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DEEPCHILLEDWET-ICE BLASTING- THEPOWEROF WATER-ICE PARTICLES

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СТРУЙНАЯ ОБРАБОТКА ОХЛАЖДЁННЫМИ ЧАСТЦАМИ ВОДЯНОГО ЛЬДА

In the present article frozen and deep chilled water-ice particles, with a temperature of around -100 °C, act as a blasting abrasive. For the acceleration of cryogenic ice particles with diameters of 0.2 - 0.7 mm the process of injector blasting is used. Hardness of deep cold ice particles is comparable, at a temperature of -100 °C, with the hardness of glass or sand. 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. Thus a subsequent cleaning is largely superfluous. On the contrary, the water formed during the processing has an additional cleaning effect. Possible applications for this innovative process are especially complex components that can be easily machined.

1 Introduction

Deburring of complex components is subject to formidable efforts in terms of time and expenses. In order to ensure quality and due to lack of operational alternatives, these efforts are inevitable. As a result, even in times of continuous automation components must often be deburred manually [5]. In order to counteract this trend and keep up with heightened requirements of production, implementation of a new and innovative deburring procedure, which will be presented here, needs to be promoted. The procedure is referred to as deep chilled wet-ice blasting (TNS in German).

The procedure investigated here is essentially a blasting method using a solid blasting abrasive. The innovative idea at the foundation of this endeavor lies in the use of ordinary ice as anabrasive. The advantage of ice is its property to not leave any solid residue behind and in that it is consequently applicable to the blasting treatment of complex component geometries, exemplary shown in Figure 1.


Fig. 1. Example-workpiece with intersection boreholes, Co. HELLER

The use of conventional blast media for purposes of abrasive blasting deburring entails the subsequent removal of blasting abrasive residue after work. In the case of complex component geometries, complete removal of said residue is not feasible. Even if elaborate removal is carried out afterwards, additional costs are generated that make the applied procedure seem ineffective. By using ice as blasting abrasive, elaborate removing procedures become obsolete which, especially in the case of complex component geometries, marks a vast and decisive advantage.

The objective is to create the potential to implement the above-described procedure of abrasive blasting by use of deep chilled water-ice particles. This requires a new form of equipment which allows the specialized fabrication of suitable ice particles.

The ice blasting procedure examined here must not be confused with dry ice blasting, which uses frozen carbon dioxide as a blasting abrasive. Dry ice or CO_2 blasting does not remove material by mechanical means, but primarily through expansion of the dry ice pellets, which in the process of sublimation abruptly increase their volume. In this case, the resulting pressure wave rips off material already loosened by thermal shock [1].

2 Theoretical backgrounds

2.1 Water-ice as a blasting abrasive

The hardness of dry ice is about 2 Mohs, which roughly compares to the hardness of gypsum. This is not sufficient for deburring metallic materials. This is different with water-ice, frozen water (H_2O). At temperatures in the upper freezing range, ice possesses the same properties as dry ice, but these change as the influence of cooling energy increases [6, 7].

The advantages of TNS result from the utilization of physical properties of the employed abrasive, water-ice. Ice constitutes an easily available, comparatively easy to fabricate material, which subsequent to transmitting kinetic energy has the ability to change its physical state in such a way that it will not leave any solid residue after use. Aside from removed material, only liquid residue like water or emulsion is left behind.

A second, even more decisive property of water-ice lies in the temperature dependence of its hardness, as shown in Figure 2. The hardness of water-ice is indirectly proportional to its temperature, which means that with decreasing temperature, hardness will increase [6, 7]. Thus, the Mohs hardness of water-ice is 2 at a temperature of -10 °C, similar to gypsum. In contrast, its Mohs hardness is 6 - 7 at a temperature of -80 °C, comparable to the hardness of glass or steel. This property of ice is at present neither considered nor utilized in ice blasting procedures, yet providing an innovative application in this field.

