Cryogenic Wet-Ice Blasting
- Process Conditions and Possibilities

Magneto-Abrasive Machining for the Mechanical Preparation of High-Speed Steel Twist Drills

Dipl.-Ing. Florian Welzel
Cryogenic wet-ice blasting - process conditions and possibilities

Prof. Dr.-Ing. habil. Prof. h.c. B. Karpuschewski
Dr.-Ing. K. Schmidt
Dr.-Ing. Th. Emmer
Dipl.-Ing.(FH) M. Petzel M.Sc.
Fields of application:
- Deburring
- Cleaning
- Surface treatment

Burr at borehole (left), chip in fluidic system (right)

Extra expenses in production due to burrs and chips

Source: Ergebnisbericht Spansauber, TU Kaiserslautern, FBK, J.C. Aurich, 2006
Structure:

1. Goals of cryogenic wet-ice blasting (in short WIB)
2. Working Principles
3. Process description of WIB
4. Experimental Results
5. Conclusions

Ice particle production machine in the IFQ
„Cryo-Tank“ for wet-ice blasting - WIB
1. Goals of Cryogenic wet-ice blasting WIB

- Simultaneous deburring and cleaning of highly complex and highly stressed components such as control blocks and engine parts
- Deburring without solid residues and required following cleaning
- Defined blasting particle size and hardness
- Limited use of chemical additives - emulsion
- No damage at the workpiece surface
- Potential for surface smoothing
- No defined edge geometry

Source: SKL-Maschinenbau GmbH
2. Working Principles

The size of the transferred energy is dependent on the:

- particle energy,
- properties such as grain shape of the abrasive, grain materials and grain hardness,
- angle of impact
- properties of the blasted surface.

The particle energy is calculated according to the basic physical formula

\[ E_{\text{kin}} = \frac{1}{2} \cdot m \cdot v^2 \]

and thus grows proportionally with the particle mass and the square of the particle velocity.
In case of cryogenic wet-ice blasting (WIB) there are some other effects:

- temperature-induced stress on the surface
- low temperature embrittlement of the ground material
- Peening pressure of the multiple fluid shock waves
- Jetting pressure of the molten water on the surface

Based on: F. W. Bach, University Hannover, IW
**Ice particles as a blasting abrasive**

“An ideal blasting abrasive should have an edged form, has a hardness of at least 6 Mohs and disintegrates into gas at room temperature completely” [J. Haberland].

![Graph showing Mohs hardness of wet ice](image)

**The Mohs hardness of ice was checked and confirmed experimentally.**
3. Process description of WIB

Manufacturing process of cryogenic wet-ice particles

• 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 atomizes over a full cone nozzle in the lid of the system and freezes in the cold atmosphere.

• Frozen ice particles accumulate in the lower part of the equipment in the hopper, that feeds them to the outlet opening.
Jet process

Water

H₂O

„Cryo-Tank“

Liquid

Nitrogen LN₂

p₁ = p₀

-100 °C

p₀ = 1

Compressed air

Nozzle

Cryogenic wet-ice particles

Workpiece

Phase 1: removal

Phase 2: rubbing

Phase 3: flush

Source: Piller Entgrattechnik
Cryogenic ice particles - „Cryo-Tank“

Cryogenic ice particles in the „Cryo-Tank“ (view from the top)

Free flowing ice particles
Cryogenic ice particles - Analysis

Form: spherical
Temperature: -100 °C
Mohs hardness: 6-7
Temperature resistance: stable
Free flowing properties: such as dry sand
3. Experimental Results

Analysis the abrasiveness of cryogenic ice particles - Equipment

Injector blasting cubicle for practical experiments

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>test specimen</td>
</tr>
<tr>
<td>2</td>
<td>fixture</td>
</tr>
<tr>
<td>3</td>
<td>nozzle</td>
</tr>
<tr>
<td>4</td>
<td>ice particles</td>
</tr>
</tbody>
</table>

Injector blasting cubicle (view inside)
Nozzle handling with cryogenic ice particles
Measurement equipment for burr measuring

