Atlas of Chips

tu technische universität dortmund

ISF

Publisher:
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Our greatest thanks go to all the people and institutions involved. These include committed partners from industry and research who have provided inspiration, contributions, chips and chip images. I would like to thank the members of the Institute of Machining Technology at TU Dortmund University for their special engagement with regard to selected chips of their own research projects and for editing the contributions of our partners. My very special thanks go to Mr. Jonas Baumann for realizing this initiative and coordinating this exceptional document of our machining research.

Dirk Biermann

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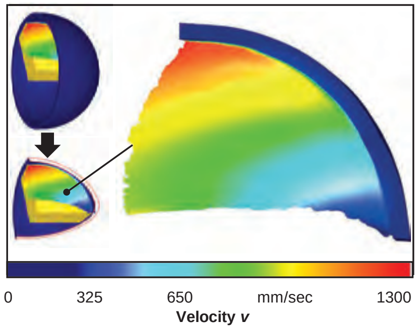
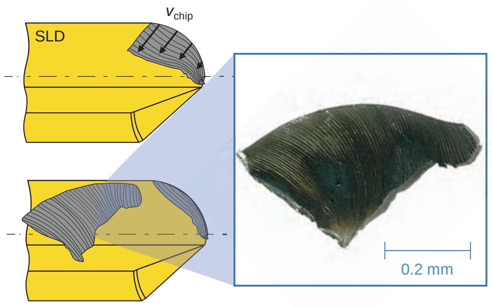




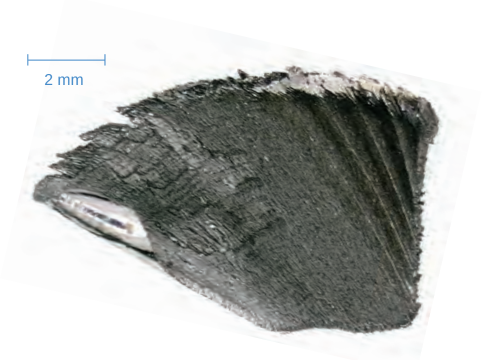
Process:

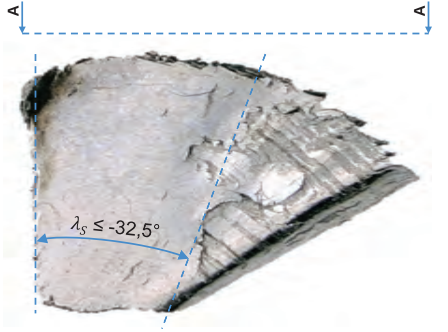
Material:	AISI 4140 / 42CrMo4+QT / 1.7225
Tool:	Botek Type 113-HP SLD, d = 5 mm
Parameters:	v_c = 65 m/min; f = 0.10 mm
Coolant:	Cutting oil, p_{lub} = 100 bar

3D-Chip formation modeling

For single-lip deep hole drilling, the tool geometry has a decisive influence on the thermomechanical loads that influence the bore's surface and subsurface during the process. By using tools with an arc-shaped outer cutting edge geometry, the normal forces acting on the guide pads can be increased compared to the tools with a standard cutting edge design. This creates a stronger mechanical impact on the bore wall, resulting in subsurface microstructure refinement as well as compressive residual stresses which can improve the components' fatigue performance. The arc-shaped cutting edge geometry produces a distinctive chip shape, which is presented here. In a 3D simulation, the chip formation process, among other process characteristics, can be modeled and analyzed in detail.

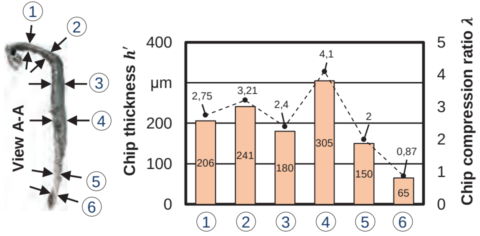
Source: Jan Nickel M.Sc.; Gabriel Brock M.Sc.
Institute of Machining Technology, TU Dortmund





Process:

Material:	Quenched and tempered steel 42CrMo4+QT
Tool:	AK-UR-system (out-of-round chambers)
Parameters:	v_c = 15…12 m/min; f = 0.075 mm; $\dot{V}_{Oil}$ = 90 l/min

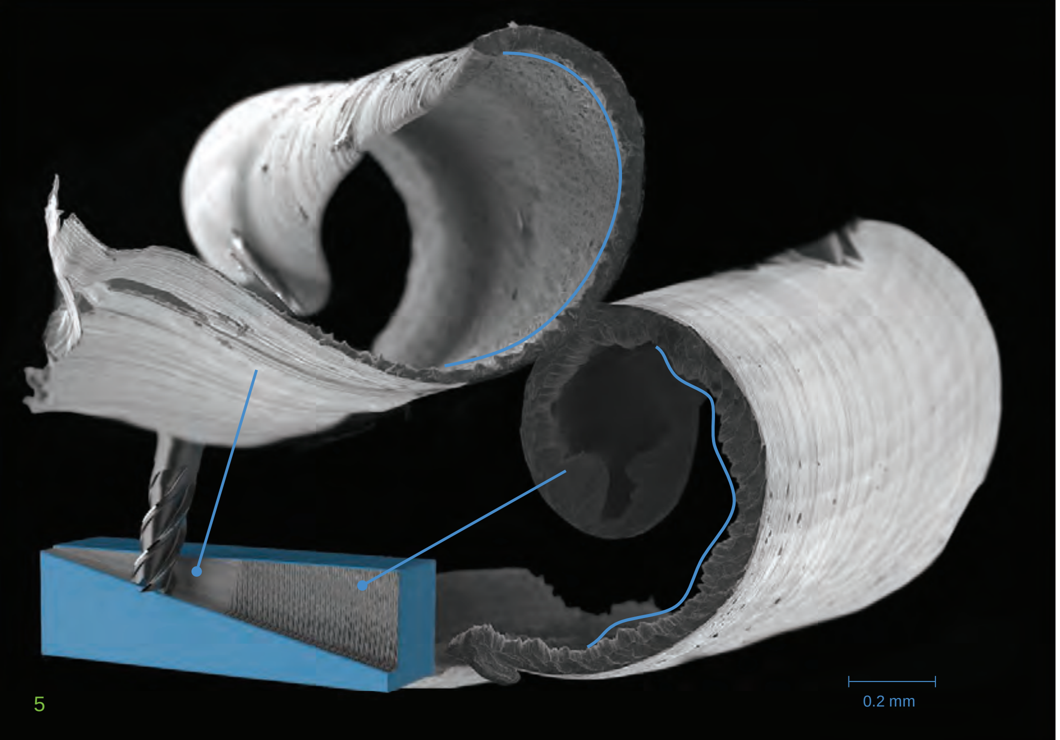


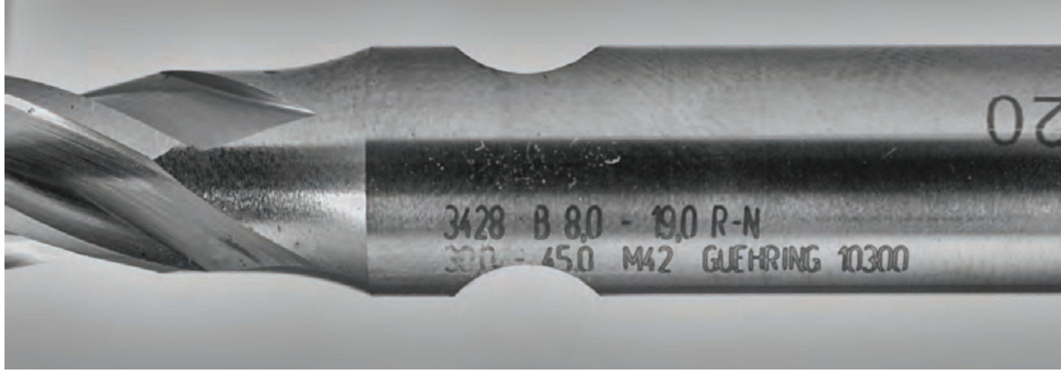
AK-UR-process

The AK-UR-process is a novel chamber boring system which allows contouring boreholes in axial and radial directions to produce special profiles required by the oil industry. The machined contour produced by this system consists of six convexities in radial direction. This results in a continuous change of the cutting speed v_c and the tool cutting edge inclination λ_S in the process.

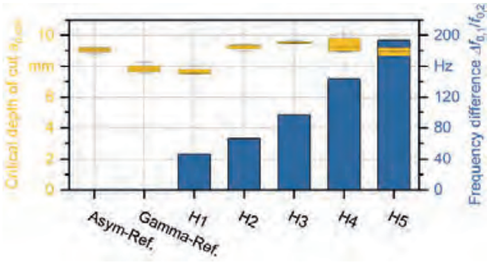
The resulting chip compression ratio λ is in the range from 4.1 to 0.87 and is related to the change of the tool cutting edge inclination in combination with the protective chamfer of the cutting edge. There are different chip forms. The bottom side of the chip shows continuous chip formation with a smooth surface in the range of $\lambda_S \leq$ -32,5°. A significant segmentation of the chip is shown on the upper side of the chip.

Source: Dr.-Ing. Moritz Fuß
BGTB GmbH, Dortmund





Process: **Shoulder milling with increasing depth of cut**
Material: EN AW-7075
Tool: Cylindrical HSS tool with modifications
Parameters: n = 12500 min^{-1}; f_z = 0.06 mm; a_e = 1 mm; a_p = 3 mm

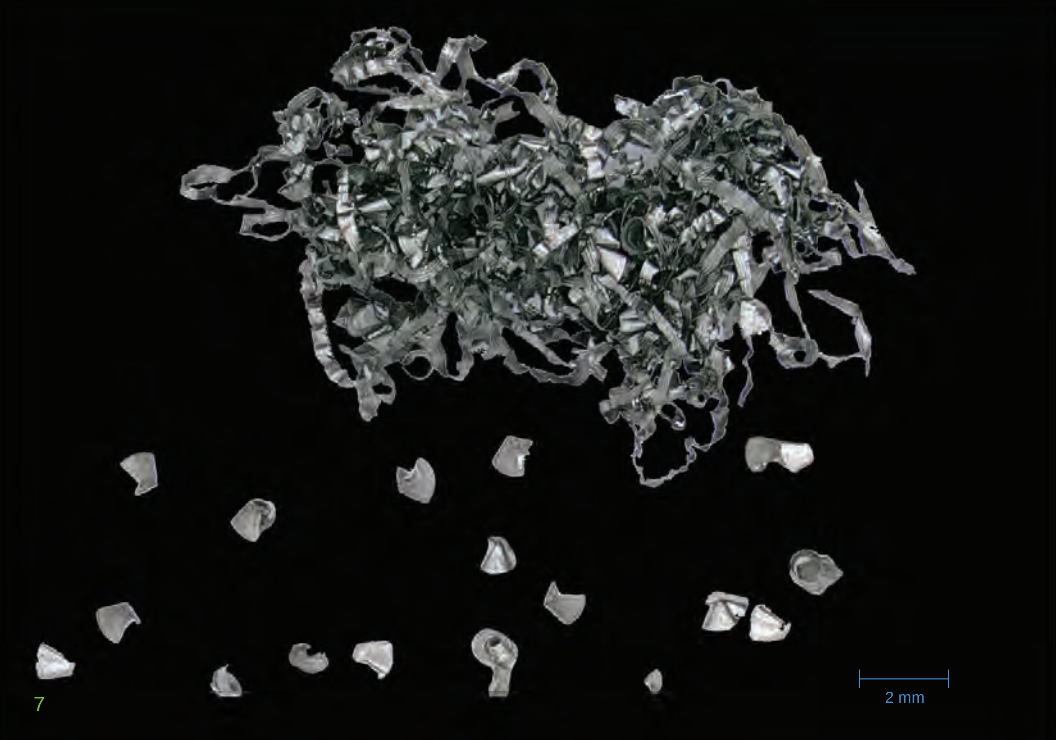


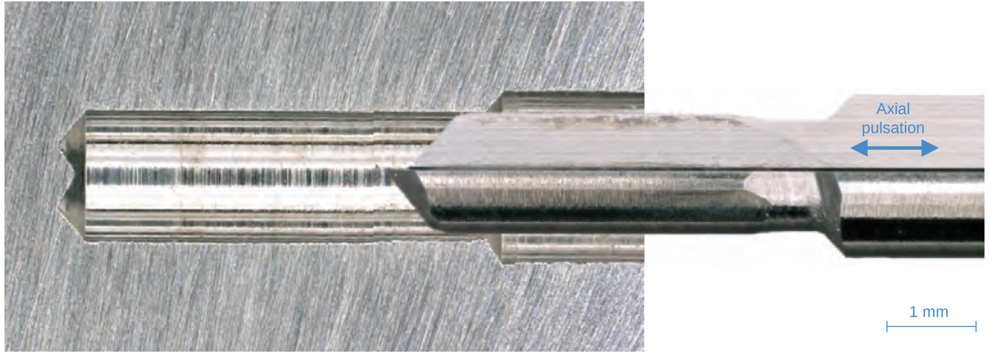
AsymTool

One objective of innovative tool development is to continuously increase process stability. Based on specific influences of dynamic asymmetries by means of structural modifications to the tool, productivity can be increased by up to 60%.

