrasive is feasible. This influence can be assessed by changing blasting materials and goods as beneficial.

2.2. Mechanism of ice blasting

The impact mechanism of the cryogenic wet-ice blasting process is primarily of mechanical nature. The ice particles hit the surface which results in deformations. Thereby, kinetic energy is transmitted into the surface leading to failures of bonding forces.

Fig. 3 demonstrates the peening mechanism of the abrasive process. It indicates that by achieving a certain peening pressure and/or jetting pressure, a chip or a particle of the surface is removed. In presence of a burr, this would be eliminated [11].

Pressure surges produced by the transmitted kinetic energy of the ice particles result in plastic deformations at the burr and thus it is removed from the surface of the workpiece. To what extent the influence of molten water, which comes as a side effect of the alternating influence of impact energy on the ice particles, adds to the build-up of pressure surges in the liquid, is still subject of further research. These phenomena can also be observed by the process of water jet cutting as well as in high-pressure water jet deburring where the internal stresses may exceed the strength of the material

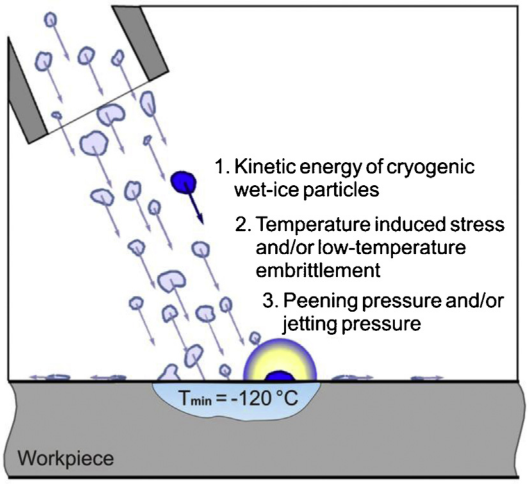

Fig. 3. Behaviour of solid wet-ice abrasive at the surface of a workpiece according to Ref. [13].

and cracks will be initiated in the surface [12]. The increased occurrence of this phenomenon leads to failure in the surface and to break-out of particles in the substance matrix. Similarly, the multiple pressure waves of individual ice particles or water droplets cause the removal of material from the composite matrix. Both phenomena occur simultaneously and debilitate the surface material structure.

The working process temperature for the cryogenic wet-ice blasting process is very cold, down to −120 °C. This results in the effect of embrittlement caused by cryogenic temperatures at most materials like steels, non-ferrous metals and plastics. Through this influence the material structure is further debilitated and burrs can be removed more easily.

This embrittlement is caused by the utilization of deep frozen ice as blasting abrasive. Extremely low temperatures in ranges of up to −120 °C deprive the environment the heat and cools down the working process. Certainly, the workpiece is being predominantly affected by this. Depending on the heat conductance capacity of the blasted material the temperature in the edge layers will drop until it reaches the temperature of the shot. Additionally, thermal shock to the material is influenced by process parameters as feed rate, nozzle offset and compressor pressure.

3. Process description

3.1. The production process of deep frozen wet-ice particles

To produce the necessary ice particles in an optimal way, dedicated equipment called "Cryo-Tank" (see Fig. 4) was developed

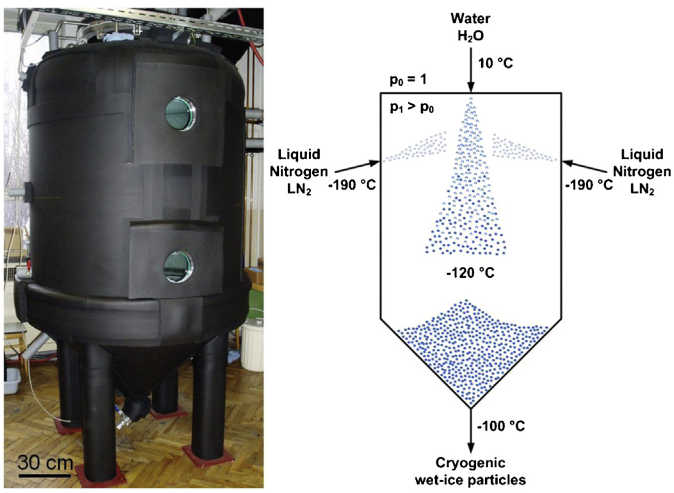

Fig. 4. "Cryo-Tank" (left), production process of cryogenic jet wet-ice inside the tank (right).