3D surface measurement station MikroCAD (GFMesstechnik), based on fringe projection
# Results of deburring with cryogenic ice particles - metallic materials

<table>
<thead>
<tr>
<th>Ice temperature [°C]</th>
<th>variable (-60; -120)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet time [sec]</td>
<td>variable (40; 80)</td>
</tr>
<tr>
<td>Jet pressure [bar]</td>
<td>15</td>
</tr>
<tr>
<td>Jet angle [°]</td>
<td>70</td>
</tr>
<tr>
<td>Jet distance [mm]</td>
<td>60</td>
</tr>
<tr>
<td>Ice particle size [mm]</td>
<td>0.1 - 0.7</td>
</tr>
<tr>
<td>Ice mass flow rate [kg/h]</td>
<td>50</td>
</tr>
<tr>
<td>Diameter air nozzle [mm]</td>
<td>4</td>
</tr>
<tr>
<td>Diameter jet nozzle [mm]</td>
<td>10</td>
</tr>
<tr>
<td>Ice particle speed [m/s]</td>
<td>140</td>
</tr>
</tbody>
</table>

![Graph showing results of deburring with cryogenic ice particles](image)

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Visual analysis - metallic materials

- The burr is completely removed from the borehole.
- WIB on metallic materials leaves just the burr root on the part.
- There is no more risk of loose material fractions during operation.
- The surface round the bore is not damaged.
- In case of metallic materials a large jet pressure is required.

Jet time: 40 sec, Wet-ice temperature: -60 °C, Jet angle: 70°,
Jet distance: 60 mm, Jet pressure: 15 bar, Particle speed: 140 m/s
Results of deburring with cryogenic ice particles - plastic materials

Test parameters WIB of plastic materials

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ice temperature [°C]</td>
<td>-40; -80</td>
</tr>
<tr>
<td>Jet time [sec]</td>
<td>20; 40</td>
</tr>
<tr>
<td>Jet pressure [bar]</td>
<td>8</td>
</tr>
<tr>
<td>Jet angle [°]</td>
<td>70</td>
</tr>
<tr>
<td>Jet distance [mm]</td>
<td>80</td>
</tr>
<tr>
<td>Ice particle size [mm]</td>
<td>0.1 - 0.7</td>
</tr>
<tr>
<td>Ice mass flow rate [kg/h]</td>
<td>40</td>
</tr>
<tr>
<td>Diameter air nozzle [mm]</td>
<td>3</td>
</tr>
<tr>
<td>Diameter jet nozzle [mm]</td>
<td>6</td>
</tr>
<tr>
<td>Ice particle speed [m/s]</td>
<td>100</td>
</tr>
</tbody>
</table>

Polyethylene (PE)  
Polypropylene (PP)
### Visual analysis - plastic materials

- The burr is completely removed from the borehole.
- WIB on plastic materials is too abrasive and destroys the surface of parts.
- The bore and the surface round the bore is damaged.
- In case of plastic materials a small jet pressure and short machining times are required.

Jet time: 20 sec, Wet-ice temperature: -80 °C, Jet angle: 70°, Jet distance: 80 mm, Jet pressure: 8 bar, Particle speed: 100 m/s
Impact analysis of cryogenic ice particles

fixed Almen strip for peening intensity and drop impingement measurement

20 mm
Analysis of the impact of cryogenic ice particles on a surface via High speed camera

Camera: Photron Fastcam ultima APX

Chosen frame rate: 15,000 fps

Resolution: 256 x 256 pixel
Conclusions

• The practical studies have shown the feasibility of deep frozen wet-ice particles as an abrasive for deburring.

• With the use of deep frozen and cryogenic wet-ice as blasting abrasive the removal of burrs on multifaceted component geometries is possible.

• The temperature-dependent hardness and removal capacity of ice have been confirmed.

• The performance of the new method is promising in metallic materials and highly abrasive in softer materials.

• The impact behavior of an ice particle on a surface is defined in terms of four successive phases: flight, impingement, disintegration and expansion.
  - Ice particles plastically deform and do not bounce off the surface.
  - The spread of particulate matter is generally visible in all directions.
  - The largest particle volume moves in the inclined direction of the surface and is rubbing on it.
Outlook

• The process parameters related to WIB jet processing must be adapted to other materials to be processed.