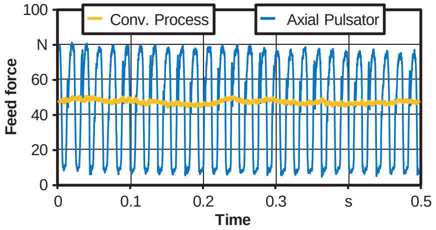
The required modifications are simple - small notches on the tool shank lead to direction-dependent dynamic properties of a four-fluted milling tool and can effectively disturb the regenerative effect. Tools modified in this way can additionally be combined with other approaches, such as flank faces equipped with functional structures to further increase process stability. Initial investigations here have shown an additional 20% improvement in process stability.

Source: Rafael Garcia Carballo M.Sc.
Institute of Machining Technology, TU Dortmund





Process: Deep hole drilling with step drills
Material: Austenitic stainless steel (X2CrNiMo17-12-2)
Tool: Single-lip step drill d_1 = 1.5 mm; d_1 = 2.0 mm
Parameters: v_c = 30 m/min; f = 0.003 mm; p_{KSS} = 130 bar
Pulsator: Stroke 15 µm; n = 0.5 strokes per revolution



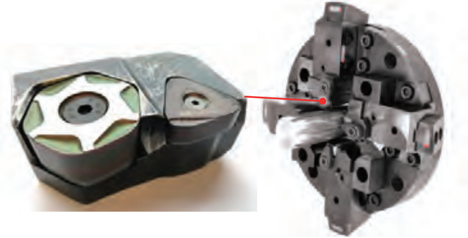
Axial pulsator

Using step drilling tools with conventional process control often involves the risk of long chip formation due to the low chip thickness, as shown in the upper part of the left picture. The use of an axial pulsator can improve chip breaking and ensure process stability under such demanding process conditions.

The continuous feed motion of the tool is superimposed with an axial oscillation. The stroke of this axial oscillation exceeds the chip thickness, resulting in a temporary interruption of chip formation. With a stroke of 15 µm at a frequency of 0.5 strokes per revolution, short chips could be produced when using a single-lip step drill due to the forced chip breaking when the tool oscillates.

Source: Pascal Volke, M.Sc.
Institute of Machining Technology, TU Dortmund

Process:	**Bar peeling**	Cutting Speed:	v_c = 30 m/min
Material:	Alloy K-500 2.4375	Feed:	f = 10.2 mm
Tool:	HNMJ 221550S60	Depth of cut:	a_p = 7 mm

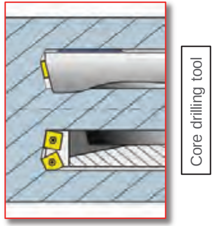


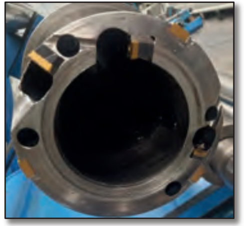
Bar peeling

Bar peeling is a high-precision machining process widely used in industrial production of bright steel after a previous drawing, rolling or forging process. The primary motivation for using this process is to achieve exact dimensional accuracies and surface finishes as well as high material removal rates. Characteristic of the bar peeling process is that the bar is fed through a rotating peeling head with a radial infeed. Applications include semi-finished products for machine manufacturers, rods as pre-material for mandrel bars, axles for wind turbines, gears, piston rods and shafts. For these purposes, the rough forged, rolled or drawn workpieces in the diameter range from 10 to 650 mm are often machined in the peeling process, producing the chips shown here as an example.

Source: Christoph Czettl, Ceratizit GmbH
Pascal Volke, Jan Nickel, ISF, TU Dortmund

Process: **BTA Trepanning**
Material: 16MnCr5 (1.7131)
Tool: BTA trepan drill head d = 200 mm
Parameters: v_c = 30 m/min; f = 0.1 mm; $\dot{V}_{Oil}$ = 180 l/min



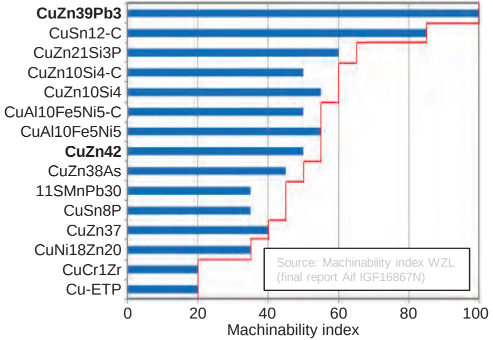


BTA Trepanning of undefined quality steel

In both deep hole drilling and trepanning, good chip breaking is important to avoid process interruptions. The chips shown here are from a deep-drilled shaft made of 16MnCr5. The material was sourced from China and the attached Chinese certification documents proved to be unreliable.

When Delta GmbH machined the material, it turned out that the material properties were not as expected, regardless of the certificate. The drilling process took many times longer than the expected 90 minutes. The problems found in machining the material, as well as the chips shown, indicate that the material was of inferior quality and did not meet the expected properties of 16MnCr5 steel.

Source: BGTB GmbH / Delta Qualitätsstahl GmbH



Source: Machinability index WZL (final report Aif IGF16867N)

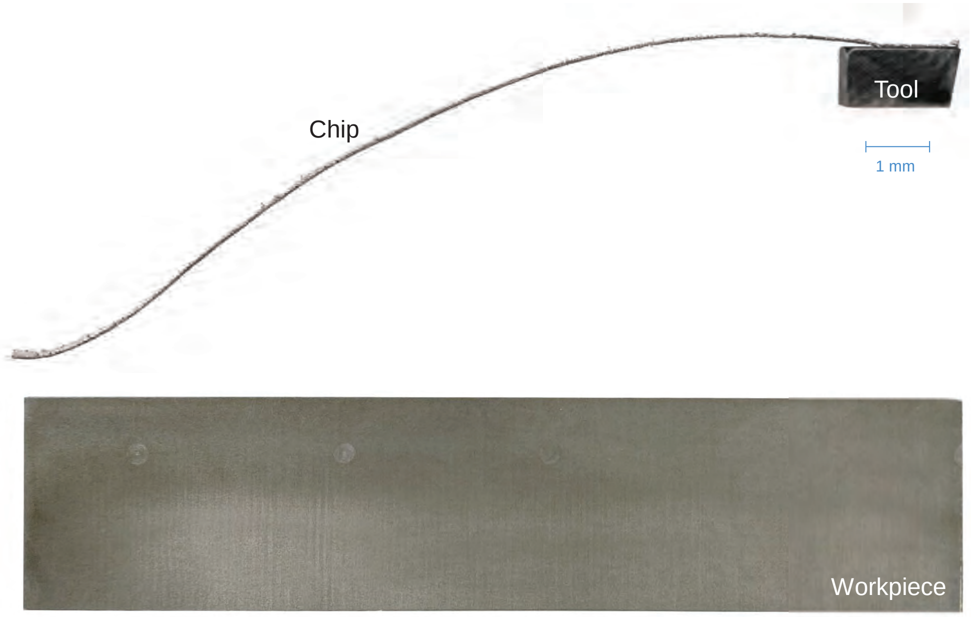
Process:	Groove-turning in free orthogonal cut
Material:	Varied (CuZn42/CuZn39Pb3) Round bar
Tool:	Groove-turn tool No chip groove
Machine tool:	DMG Mori NZX 1500
Parameters:	Cutting speed v_c = 150 m/min Feed f = 0.1 mm Depth of cut a_z = 3 mm
Cooling-lubrication:	Flood-cooling with oil

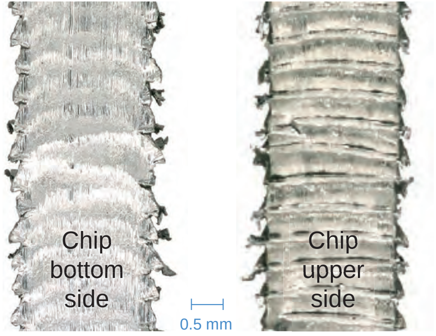
Challenge of lead-free material

Lead is an element that is harmful to health and the environment. On the other hand, it can impart improved machinability to alloys such as brass. In particular, the chip breaking behavior can be improved by adding lead. This is reflected, in summary, in the very different machinability indexes of the alloys.

What looks like a beautiful gold curl to the layman is a challenge for machining in terms of removal from the machine tool. In order to dispense with the use of lead in the alloy in the future and still enable process-reliable machining of brass, alternative solutions must be identified in terms of material composition and tool design.

Source: Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University

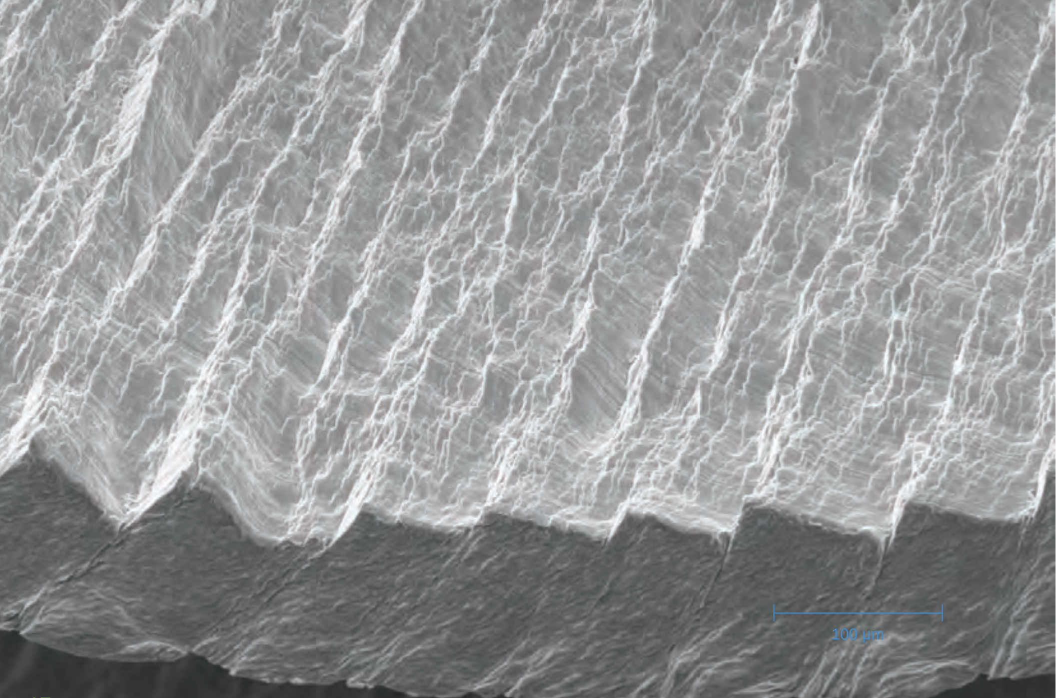


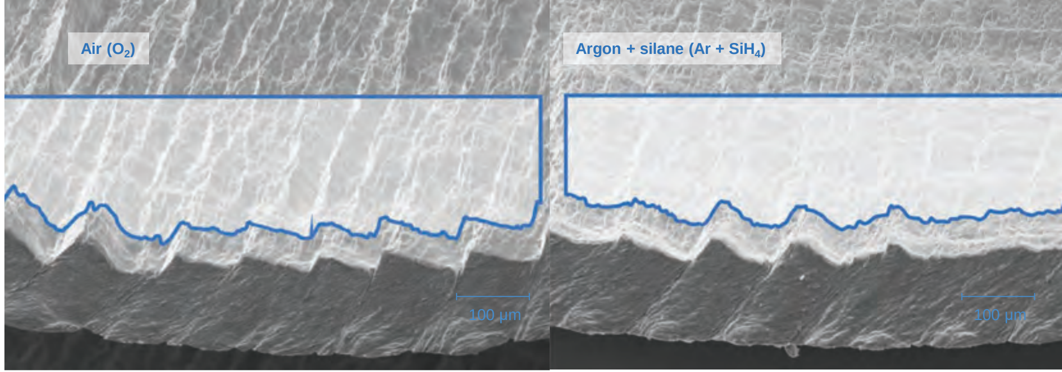


Chip elongation

During machining, the material is strongly compressed before the chip is formed and separated from the workpiece. For most materials, this results in a chip thickness higher than the previously set uncut chip thickness. This is referred to a chip compression $\lambda > 1$. As a result, the length of the resulting chip is shorter than the cutting length due to volume constancy. When machining titanium alloy Ti6Al4V, segmented chip formation with unstable chip flow is characteristic. Instead, the accumulated material slides along a shear plane and the next segment is formed. In this case, the chip compression of the individual segments can still be higher than one, but the resulting cohesive chip can be longer than the cutting length. Thus, the average chip compression occurs to be $\lambda < 1$.