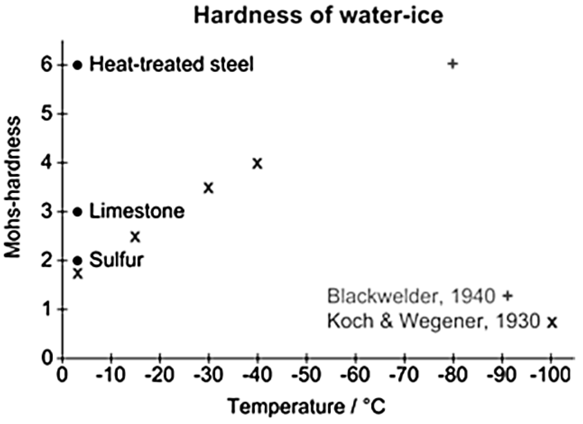

Fig. 2. Mohs hardness of water-ice [2]

"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 [1]". Even though water-ice does not completely fulfil all three of these requirements since it will melt to a liquid and not become gaseous, it is very close to the definition of a perfect abrasive according to [1]. In order to fulfil that last requirement, machined workpieces could be dehumidified by simple drying procedures.

Another aspect should be noted at this point: As a result of its temperature-dependent hardness, water-ice is the only abrasive that can be adapted to the conditions and requirements of the process, from hard to very soft.

2.2 Mechanism of ice blasting

The primary procedural mechanism is based on the impact of ice particles on the workpiece surface. In the process of hitting the workpiece that needs deburring, kinetic energy is transformed into severing energy through deceleration. Figure 3 demonstrates the mechanism of the severing process. It indicates that by observing a certain blast angle, a chip is severed out of the surface. If there is a burr present, it will be removed preferentially, since it protrudes from the surface [3].

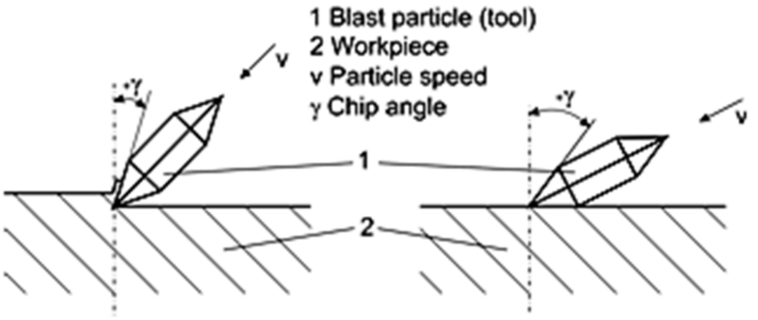

Fig. 3. Behaviour of a solid blasting abrasive at surface of a workpiece [3]

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 subject to speculation. This phenomenon can be observed in the procedures of water jet cutting as well as in high pressure water jet deburring. When inner tensions rise up to the point where they exceed the material strength, cracks begin to appear. Spreading and aggregation of these cracks will then lead to the removal of surface material [4]. At the same time multiple pressure waves from the impact of drops accumulate to pressures so high that material gets broken out of the substance matrix.

Another secondary mechanism is being caused by the influence of low temperatures on the brittle fracture characteristics of a wide variety of materials, e.g. steels, non-ferrous metals, or plastics. Only non-austenitic steels are the exception. In all other materials, embrittlement caused by cold will lead to a weakening of the atomic grid structure, also known as substance or particle matrix, and as a result thereof to a decrease in material strength.

This embrittlement is brought about by the utilization of deep-frozen ice as blasting abrasive. Extremely low temperatures in the range of up to -100 °C deprive the environment of heat and cooling it down in the process. Naturally, 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 rate of feed, nozzle offset and compressor pressure.

3 Process descriptions

3.1 The production process of deep chilled wet-ice particles

To produce the ice particles process optimally, the equipment called “Cryo-Tank” (see Figure 4) was developed and builds up as a prototype at the IFQ of the Otto-von-Guericke-University Magdeburg. With it, deep chilled and blasting capable wet-ice particles can be produce.