• The performance of the WIB machining will be examined for other machining tasks:
  - surface finishing and surface preparation
  - decontamination and decoating of surfaces
  - cleaning of turbines or turbine parts

• Realization of a jet lance for machining bore intersections.
Magneto-Abrasive Machining for the Mechanical Preparation of High-Speed Steel Twist Drills

B. Karpuschewski (1)\textsuperscript{a}, O. Byelyayev\textsuperscript{a}, -V.S. Maiboroda\textsuperscript{b}

\textsuperscript{a} Institute of Manufacturing Technology and Quality Management IFQ, Otto-von-Guericke-University of Magdeburg
\textsuperscript{b} Institute of Mechanical Engineering, National Technical University of Ukraine “KPI”, Kiev

- Introduction

- Experimental setting

- Results

- Conclusion and outlook
Cutting process as a system

- **Input quantities**
  - Determined by:
    - Material
    - Tools
    - Machine setting
    - Characteristics of the machine
    - Supporting media

- **Process**
  - Process quantities describe:
    - Mechanical
    - Thermal
    - Chemical interactions during material removal

- **Output quantities**
  - Describe:
    - Workpiece
    - Tool
    - Chips
    - Machine
    - Supporting media after material removal
Cutting tool properties

- **Cutting tool**
  - Tool material
  - Tool geometry
  - Coating

- **Cutting parameters**

- **Coolant**
  - Macro geometry
  - Micro geometry of the cutting edges
    - Cutting edge radius
    - Cutting edge chipping
    - Cutting edge form
  - Quality of functional surfaces
Quality characteristics of a helical drill

- Radius of the cutting edge:
  - Sharp cutting edge
  - Rounded cutting edge

- Chipping of the cutting edge

- Quality of the tool surfaces:
  - Flank face margin/land
  - Rake face (chip space)

- Width of flank wear land
- Wear of chisel edge
- Crater wear
- Wear of the land (margin)
- Corner wear of cutting edge
Cutting edge preparation methods

- jet machining
- brushing
- magneto-abrasive machining
- immersed tumbling/drag finishing
Basic principle of magneto-abrasive machining

working gap - $A_s$

workpiece

ferromagnetic grains

magnetic poles

N

S
Commercial magneto-finishing system

source: Magnetfinish GmbH
Test system for magneto-abrasive machining with a ring-shaped configuration
Orientation of the drill in the MAM-system

-moving direction towards the drill point (→ d.p.)

-from the drill point (← d.p.)

outer pole shoe

15°

centred position (Z)

16

16

inner pole shoe

18 - 22°

5...8

shifted position (V)

6...10
# Drill properties

<table>
<thead>
<tr>
<th>Twist drill type</th>
<th>N (normal)</th>
<th>Material composition HSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter D</td>
<td>6.8 mm</td>
<td>C 0.828</td>
</tr>
<tr>
<td>Number of cutting edges</td>
<td>2</td>
<td>Si 0.312</td>
</tr>
<tr>
<td>Drill-point angle $\sigma$</td>
<td>118°</td>
<td>Mn 0.283</td>
</tr>
<tr>
<td>Side rake angle $\gamma_f$</td>
<td>30°</td>
<td>P 0.001</td>
</tr>
<tr>
<td>Diminution</td>
<td>standard</td>
<td>Cr 3.86</td>
</tr>
<tr>
<td>Land width $b_f$</td>
<td>0.7 mm</td>
<td>Mo 4.56</td>
</tr>
</tbody>
</table>

![Diagram of drill properties](image)

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## Varied process parameters