Source: Sebastian Berger M.Sc.
Institute of Machining Technology, TU Dortmund



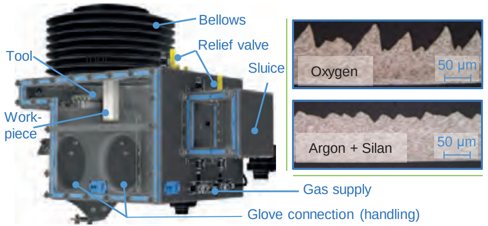


Chip formation of Ti-6Al-4V in oxygen-free atmosphere

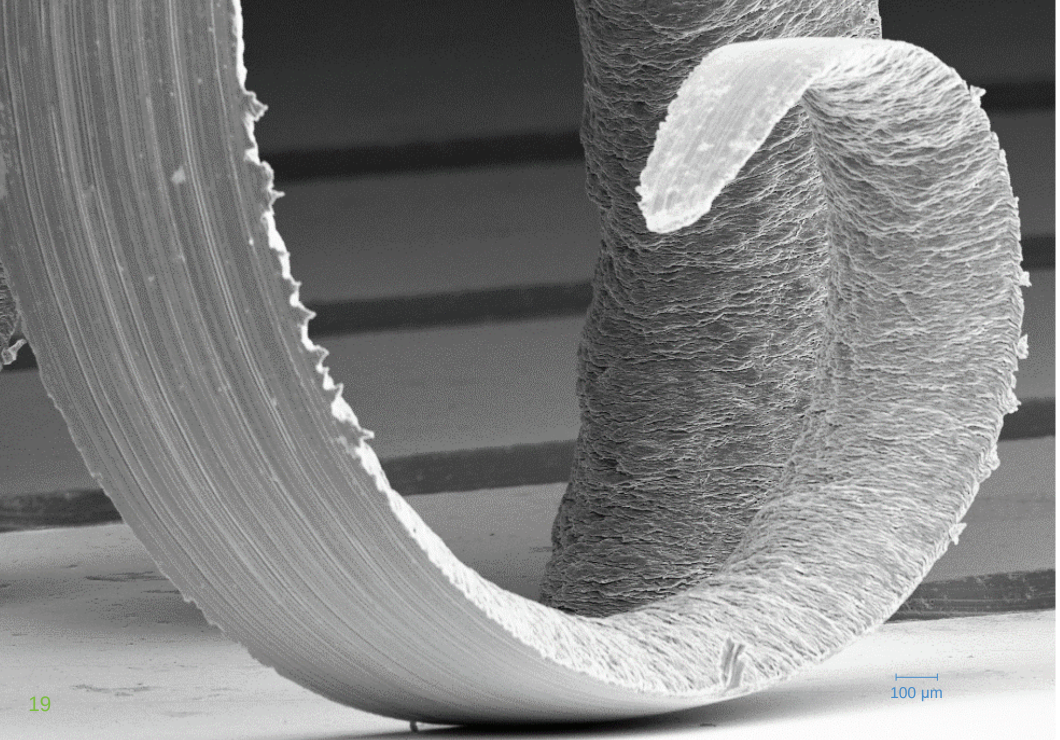
Machining of titanium and titanium alloys is subject to the influence of the workpiece material's low thermal conductivity and its notable chemical affinity to surrounding process elements, such as oxygen, particularly when exposed to elevated process temperatures. Cutting processes of titanium and titanium alloys such as Ti-6Al-4V are usually characterized by unfavorable chip formation with typical segmented surfaces of the occurring chips.

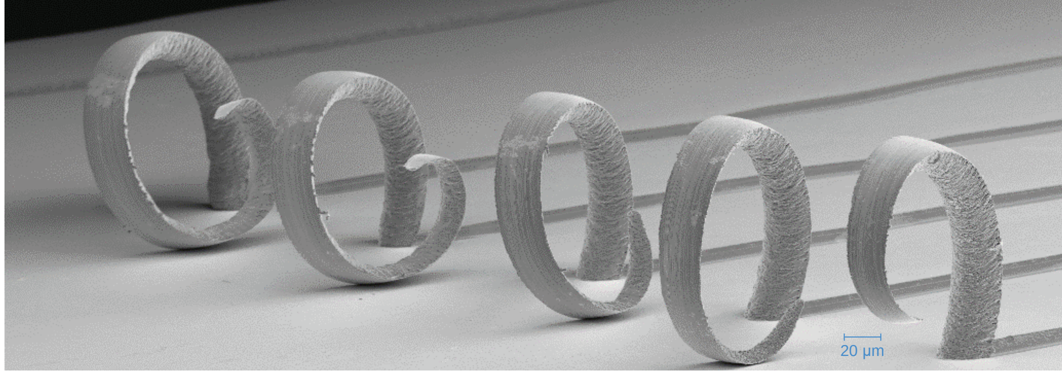
Creating an almost oxygen-free atmosphere by the use of argon and silane in an encapsulated discontinuous orthogonal cutting process affects the occurring friction and temperature. Due to reduced friction and temperature, the occurring feed forces are up to 16.5% lower under inert gas atmosphere. In addition, the typical segmentation of the chips is significantly reduced.

Process:
Material: Ti-6Al-4V
Tool: uncoated cemented carbide insert; $\alpha = 6°$; $\gamma = 6°$
Parameters: $v_{c\,max} = 80$ m/min; $h = 0.1$ mm; $w = 3$ mm
Medium: air (O_2); argon + silane ($Ar + SiH_4$)



Source: Dr. Benjamin Bergmann, Florian Schaper M.Sc.
IFW, Leibniz University Hannover





Chip root generation

The generation of chip roots by cutting interruptions is widely used to analyze and characterize chip formation mechanisms. Accurate characterization requires a sudden interruption with minimal separation time, achieved by accelerating the workpiece or displacing the cutting tool opposite to the cutting motion. In this study, workpiece acceleration was achieved using a stop mechanism on the tool side, resulting in acceleration distances of 1.66 µm per m/min of cutting speed. Despite these substantial distances relative to chip thickness, the analyses do not reveal any constraints in understanding the factors influencing chip formation.
In the case shown, the impact of cutting speed is manifested as a notable decrease in chip compression with increasing cutting speed.

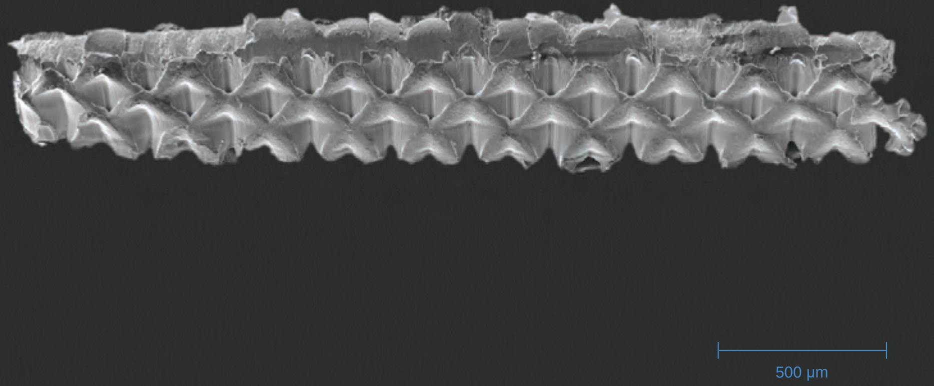
Process:
Material: S235JR (1.0038)

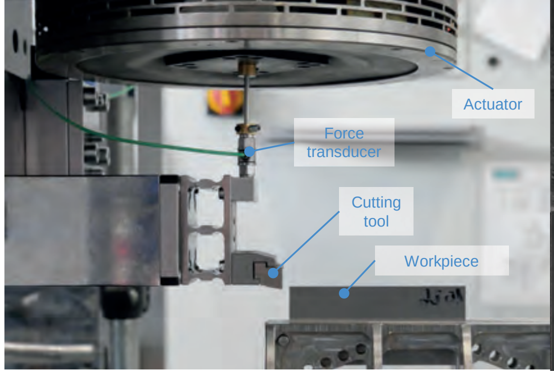
Tool: Rake angle γ_0: 13°
Clearance angle α_0: 7°
Corner radius r_ε: 100 µm

Parameters: Cutting depth a_p: 30 µm
Cutting speed v_c: 30 … 300 m/min

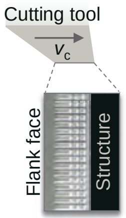
(from left to right: 300; 240; 120; 60; 30 m/min);

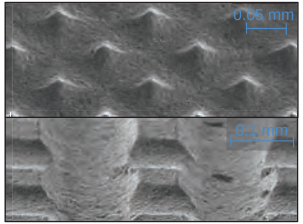
Source: Dr.-Ing. Jan Kästner
IFW, Leibniz University Hannover

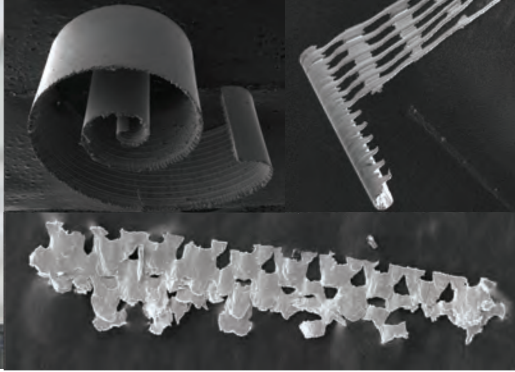




Process: **Orthogonal cutting**
Material: Aluminum alloy 7075-T6
Tool: HSS cutting tool with structured chamfer
Parameters: v_c = 180 m/min; a_p = 0.1 mm; a_p = 4 mm
Actuator: $d_{n,amp}$ = 15 µm; periodic oscillation f_{exc} = 1611 Hz







"Waffle chips"

The occurrence of process damping in machining is an effective influencing factor in suppressing regenerative chatter vibrations. Although process damping is typically attributed to worn tools at low cutting speeds, the use of tools with flank face chamfers is an effective strategy to specifically increase process stability over a wide range of speeds. To further increase the damping potential of the chamfer, a modification with surface structures was carried out. Using a setup that provides defined, high-frequency tool vibrations, basic relationships of the dynamic chamfer-workpiece contact were characterized and the influence of structure variants on the energy dissipation and its damping potential was evaluated.

Source: Timo Platt M.Sc.
Institute of Machining Technology, TU Dortmund
Florian Wöste M.Sc.
Virtual Machining, TU Dortmund

Process: **Circular face milling**
Material: X2CrNiMo18-14-3 (1.4435)
Tool: Milling cutter with indexable inserts, *d* = 32 mm
Parameters: v_c = 80 m/min; f_z = 0.1 mm;

Circular face milling

In order to obtain accurate and reliable results in deep hole drilling investigations of stainless steel, the sample preparation is crucial. The face of the sample serves as a reference plane for measuring the straightness deviations of the bore holes. The surface of the samples is smoothed using a face milling process to create a uniform surface by guiding the tool in a circle around the sample to remove material from the surface.

However, the particular kinematics of the circular milling path, with an increasingly narrow width of cutting engagement in the final orbit, and the toughness of the material hindering chip separation and promoting burr formation result in the formation of a chip with characteristic spirals.

Source: Mike Zimon M.Sc.
Institute of Machining Technology, TU Dortmund

Process:	**Face milling**
Material:	Polyoxymethylen Copolymer (POM-C)
Tool:	Face milling cutter, 6 cutting edges d = 80 mm
Parameters:	v_c = 200 m/min; f = 320 mm/min; a_p = 8 mm
Coffee:	Neues Schwarz unión progreso Espresso

Whole bean

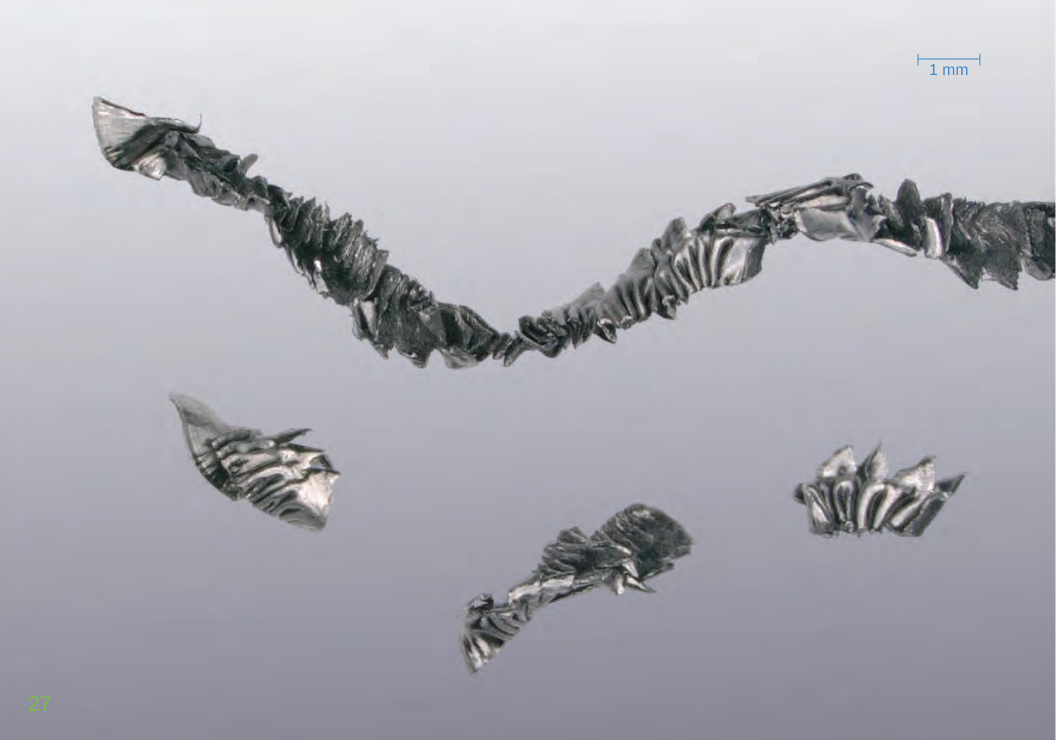
Growing altitude:	1500 – 1650 m
Origin:	Peru
Aromas:	grape, walnut, chocolate
Roast:	medium

Decorative chips

The scientific exchange through lectures, demonstrations and panel discussions at conferences and seminars or through guest lectures in the context of academic courses thrives on the willingness of the people involved to share their knowledge and expertise with others. The small attentions and presents, such as ISF cups with selected coffee specialties from a local roastery in Dortmund, are well packaged with decorative chips from our own production.