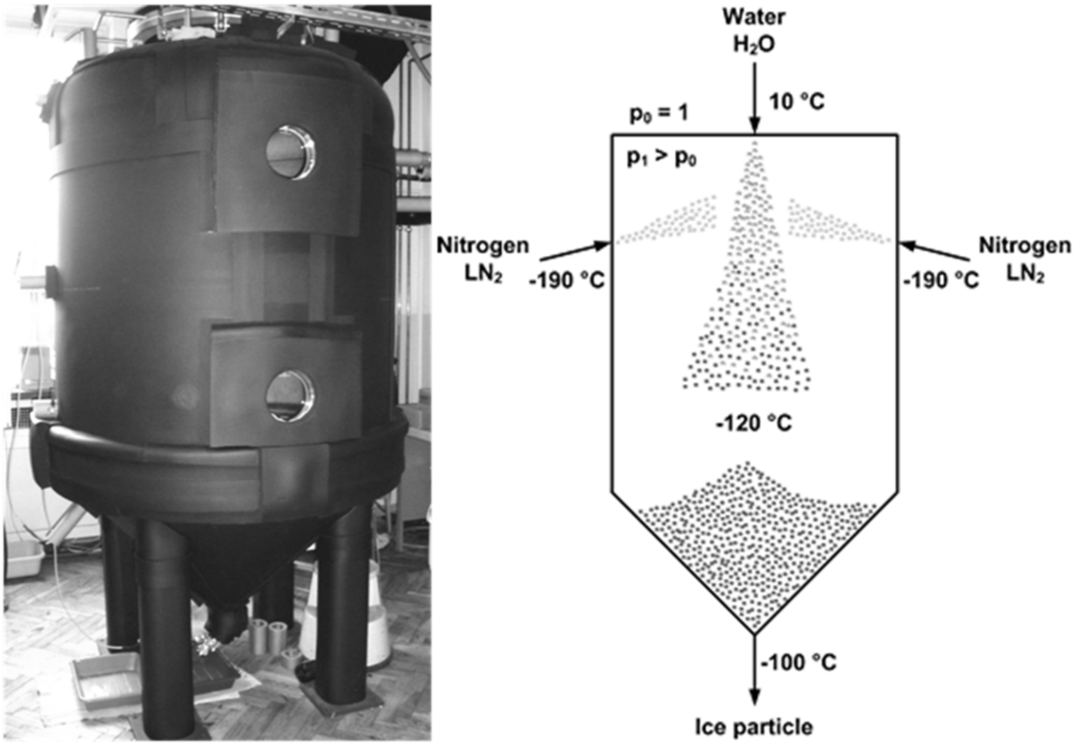

Fig. 4. “Cryo-Tank” (left) and production process of blast ice (right)

The manufacturing process of the blasting ice particles is as follows:

- The “Cryo-Tank” is cooled down via a ring tube in the upper part of the system by liquid nitrogen LN_2 till at least -120 °C.
- Water atomize over a full cone nozzle in the lid of the system and freezes in the cold atmosphere.
- Frozen ice particles as shown in Figure 5 accumulate in the lower part of the equipment in the hopper that feeds them to the outlet opening.
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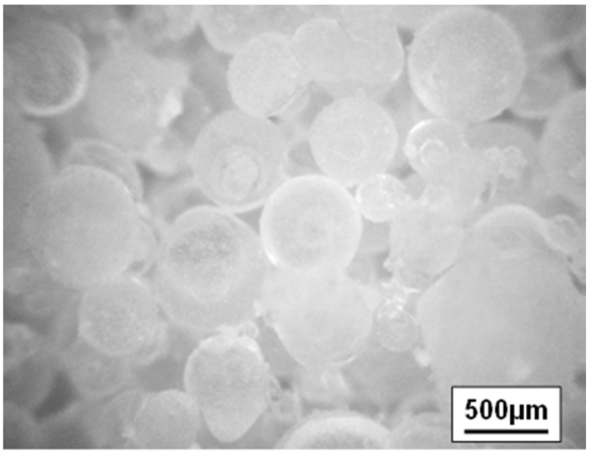

Fig. 5. Blasting ice particles in a diameter range of 0.2 - 0.7 mm

3.2 The deep chilled wet-ice blasting process

The deep chilled wet-ice blasting process (in German TNS) proceeds as follows and shown in Figure 6:

- From the hopper of the "Cryo-Tank" the ice particles come to the injector blasting method where they load as an abrasive.

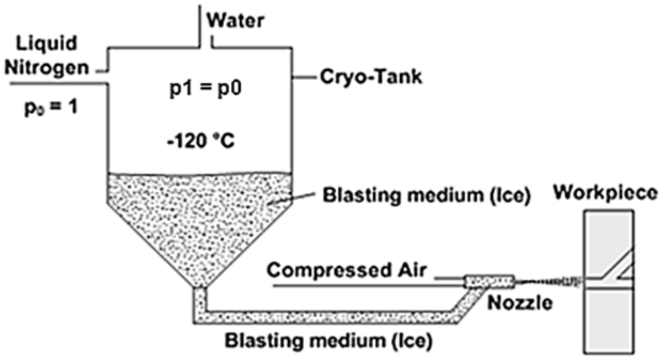

Fig. 6. Procedural description of TNS process

- Due to the injector spray gun, a vacuum is created in the load line, which carries particles of ice in the mixing chamber of the spray gun.
- There they where accelerated by compressed air and impact later on the part surface.
- Here the kinetic energy is released in form of deformation or abrasion at the component.