<table>
<thead>
<tr>
<th>drill group</th>
<th>machining time [s]</th>
<th>drill position</th>
<th>powder type/ particle size [μm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>untreated drills</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4x15 4x30</td>
<td>Z</td>
<td>P1 (splintered) 160/100</td>
</tr>
<tr>
<td>3</td>
<td>4x15 4x15</td>
<td>V</td>
<td>P2 (spherical) 315/200</td>
</tr>
<tr>
<td>4</td>
<td>- 4x15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4x10 4x20</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>4x15 4x30</td>
<td>Z</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>4x10 4x20</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>4x15 4x15</td>
<td>Z</td>
<td>powder P2 ≈ 95% mixture P1 ≈ 5%</td>
</tr>
<tr>
<td>9</td>
<td>- 4x15</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Powder characteristics 1

powder P1 (splintered)

grain size: 160/100 μm

powder P2 (spherical)

grain size: 315/200 μm
Powder characteristics 2

powder P1 (splintered)

grain size: 160/100 μm

“pseudo alloy” resulting from spray melting

ferromagnetic matrix Fe-Si (2) with embedded carbide abrasive particles TiC (1)
Geometry measurements at the drill

- Cutting edge chipping \( R_t \)
- Surface roughness \( R_z \)
- Stylus fin
- Measuring direction
- Flank face
- Rake face
- Land (margin)
- Cutting edge radius \( r_n \)
- Corner edge roundness \( r_{cor} \)
Optical cutting edge measurement

- Camera view of a cutting edge
- Cutting edge with micro fringe projection
- Colour coded height image of the cutting edge
- Height image with inserted cutting lines
- Single cutting line presentation with radius determination
- 3D-contour of the cutting edge

Source: GFM
Cutting edge of a helical drill before and after MAM

grinding

MAM

50 µm
Cutting edge chipping for different drill groups

- Drill position “V”
- Drill D = 6.8 mm
- 18 measurements

- Powder mixture
  - 95% - P2
  - 5% - P1

- Mean value
- Standard deviation

Drill group:
- P1: 160/100
- P2: 315/200

Average cutting edge chipping (Rt) vs. drill group.
Cutting edge radii for different drill groups

- Drill position "V" with powder mixture:
  - 95% - P2
  - 5% - P1

Average cutting edge radius $r_h$

<table>
<thead>
<tr>
<th>drill group</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>radius (µm)</td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>25</td>
<td>30</td>
<td>35</td>
<td>40</td>
<td>45</td>
<td>50</td>
</tr>
</tbody>
</table>
Determination of the corner edge rounding

$\rho_{\text{cor}}$
Corner edge roundness for different drill groups

![Graph showing corner edge roundness for different drill groups.](image)

- drill position “V”
- powder mixture
  - 95% - P2
  - 5% - P1
- P1 160/100
- P2 315/200

<table>
<thead>
<tr>
<th>Drill group</th>
<th>Average corner edge radius $r_{cor}$ (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
</tr>
<tr>
<td>6</td>
<td>60</td>
</tr>
<tr>
<td>7</td>
<td>70</td>
</tr>
<tr>
<td>8</td>
<td>80</td>
</tr>
<tr>
<td>9</td>
<td>90</td>
</tr>
</tbody>
</table>
Influence of MAM on drill surface roughness

- untreated
- MAM (drill group 2)

<table>
<thead>
<tr>
<th>Surface Roughness Rz</th>
<th>Flank Face</th>
<th>Rake Face</th>
<th>Land</th>
</tr>
</thead>
<tbody>
<tr>
<td>µm</td>
<td>2.5</td>
<td>3.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Mean value and standard deviation.

- rake face
- MAM

200 µm
Drill land roughness for different drill groups

- **Drill position “V”**
- **P1 160/100**
- **P2 315/200**
- Powder mixture: 95% - P2, 5% - P1
Drill wear measurement

land (margin)

flank face

marked line

chisel edge

major cutting edge

corner wear \( VB_E \)

wear pattern

\[ a_0 - a \]

\[ VB = a_0 - a \]

\[ VB_E = a_0 - a_c \]

\( a_0 \) - distance between marked line and cutting edge in unworn condition
Corner wear depending on varying cutting edge geometry