The production of the white chips from a thermoplastic material is of course carried out without cooling lubricant. The appropriate chip shape from a face milling process of block material was determined in a series of tests under variation of cutting speed, feed rate and cutting depth.

Source: Nicole Kneppe, Kim Roberts, Jaskirt Sharif
Institute of Machining Technology, TU Dortmund

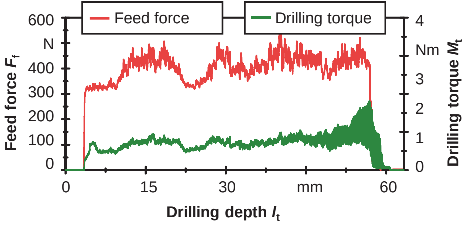


Deep hole drilling of titanium

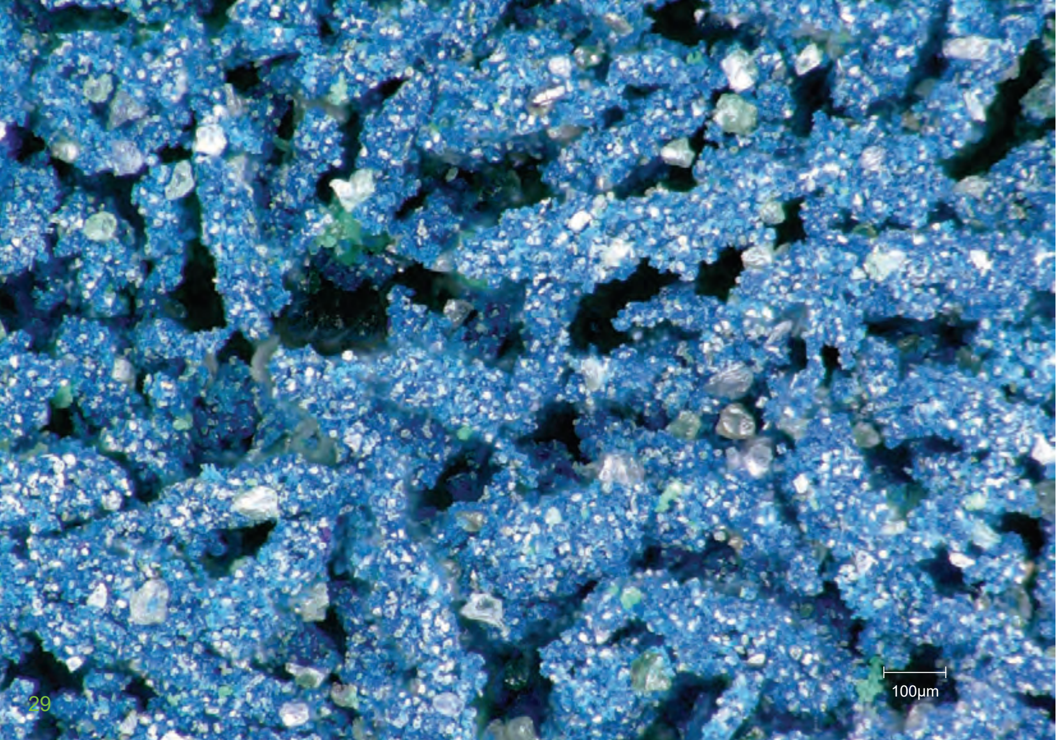
Due to the material properties such as high specific strength and very good corrosion resistance, titanium and its alloys are frequently used in the aerospace, automotive and chemical industries. However, the low thermal conductivity leads to high thermomechanical tool loads during machining, which requires an optimum cooling lubricant supply to the cutting edge.

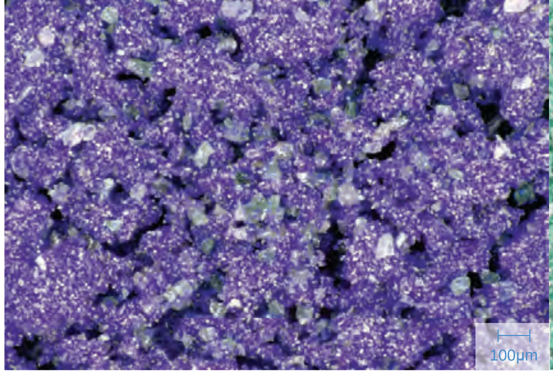
In addition to the cooling effect, the cooling lubricant supports the removal of the chip from the bore hole. This is particularly important, since the material's toughness promotes the formation of long chips that can jam in the flutes of the drill and lead to tool failure.

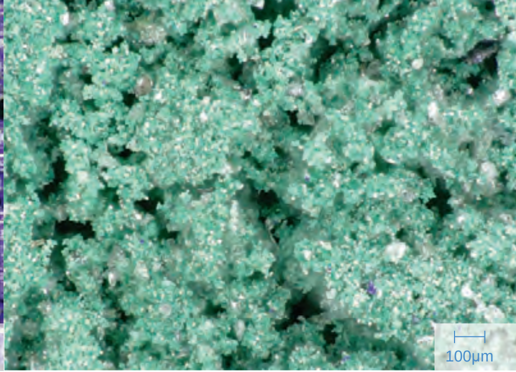
Process: **Deep hole drilling**
Material: Titanium alloy Ti6Al4V (3.7164)
Tool: Deep hole twist drill, d = 3.0 mm, solid carbide
Parameters: v_c = 30 m/min; f = 0.065 mm;
p_{KSS} = 120 bar; l/d-ratio = 20



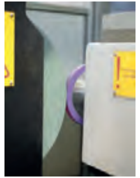
Source: Mike Zimon, M.Sc.
Institute of Machining Technology, TU Dortmund







Process:	**Dressing process**
Material:	Elastically bonded diamond grinding wheels Grain size: $d_G \approx 10 \dots 15$ µm
Tool:	Dressing wheel, SiC (grain size: F240)
Parameters:	$q_d = 0.8$ (down-dressing), $a_{ed} = 2$ µm, $U_d = 14$
Coolant:	None

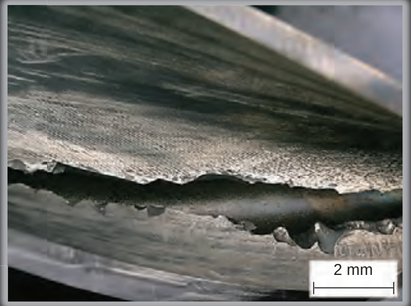


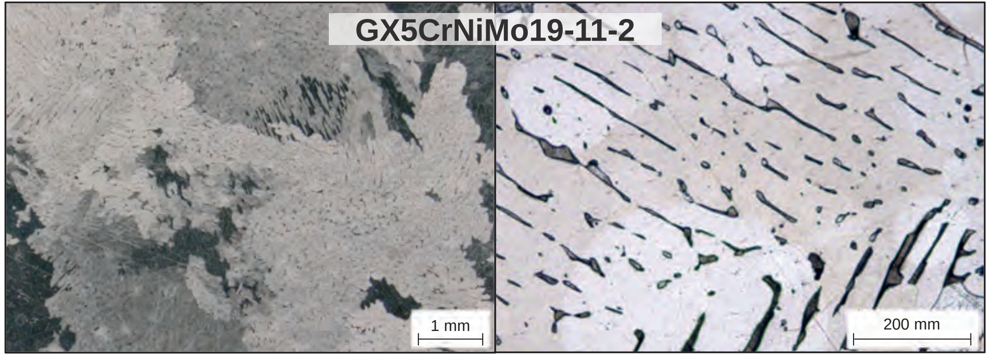
Dressing of elastically bonded diamond grinding wheels

Elastically bonded diamond grinding wheels are a suitable tool concept for the fine-finishing of functional surfaces, for example of cemented carbide cutting tools. One application in this context is the preparation of the flutes of twist drills. By fine-finishing the flutes, it is possible to enhance the reliability of the drilling process.

A key boundary condition for a targeted fine-finishing process is the dressing of the elastically bonded diamond grinding wheels. The dressing process determines the shape and profile of the elastically bonded diamond grinding wheels as well as the topography. The microscopic images show chips generated during the dressing process for different specifications of the grinding tools.

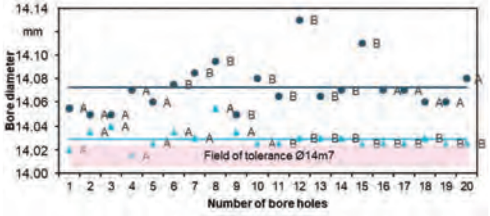
Source: Dr.-Ing. Monika Kipp
Institute of Machining Technology, TU Dortmund





General Parameter	MQL Parameters
Material: GX5CrNiMo19-11-2 Tool: Twist drill; *d* = 14 mm	Cutting speed: v_c = 20...45 m/min Feed: f = 0.1...0.175 mm

		Flood cooling parameter
● MQL	▬ Median MQL	Cutting speed: v_c = 60 m/min
▲ Flood cooling	▬ Median Flood	Feed: f = 0.1 mm
A: Tool-1	B: Tool-2	

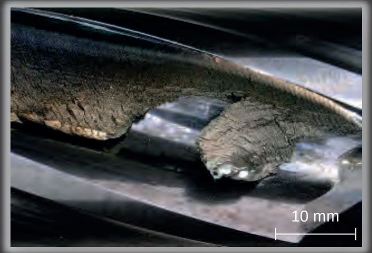


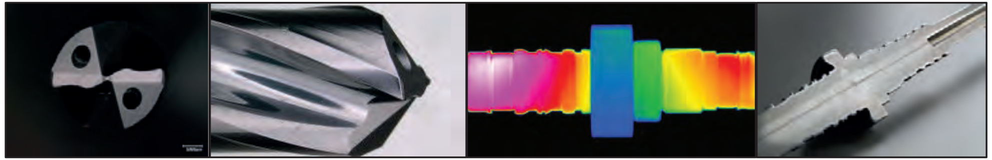
Drilling in high alloy cast steel with MQL

Turbomachinery has a rich history and is characterized by its precise, technologically advanced components. Whether used in power plants as steam turbines operating under high temperatures or utilized in the processing of highly toxic gases, the materials used in turbomachines must withstand extreme conditions. Considering the demanding nature of these materials, which are already difficult to cut even with traditional flood lubrication methods, MQL has received limited attention in this field.

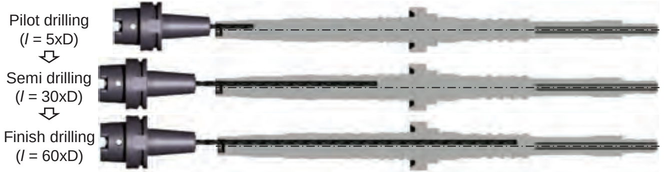
This study focuses on the analysis of drilling and tapping processes under MQL, as these processes pose significant challenges due to the elevated temperatures at the cutting edges of the tools, which are difficult to access within the workpiece.

Source: Martin Sicking, M.Eng.
Institute of Machining Technology, TU-Dortmund

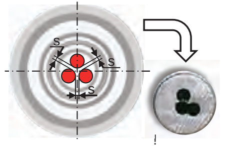




Three-stage deep hole drilling process



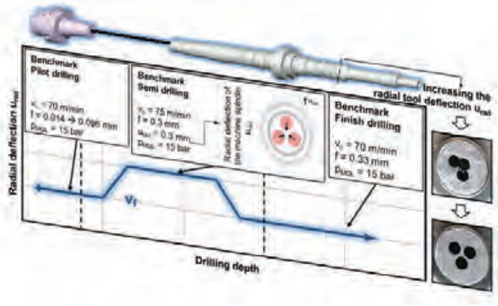
Gap width and center deviation



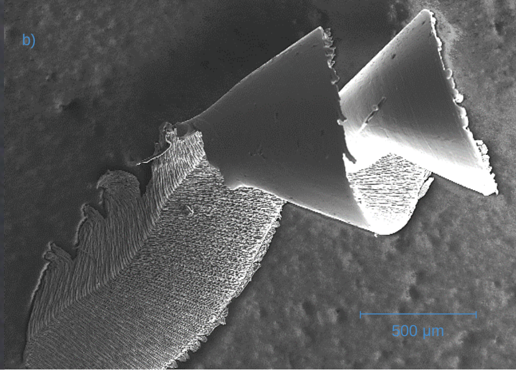
$s_{nom} \approx 1{,}7\text{ mm} \wedge s(l) \geq s_{nom}$

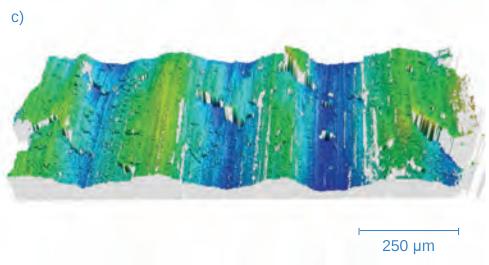
Energy efficient high performance deep hole drilling

The main objective of this project was to develop and validate the fundamental knowledge and methodology for simulating and compensating for thermomechanical distortions in deep hole drilling of complex drive components. The goal was to minimize both mechanical and thermal stress on the components while enabling a highly efficient and productive MQL deep hole drilling process. Deep hole drilling, especially when transitioning from conventional flood lubrication to MQL, is considered one of the most challenging machining operations due to difficulties in chip removal and managing heat input. Therefore, the success of implementing energy-efficient MQL technology relies heavily on addressing these challenges.