4 Practical investigations of the removal capacity of deep chilled ice particles

The deburring results shown in Figure 7 were assured at a tempered steel 42CrMo4, an aluminium alloy AlMg5 and a plastic material polyethylene. The results were got by comparing the same component before and after the TNS processing by different measuring methods. It shows that the adherence machining burrs removed by the blasting machining with the deep cold ice particles, up to the burr root.

Below to better illustrate some concrete examples are shown using light microscopy and related GFM measurement diagrams of the borehole edge. Figure 8 and Figure 9 show the deburring results at a tempered steel 42CrMo4. In the photographs is the same component, as shown before and after the TNS processing. Comparing the two images shows that the adherence machining burrs removed by the blasting machining with the deep chilled ice particles, up to the burr root. The underlying measurement graphs will show the same area of the component. Comparing these measurements the deburring is also concrete measured. The used test parameters are shown in Table 1.

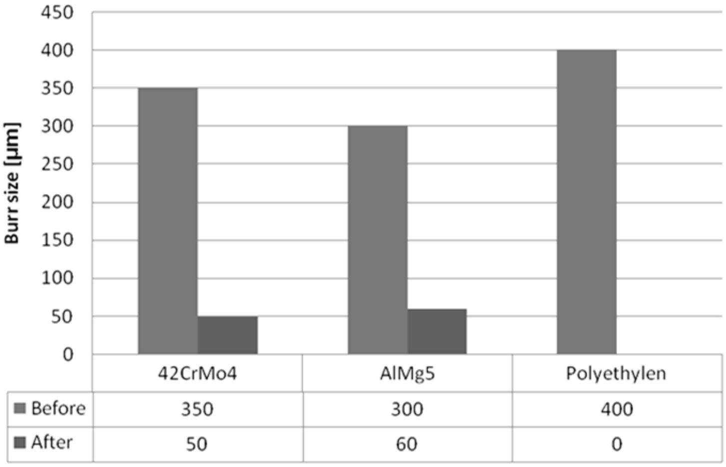

Fig. 7. Results of the TNS machining at different materials

Table 1

Test parameters TNS machining

Test parameters TNS deburring/machining			
temperature of ice particles [°C]:	-100	blasting angle [°]:	70
blasting time [s]:	20	blastingdistance[mm]:	80
blastingpressure[bar]:	15	jet nozzles (AD/BD) [mm]:	4/10
particlesize[mm]:	0.2-0.7	material:	42CrMo4