Twist drill: HSS
D = 6.8 mm, type N
uncoated
workpiece: St 52
cutting parameters:
v_c = 30 m/min
f = 0.2 mm/rev
coolant: emulsion 5%

corner wear VBE

0.6

0.4

0.2

0.1

0

mm

0

2

4

6

8

10

14

tool life travel path L_f

r_{cor} = 59 \mu m
r_n = 16.5 \mu m

r_{cor} = 23 \mu m
r_n = 12.7 \mu m

r_{cor} = 33 \mu m
r_n = 13.7 \mu m

r_{cor} = 37 \mu m
r_n = 12 \mu m

r_{cor} = 43 \mu m
r_n = 18.2 \mu m

r_{cor} = 3 \mu m
r_n = 9.8 \mu m

ground
MAM drill group 2
MAM drill group 6
MAM drill group 3
MAM drill group 5
MAM drill group 9
 Modifications of initially sharp cutting edges

**grinding**

- a) $r_{cor} = 3 \, \mu m$
  - after 5 drillings

- b) $r_{cor} = 55 \, \mu m$
  - after 10 drillings

- c) $r_{cor} = 20 \, \mu m$
  - after 7 drillings

**MAM**

- after 10 drillings
  - 400 \, \mu m

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Approximation of experimentally determined tool life

- Untreated (drill group 1): $V_{BE} = 0.52 \text{ mm}$, $r_{cor} = 3 \mu \text{m}$
- MAM (drill group 9): $V_{BE} = 0.19 \text{ mm}$, $r_{cor} = 35 \mu \text{m}$

Tool life travel path $L_f$ = 6.72 m (240 holes)
Avoidance of the run-in period of drill wear by means of MAM

![Graph showing the comparison of untreated and MAM-treated tool wear with wear pattern images](image)

<table>
<thead>
<tr>
<th>wear pattern after first drilling</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r_{cor} = 3 , \mu m$</td>
</tr>
<tr>
<td>$r_{cor} = 59 , \mu m$</td>
</tr>
</tbody>
</table>

- **corner wear $V_{BE}$**
- **tool life travel path $L_f$**
- **run-in period**
- **regular wear**
- **progressive wear**
Concept of a new MAM system
Conclusion

- improvement of the quality of drill cutting edges and all surfaces
- reproducible generation of adapted cutting edge micro geometries
- realisation of cutting edge micro structuring and surface improvement in one process step
- increase of cutting edge and corner stability
- avoidance of the run-in period of drills
- increase of tool life of uncoated drills up 87%
- (2 times increase of the tool life of coated drills)
Wear behaviour of coated drills

- Untreated
- Micro blasting + TiN
- Micro blasting + TiN
- MAM + TiN
- MAM + TiN + MAM

- f = 0.2 mm/rev
- f = 0.25 mm/rev

Twist drill: HSS
D = 7.0 mm, type N
TiN coated
Workpiece: S 355
Cutting parameters:
- vc = 30 m/min
- f = variable
- Coolant: emulsion 5%

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Micro geometry of a cutting edge

form factor $K = \frac{S_\gamma}{S_\alpha}$

- sharp cutting edge
- rake face
- profile of the cutting edge
- flank face

source: IFW
Principle of fringe projection

Source: GFM Teltow

CCD-camera (Charge-Coupled Device)

DMD-array (Digital Mirror Device)

Light source

Telecentric optical system

Measurement depth

Projection optics

3D-profile

Projection area

Measurement area

Camera axis

Sensor housing

Projection axis

Reference or 0-level

Source: GFM Teltow
Influence of Corner Edge Preparation on the Performance of Drills

Edge brushing of inclined driven tools

T1 = 1 min
T2 = 2 min
T3 = 3 min

Source: as ground R = 3 µm
R1 = 11 µm
R2 = 15 µm
R3 = 21 µm

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Influence of edge preparation on the performance of coated inserts

Drag Finishing in polishing machine by special powder

with 2 driven axes

with 3 driven axes

source: FLATIT®

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Influence of edge preparation on the performance of coated inserts

source: FLATIT®
Edge preparation with magnetic powder with robot manipulation for large scale tool production
Edge preparation of small tools (d > 1mm) with magnetic powder head as a „grinding wheel"

source: MF & Schütte