Source: Martin Sicking, M.Eng. / Dr.-Ing. Ivan Iovkov
Institute of Machining Technology, TU-Dortmund



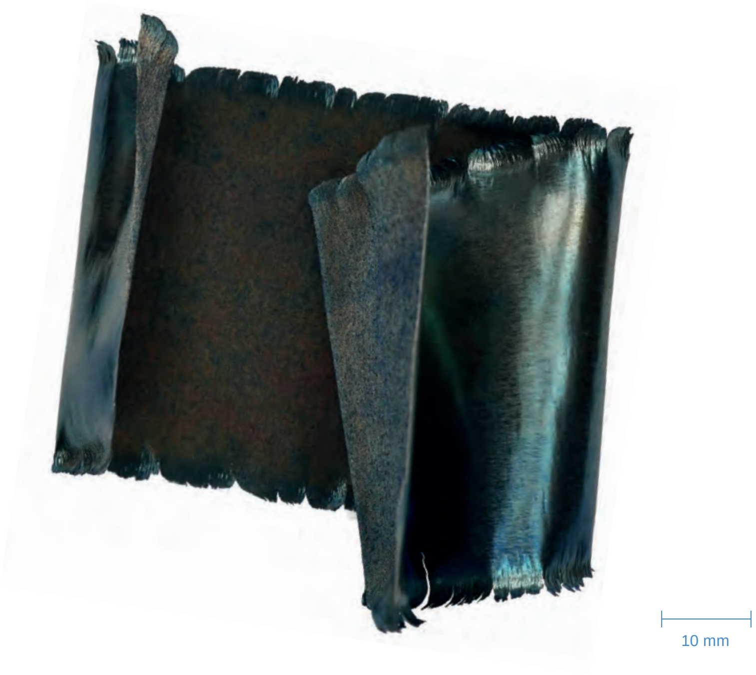


Examination methods for analyzing chips

When working as a student assistant at the Institute of Machining Technology at the TU Dortmund University, analyzing chips is a regular tasks. Usually, they are collected and sorted in type cases as shown on the prior page. Depending on the chip size and the properties to be examined, different microscopes can be used.

Thereby, the reflected-light microscope is the most frequently used variant (figure a). It offers the possibility to quickly determine important parameters such as chip compression and curvature. For a more detailed representation of a chip's structure, a scanning electron microscope (figure b) is utilized. Alternatively, a confocal microscope can be used to create a digital representation of the chip's surface topography (figure c).

Source: Dr.-Ing. Marko Kirschner, Jannis Saelzer M.Sc.
Institute of Machining Technology, TU Dortmund



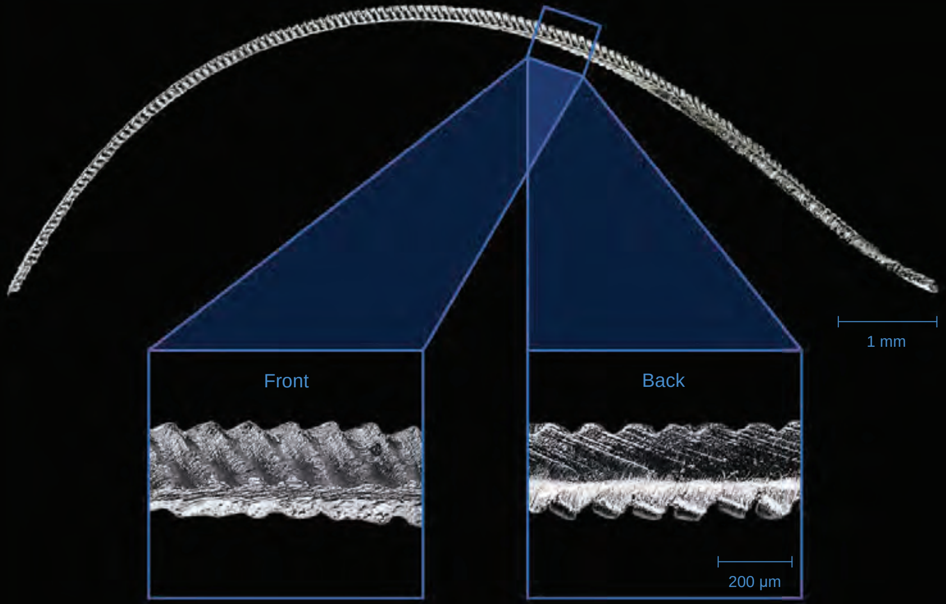
Process: **External grooving**
Material: High Speed Steel HSS
Tool: Ceramic Insert, width 50 mm
Parameters: v_c = 10 … 15 m/min; f = 1 mm

External grooving of high-speed steel

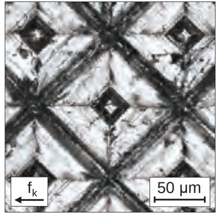
In the production of rollers, the barrel, which is subjected to high loads during use, is prefabricated from high-speed steel (HSS) in a centrifugal casting process. Subsequently, the bearing and drive journals are made from GGG60/GGG70 in mold casting, using the barrel as an insert. Due to the high wear resistance of HSS, machining the barrel is a challenge for conventional carbide tools.

By using ceramic inserts, machining can be realized by external longitudinal turning and external grooving. With a width of the grooving insert of 50 mm at a feed rate of f = 1 mm, the machining of the rolls can be realized very productively.

Source: Univ. Prof. Dipl.-Ing. Dr. techn. Friedrich Bleicher,
IFT TU Wien

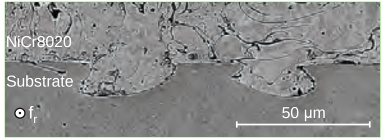


Process: **Cross knurl milling**
Material: 42CrMo4+QT (1.7225)
Tool: Type BL15/BR15 (tungsten carbide), pitch: 0.1 mm
Parameters: f_k = 0.075 mm; v_k = 50 m/min; a_k = 0.20 mm
Lubrication: Emulsion, 6%

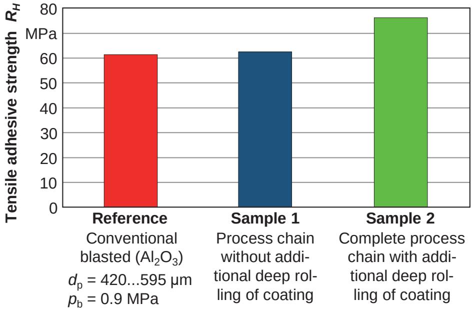


Following steps of the complete process chain

Substrate deep rolling -mechanical-	***NiCr8020 APS coating***	***Coating deep rolling -hydrostatic-***
$f_{r,S}$ = 0.05 mm $v_{r,S}$ = 50 m/min $a_{r1,S} = a_{r3,S}$ = 0.245 mm $a_{r2,S} = a_{r4,S}$ = 0.265 mm d_{Ball} = 4.06 mm Emulsion, 6%		$f_{r,S}$ = 0.05 mm $v_{r,S}$ = 50 m/min $p_{r1,C} = p_{r2,C}$ = 10 MPa d_{Ball} = 4.00 mm Emulsion, 6%



Tensile adhesive strength values of the tested samples

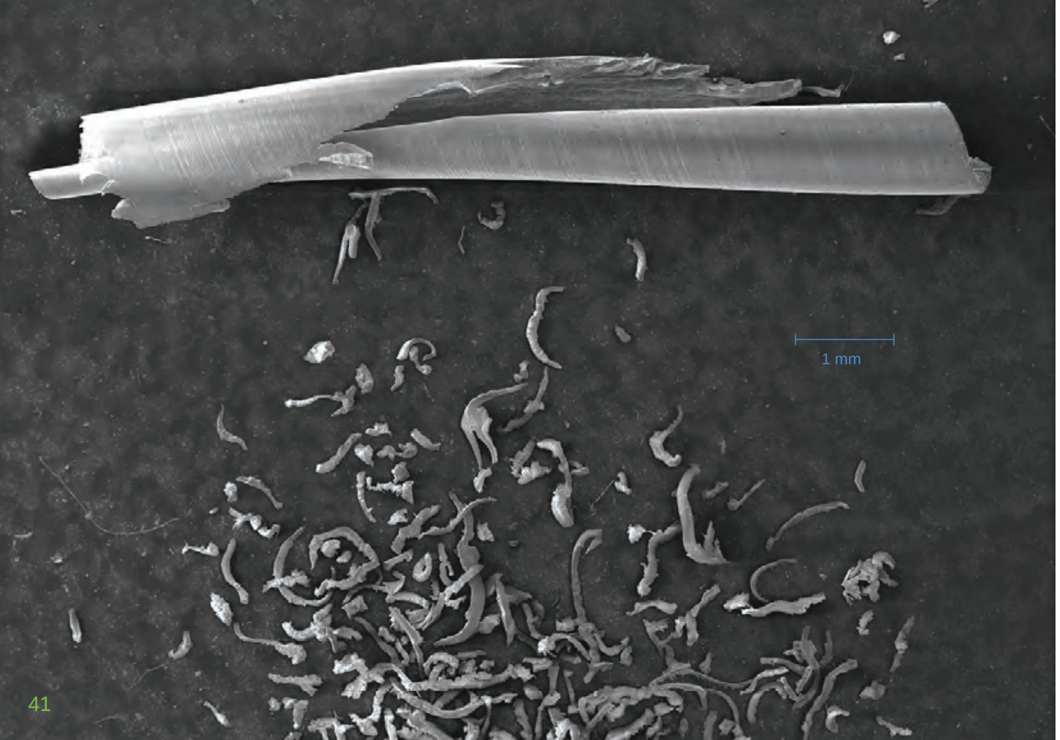


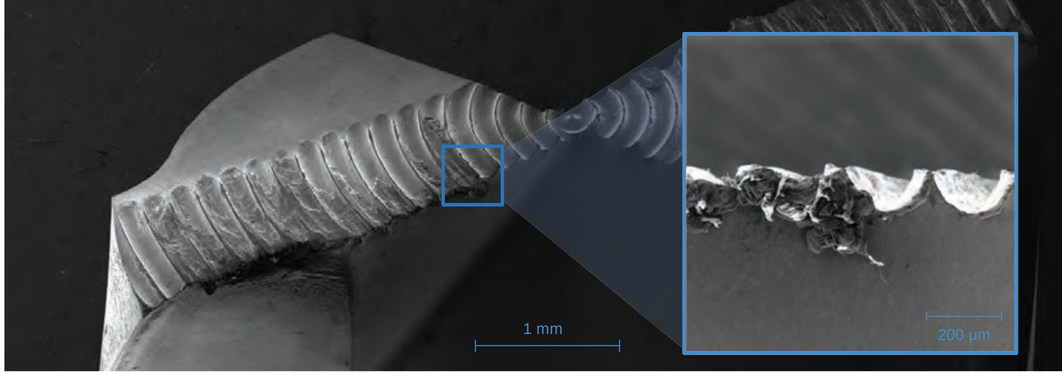
Form-locked bonding of coatings

Cross knurling is typically used to improve the haptic properties of components such as adjusting wheels. The two knurling wheels, which are at opposite angles to each other and are only rotated by turning the shaft-shaped components, mill a pyramid-shaped structure into the surface. This results in the typical chip shape shown on the left side, which is a negative of a milled structure area.

However, cross knurling can also be used as part of an innovative process chain. Subsequent multistage rolling of the knurling structure results in symmetrical undercuts, which enable a form-locked substrate bonding of thermal sprayed coatings. Tensile adhesive strengths in the range of conventionally blasted samples can be achieved. Further two-stage rolling of the coating leads to a significant improvement in the layer adhesion.

Source: Dipl.-Ing. Florian Vogel
Institute of Machining Technology, TU Dortmund



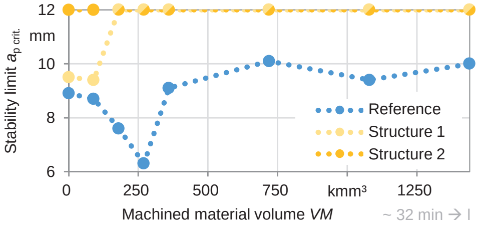


GammaTool

The use of structured flank faces on the frontal cutting edge of milling tools can significantly increase the dynamic process stability. This approach to avoid regenerative oscillations is characterized in particular by its universal applicability. In an experimental evaluation, potentials of up to 69% higher productivity were demonstrated.

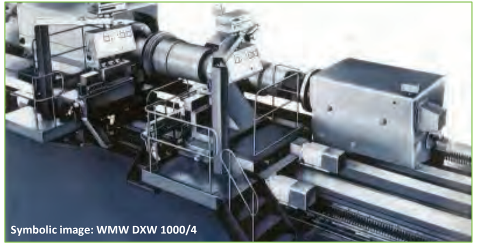
Two types of chips are formed in the process. A **volume chip**, which is formed on the circumferential cutting edge, is the result of the significant material removal. In addition, **microchips** are generated by cuts of the structured frontal cutting edge in the material, whose interaction with the structure flanks causes a stabilizing effect.