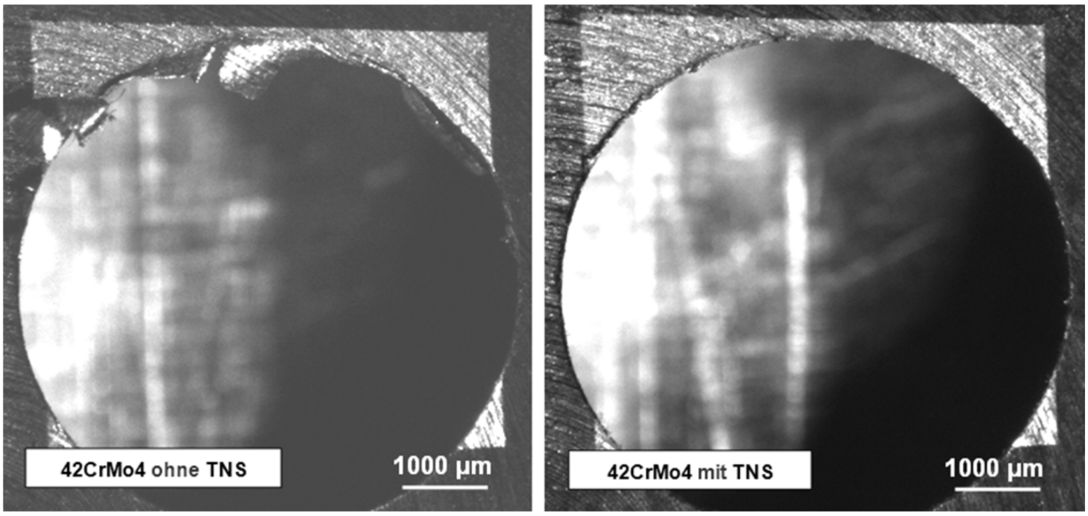

Fig. 8. Before/After images from test workpiece of 42CrMo4

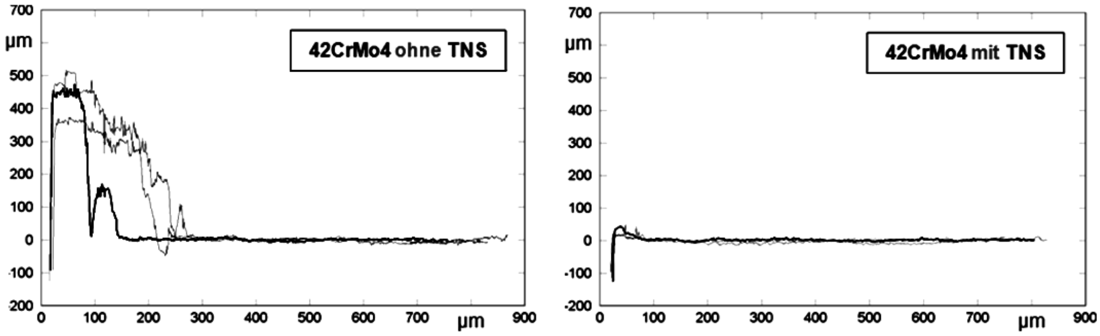

Fig. 9. Before/After graphs from test workpiece of 42CrMo4

5 Summary and outlook

Removal of adherent burrs on complex components and workpieces constitutes a problem in production engineering. Especially the automated implementation into the process of production is difficult to achieve. Reasons for this are the complexity of components, the insufficiently foreseeable shape in which burrs manifest and the imprecise means to predict their areas of origin on the component. Huge research efforts are undertaken to successfully forecast the formation of burrs using computer-based methods of simulation. This also holds true for the reliable detection of burrs on said components. All of these developments are made in an attempt to optimize and advance methods for the removal of burrs and prevention of their formation.

A novel procedural variant for abrasive blasting deburring processing of workpieces has been presented. It includes the use of deep chilledwet-ice as blasting abrasive for the removal of burrs on complex component geometries. In this context, temperature-dependent hardness and removal capacity of ice have been confirmed.

Looking ahead the performance of the TNS machining is examined for other machining tasks. There are considerations to using the new method for the surface finishing and for the stripping of surface preparation or the preparation of functional surfaces. There are already first results of preliminary analyses to look positively into the future.

Аннотация. *В данной статье крупицы охлажденного до -100°С водяного льда рассматриваются с точки зрения их использования в качестве абразива для струйной обработки. Частицы льда диаметром 0,2-0,7 мм испытывались в процессе инжекторной струйной обработки. Твердость таких частиц льда при температуре -100°С достигает уровня твердости стекла и песка. К достоинствам использования охлажденного водяного льда в качестве абразивного материала относится полное отсутствие остатков абразива после обработки. Абразивные частицы, тая, превращаются обратно в воду. Это в свою очередь обеспечивает очистку обрабатываемой заготовки от частиц удаленного с заготовки материала. Областью применение для этой инновативной технологии является струйная обработка деталей сложной конструкции.*

Ключевые слова: водяной лед, струйная обработка.

Анотація. *У даній статті крупиці охолодженого до -100°С водяного льоду розглядаються з точки зору їх використання в якості абразиву для струменевої обробки. Крупиці льоду діаметром 0,2-0,7 мм випробовувалися в процесі інжекторної струменевої обробки. Твердість таких крупиць льоду при температурі -100°С досягає рівня твердості скла та піску. До переваг використання охолодженого водяного льоду в якості абразивного матеріалу відноситься повна відсутність залишків абразиву після обробки. Абразивні частки, тая, перетворюються у воду. Це в свою чергу забезпечує очищення оброблюваної заготовки від частинок віддаленого з заготівлі матеріалу. Областю застосування для цієї инновативной технології є струменевий обробка деталей складної конструкції.*

Ключеві слова: крупиці, водяний льод, струменева обробка.

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