Process:
Material: EN AW-7075 T651
Tool: HSS end mill cutter; $z = 2$; $D = 8$ mm; $l_{max} = 12$ mm
Parameters: $n = 14300$ min^{-1}; $a_p = 10$ mm; $a_e = 3.5$ mm; $f_z = 0.12$ mm



Source: Jonas Baumann M.Sc.
Institute of Machining Technology, TU Dortmund

Process:	**Turning (grooving)**
Material:	Steel
Tool:	P40 carbide turning tool
Parameters:	v_c = 60 … 80 m/min; f = 3 mm

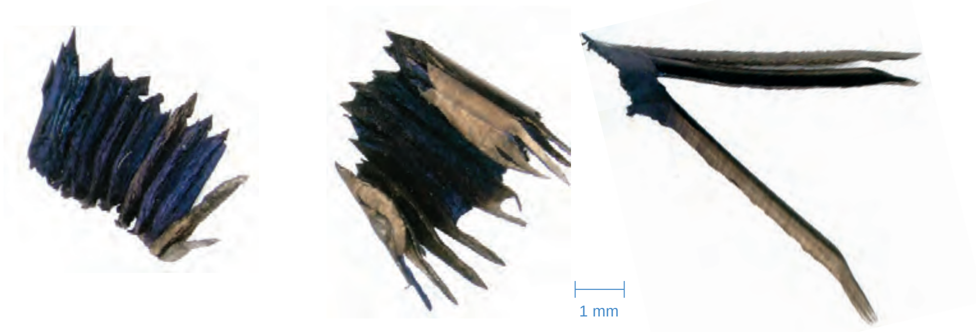


Symbolic image: WMW DXW 1000/4

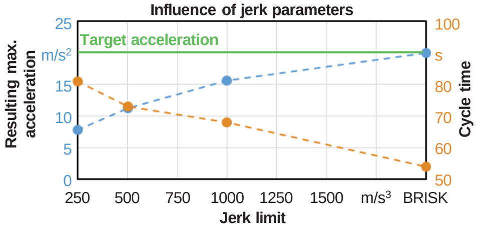
Heavy-duty grooving

In order to maintain peak productivity when turning massive workpieces, it is imperative to achieve high material removal rates. However, this results in the production of chips that can prove to be quite challenging to handle. An illustrative example is the case of a chip that was produced during the grooving of a roller way back in 1982. At that time, the machine tool used was capable of providing the enormous power that was required for the process. Nevertheless, the sheer weight of the chips, that dropped into the machine from a height of nearly one meter, made it necessary to stop the operation and rethink the process, in order to avoid damaging the machine bed. The chip shown in this example had a width of 80 mm and weighed 364 grams.

Source: Ulrich Krenzer, MAPAL
Fabrik für Präzisionswerkzeuge Dr. Kress KG



Process: **Milling**
Material: 42CrMo4
Tool: End mill, $d = 10$ mm, 4 teeth
Parameters: $v_c = 200$ m/min; $f_{z,pl.} = 0,5$ mm; $v_{f,pl.} = 10.610$ mm/min; $f_{z,traverse} = 0,5$ mm; $v_{f,traverse} = 1.061$ mm/min

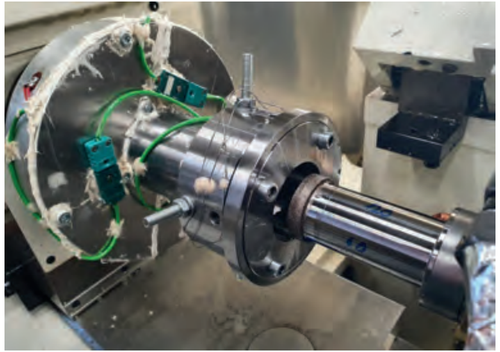


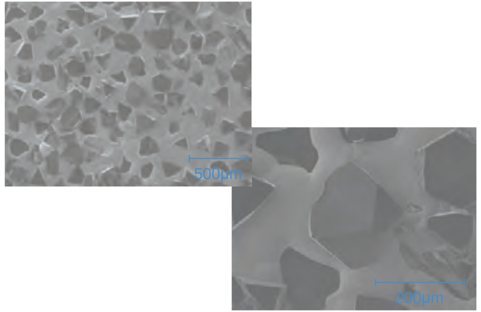
High dynamic milling

In highly dynamic milling processes, the maximum axis accelerations often reduce the productivity of the processes when using conventional machining centres. Above all, the instantaneous temporal rate of change of the acceleration, i.e. the jerk, has a great influence on the process time and the realization of the maximum acceleration of the axes.

With a parallel kinematic machine structure, the Quickstep HS 500 Neon machining center makes optimum use of the maximum axis acceleration of 20 m/s^2 and without jerk limitation travel speeds of $v_{f,plunge} = 10.610$ mm/min and $v_{f,traverse} = 1.061$ mm/min could be achieved on short acceleration paths. The picture on the left shows chips from the plunge milling phase, the chips above show the transition from plunge milling to traverse milling from left to right.

Source: Univ. Prof. Dipl.-Ing. Dr. techn. Friedrich Bleicher,
IFT TU Wien





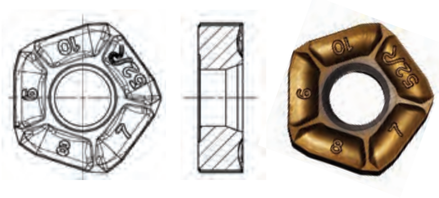
Process: **High speed internal traverse grinding**
Material: 100Cr6 (60±2 HRC)
Tool: Electroplated cBN grinding wheel, B181
Parameters: Grinding tool velocity v_t = 80 m/s;
Workpiece velocity v_w = 1.33 m/s;
Total radial stock removal: $a_{e,tot}$ = 0.050 mm,
Axial feed rate: v_{fa} = 600 mm/min

Internal traverse grinding

Internal traverse grinding using electroplated cBN tools is a highly efficient manufacturing process for bore grinding. Contoured grinding wheels with a conical roughing zone and a cylindrical finishing zone are used. This allows both high material removal and smoothing of the workpiece surface, but also results in a high local thermomechanical load on the tool and workpiece. In order to determine the thermomechanical load, a geometric physical simulation and FEM are used.
Two types of chips are formed in the grinding process. A longer and strongly segmented chip is produced in the roughing zone and small discontinuous chips in the finishing zone. The FEM results reveal high plastic deformation in periodically repeating areas of the chip and matching periodic build-up of strain in the shear zone.

Source: Tountzer Dereli M.Sc., Nils Schmidt M.Sc.
Institute of Machining Technology, TU Dortmund

Process: **Face milling with a milling head**
Material: Tool steel (40CrMnNiMo8-6-4)
Tool: Milling head *d* = 315 mm
Parameters: v_c = 60 m/min; f_z = 0,5 mm; a_p = 3,5 mm; a_e = 270 mm

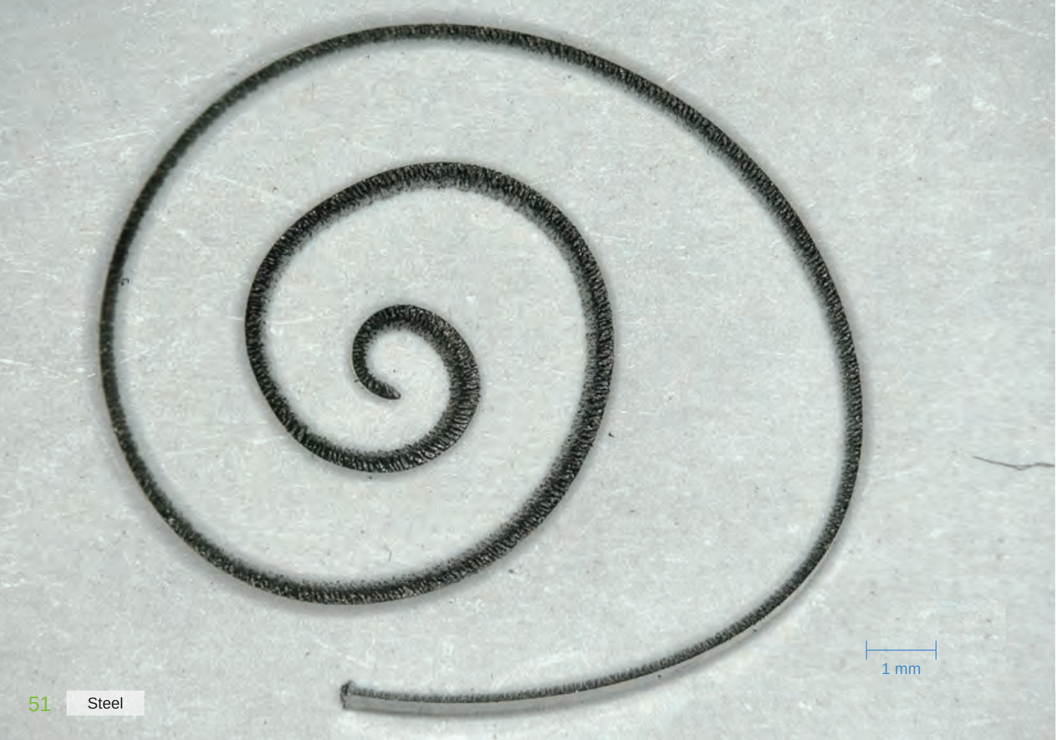


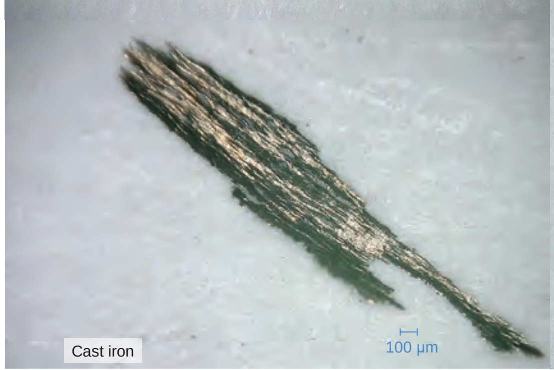
High-performance face milling

Highly stressed components in the field of tool and mould making are typically manufactured from solid material using milling processes. The first step in the process chain is usually a face milling process to remove the mill scale, bring the blank into shape and to ensure constant engagement conditions for further process steps.

For the machining of a tool steel (1.2738) with a hardness of 280 - 325 HB and a strength of approx. 950 - 1100 MPa, a milling head with a diameter of *d* = 315 mm and a total of 14 cutting edges was used. The inserts are specially designed for face milling processes with varying cutting depths and changing material properties due to the presence of mill scale.

Source: Univ. Prof. Dipl.-Ing. Dr. techn. Friedrich Bleicher,
IFT TU Wien





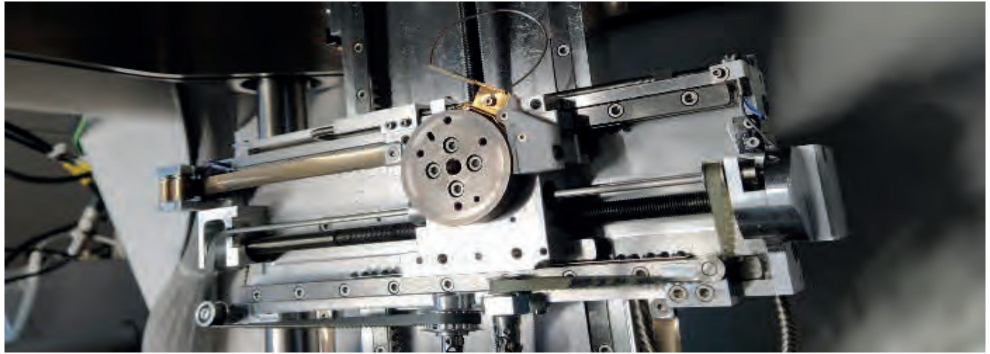
Process:	**Face milling – HSC process**
Material:	Aluminium (AlSi7Mg0,3), cast iron (GG-25), steel (C45)
Tool:	Face milling cutter, z = 1, Ø = 100 mm, AlTiN-coating, carbide
Parameters:	a_p = 0.1 mm; a_e = 70 mm; f_z = 0.6 mm Cutting velocity: - Steel: v_c = 1500 m/min - Cast iron: v_c = 1400 m/min - Aluminium: v_c = 5200 m/min

High-speed milling

In this project, high-speed milling of various materials was implemented using a face milling cutter. The tool has a cutting edge made of tungsten carbide and is designed to produce smooth surfaces while at the same time being highly economical. In this way, the grinding process can be partially eliminated.

Experiments were carried out by varying the cutting speed for the materials C45, GG-25 and AlSi7Mg0.3. The strategy of an inverse cutting ratio with $b/h < 1$ was followed in order to positively influence the dynamics of the cutting process by reversing cutting parameters and effective mechanisms. The objectives of this strategy are to increase process stability as well as surface quality and, in addition, to increase productivity.

Source: Gerrit Kuhlmann; Dmytro Borysenko
Leibniz-IWT Bremen



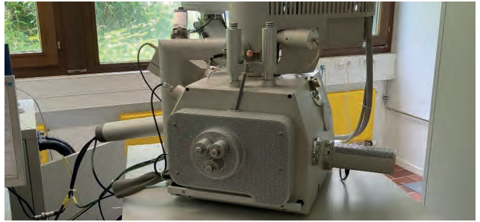
In-situ analysis of chip formation

By applying a specific cutting appliance in an SEM microscope FEI Quanta 600 FEG, the in-situ analysis of developing microchips can be achieved. Conducting experiments with different cutting parameters provides exceptional insight into the different phases of chip formation to understand and highlight its characteristics depending on its particular cutting conditions.

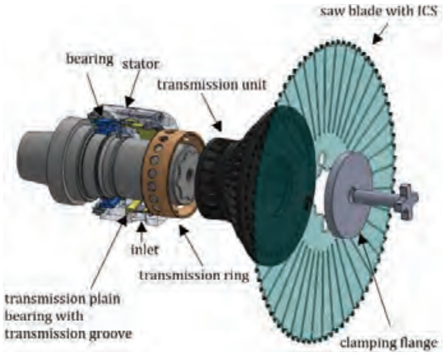
The experimental setup shown includes a brass workpiece in contact with a special tool made of PN90 grade carbide.

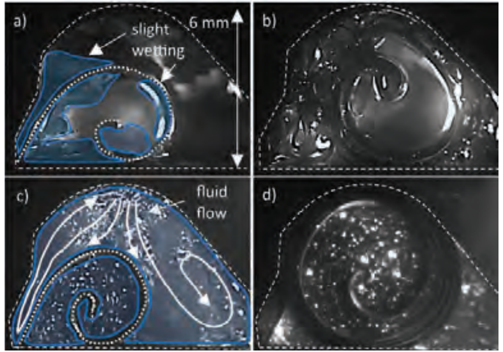
Process information

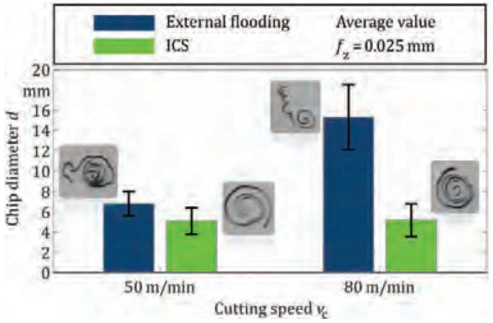
Microscope:	FEI Quanta 600 FEG Scanning electron microscope
Material:	Brass
Tool:	Cemented Carbide PN 90 custom-made cutting tool



Source: RPTU Kaiserslautern-Landau
Prof. Dr.-Ing. Jan C. Aurich



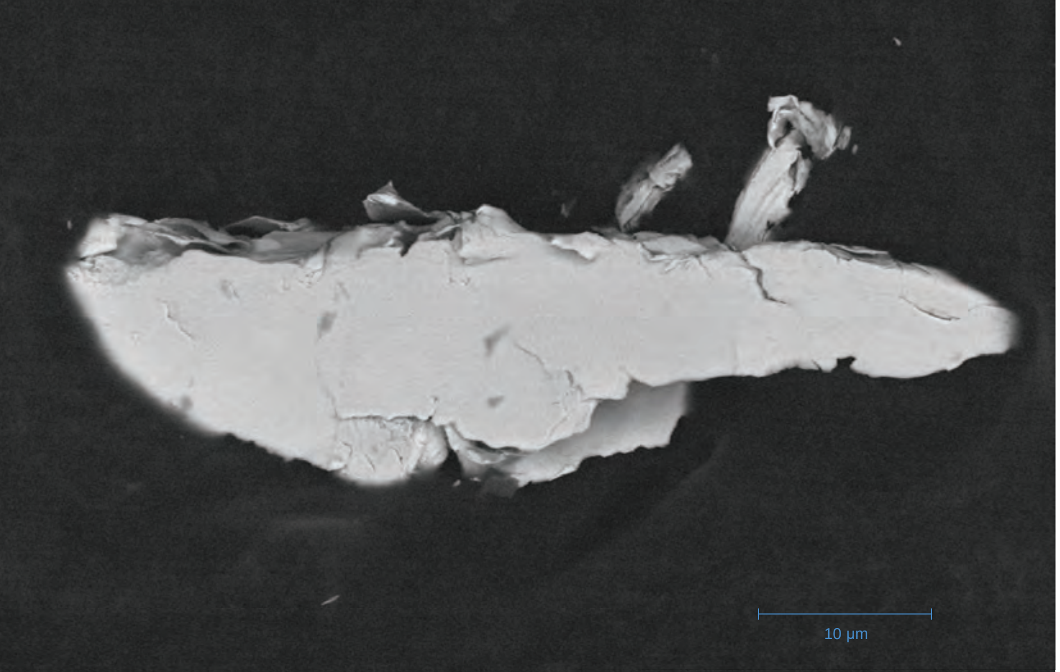


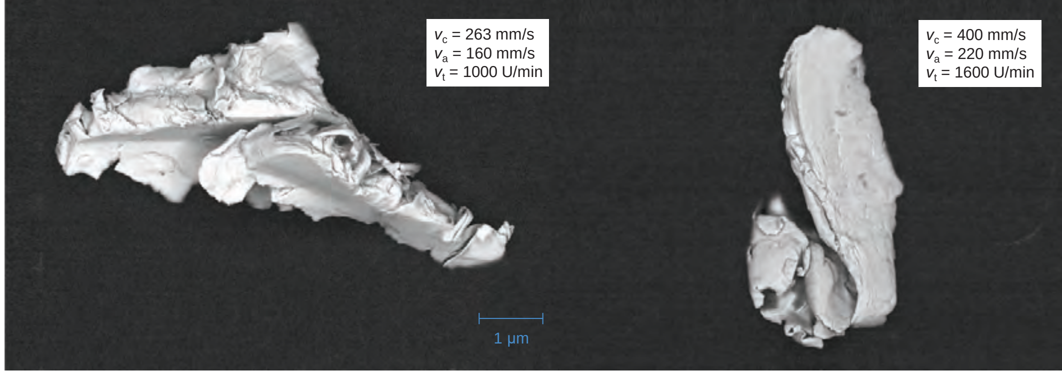


Internal coolant in circular sawing

Within the DFG priority program "SPP2231 Efficient Cooling, Lubrication and Transport - FluSimPro", the behavior and interactions of cooling lubricants in production processes are being investigated. In the subproject (Effi-Ti-Sim) the integration of an internal coolant supply (ICS) in a circular sawing tool is explored. The experiments revealed that ICS in sawing can have a positive effect on the chip formation process. The size of the saw tooth gullet between two cutting edges can be reduced, allowing a higher number of teeth to be integrated into a tool. This leads to increased productivity. Moreover, the investigations showed that an ICS allows a significant reduction in the amount of cooling lubricant supplied and improves the thermal tool load as well as the workpiece surface quality.

Source: Hans-Christian Möhring, Christian Menze
IfW, Universität Stuttgart



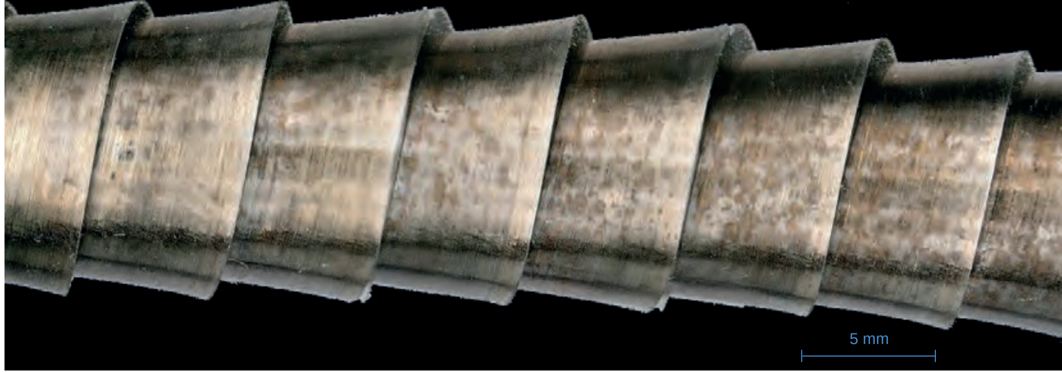


Internal long-stroke honing of small diameters

Honing is one of the most established precision machining processes for the manufacturing of high-precision functional components. Honed surfaces represent a finished functional surface for sliding, sealing and guiding under mechanical load. This results in high requirements in terms of shape, dimensional and positional accuracy as well as edge zone and surface quality. The achievable tolerances are in the submicrometer range. Investigations on the chip development under different cutting speeds show a wide range of chip shapes. Predominantly micro discontinuous chips between 6 and 80 µm length are observed.

Process:
Material: 16MnCr5 (1.7131), HRC20, case hardened
Machine: Kadia Produktion GmbH + Co of type LH 30/300R
Tool: Kadia Tool for bores less then 10 mm, 1 honing stone, 2 guiding stones, abrasive grain size D64
Parameter: Cutting velocity v_c = 263 mm/s, oscillation speed v_a = 160 mm/s, rotation speed v_t = 1000 1/min, radial feed force F_R = 40 N

Source: Murat Güner, Institute of Manufacturing Engineering, Saarland University

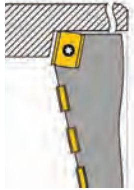


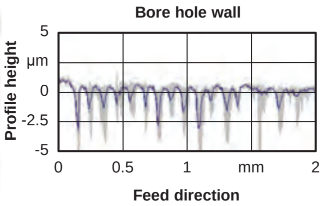
ISF "Record-Chip"

For components designed to withstand enormous stresses, the materials used must be acid and heat resistant and exhibit high strength and corrosion resistance. Combined with the usually high toughness of these materials, extreme long chip formation often occurs during machining.

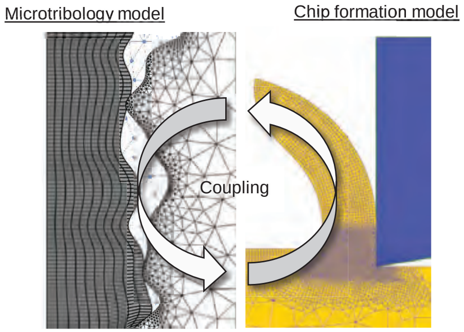
When boring a sample of an amagnetic austenitic steel from $D \approx 133$ mm to $D = 153$ mm with an STS deep hole drilling tool, moderate process parameters were used to reduce the tool load with no chip breakage occurred. Since only one cutting edge of the tool was engaged in this process, the resulting chip, with a length of ***L* = 79.5 m,** could be safely transported through the drill tube in one piece.

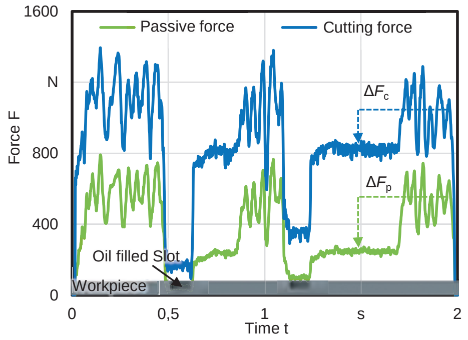
Process:	**Boring with a STS deep hole drilling tool**
Material:	amagnetic stainless steel (corrosion, acid and heat resistant)
Tool:	STS drill head $d = 153$ mm
Parameters:	$v_c = 30$ m/min; $f = 0.1$ mm; $\dot{V}_{Öl} = 180$ l/min

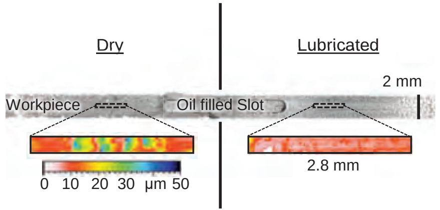




Source: Dr.-Ing. M. Metzger, S. Michel M.Sc.
Institute of Machining Technology, TU Dortmund





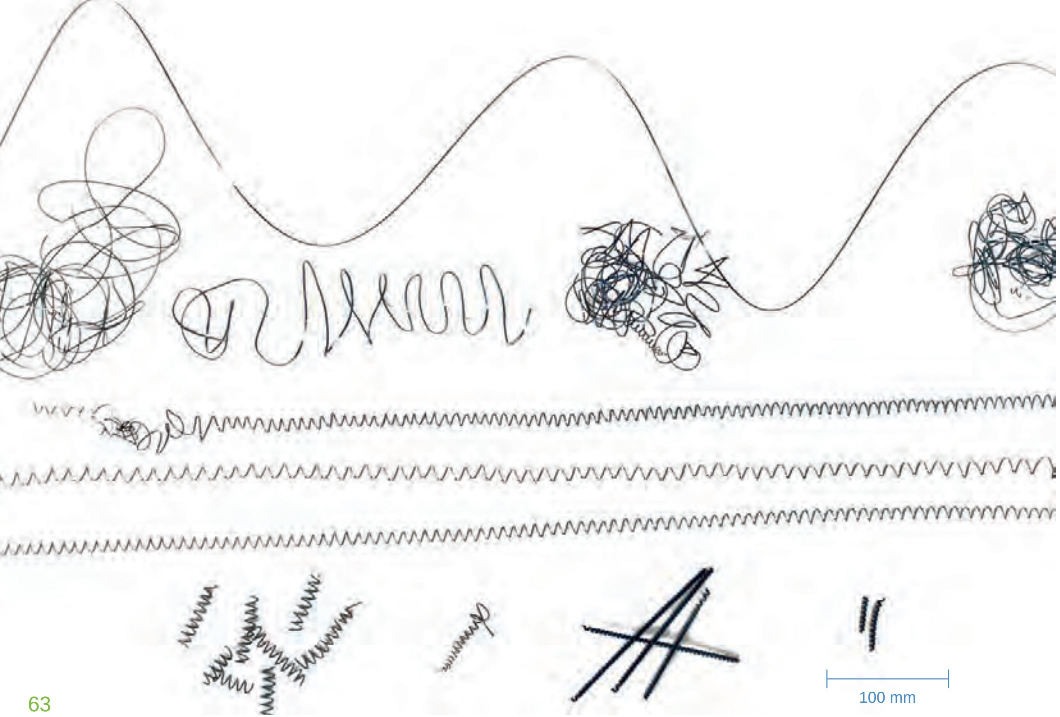


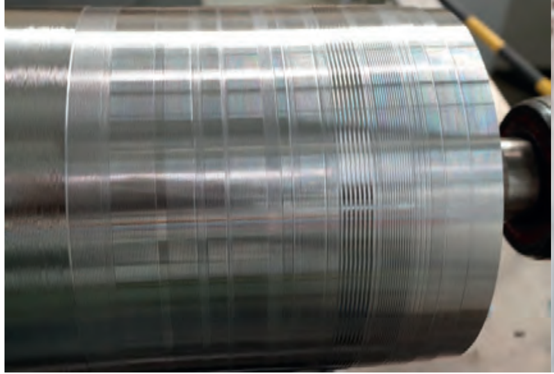
Material:	AISI 1045	Tool material:	K40 UF
Witdh of cut:	$b = 2$ mm	Cutting speed:	$v_c = 5$ m/min
Rake angle:	$\gamma = 0°$	Uncut chip th.:	$h = 0.15$ mm
Rake face:	Polished	Cutting fluid:	Vascomill MMS

Lubricated chip formation

By sophisticated injection of a load-bearing lubricating film into the secondary shear zone, it has been possible to fundamentally influence the chip formation process. By reducing friction, it was possible that not only the forces could be lowered by up to 60%, even the average chip thickness could be reduced by one third, with less fluctuation. Moreover, the resulting workpiece surface in the lubricated areas exhibits a significantly improved surface quality. All these positive effects can be attributed to an influence on the chip flow. With the help of a microtribological model of the secondary shear zone, the working principle of this mechanism is to be mapped and better understood in order to enable a transfer to industrially relevant machining processes.

Source: Jannis Saelzer, M.Sc.
Institute of Machining Technology, TU Dortmund





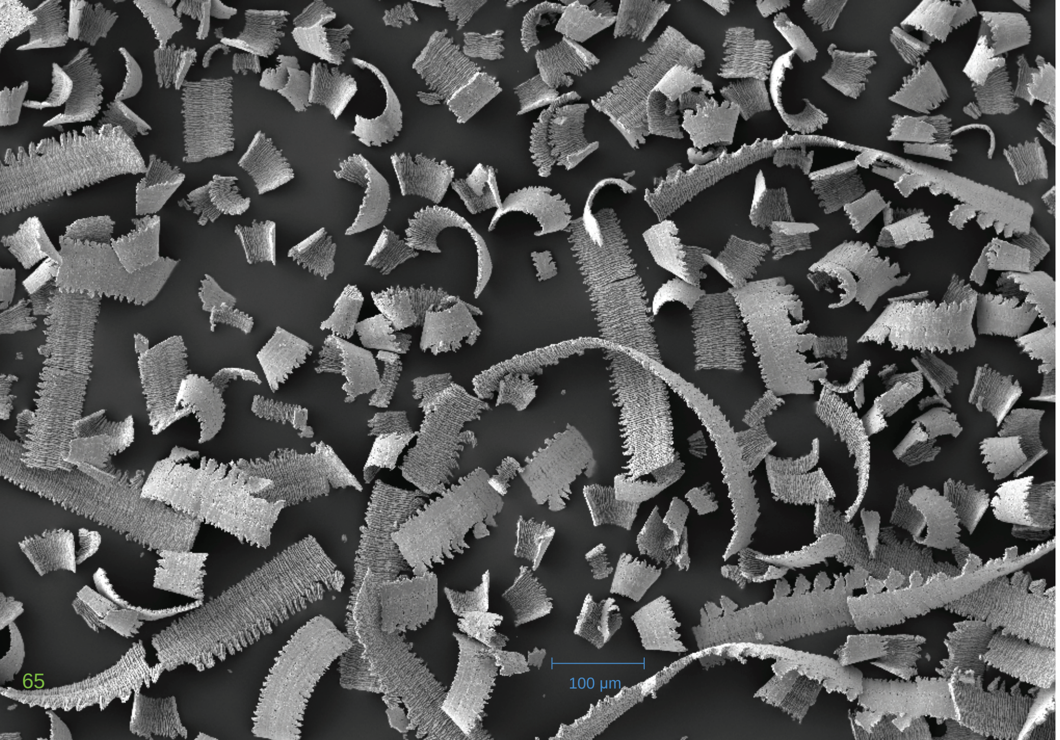
Process:	**Turning**
Material:	High-carbon steel 1.0503
Tool:	Turning tools with rake angles from -15° to +15° and setting angles from 30° to 93°, carbide with TiN coating
Parameters:	Cutting speed v_c = 100 … 200 m/min; feed f = 0.13 … 0.19 mm; infeed a_p = 0.5 mm

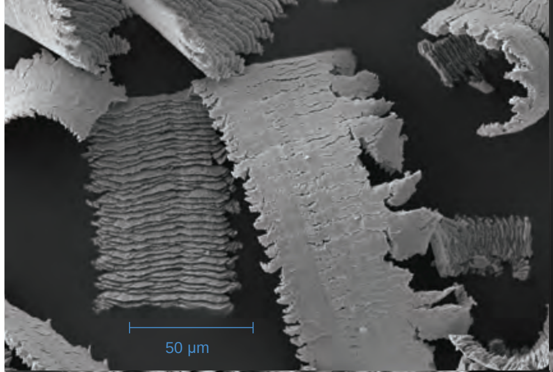
Machining trials in education

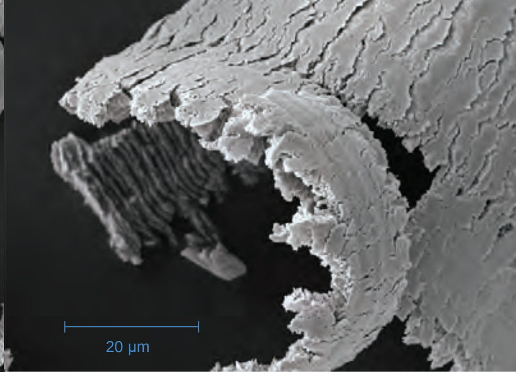
In a laboratory experiment, second semester mechanical engineering students at Schmalkalden University of Applied Sciences are investigating the influences of the cutting wedge geometry and process configuration on chip formation, chip shape and process forces.

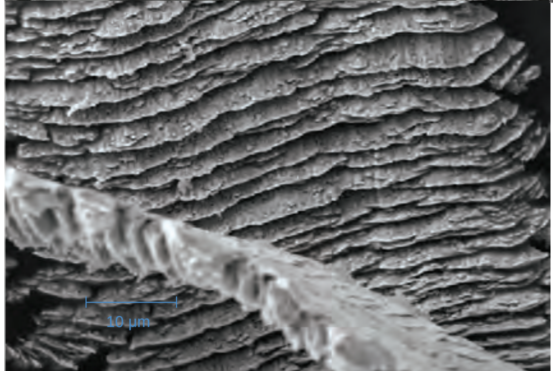
For example, larger rake angles tend to result in lower cutting forces, but they also lead to continuous flow chip formation. The resulting ribbon and snarled chips can be difficult to remove, damage the workpiece surface, and affect the tool life. Smaller positive or negative rake angles, on the other hand, promote chip breaking and lead to the formation of short, highly curved chips. The influence of the setting angle and the process parameters of cutting speed and feed rate is also being investigated.

Source: Jun.-Prof. Dr.-Ing. Andreas Wirtz
Schmalkalden University of Applied Sciences









Machining with NPDs

Process:	**Turning**
Material:	WC-Co CKi®12
Tool:	Laser machined NPD cutting tool
Parameters:	v_c = 50 m/min; a_p = 15 µm; f = 14.9 µm; no coolant

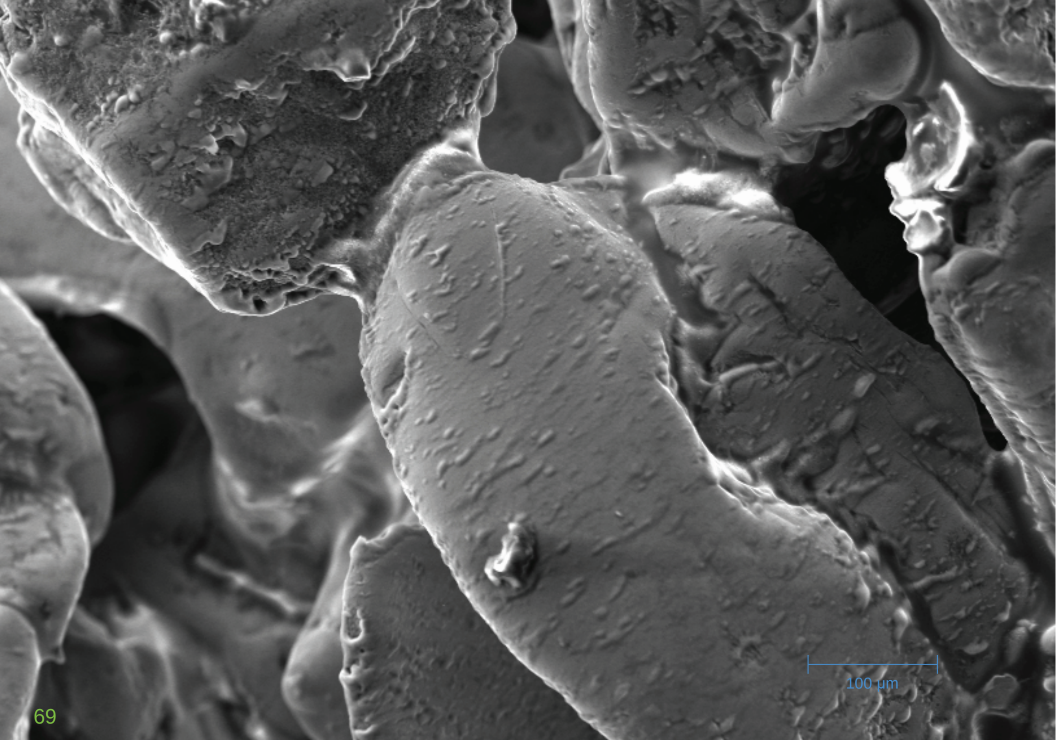
Due to both high hardness and strength and the resulting wear resistance, the machining of cemented carbides such as WC-Co remains a challenging task. The usage of binderless nanopolycristalline diamond (NPD) with a laser machined cutting edge design is a new approach to overcome the existing limitation. It allows the formation of chips with a segmented and regular structure despite the brittle-hard character of the material.

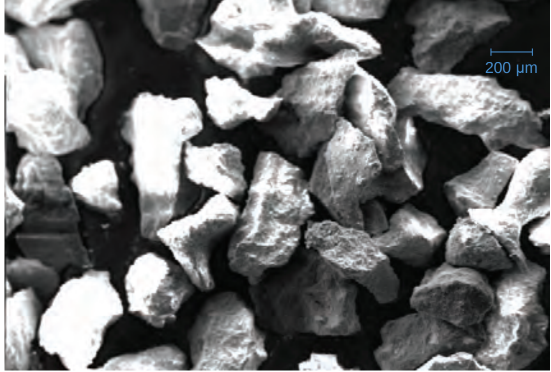
Source: Prof. Dr. h. c. Dr.-Ing. Eckart Uhlmann
IWF, TU Berlin

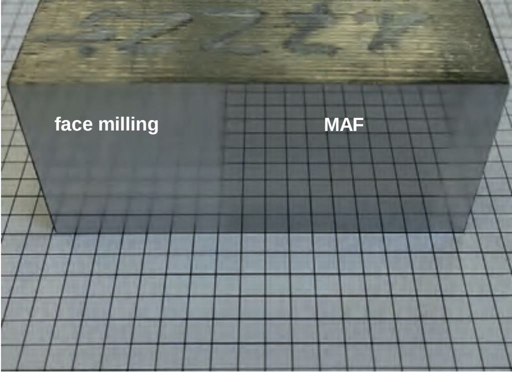
Macro chips

The enormous chips in the picture are produced during the machining of large shafts, such as crankshafts of huge dimensions for railroad or ship engines or turbine shafts for power plants. The temperatures occurring in the process, combined with the alloying elements used in the steel have an influence on the tempering colors of the chips, resulting in their bluish or golden coloration. The gold-colored chip shown here has a width of 55 mm and a thickness of 3.6 mm. Remarkable is the lamellar structure on the surface of the chip. These sawtooth-like lamella are formed when the material is sheared under the high stresses along the developing shear planes. On an unwound length of 865 mm, about 520 chip lamellae have formed.

Source: Jan Nickel, ISF, TU Dortmund
Antonius Albers, Seco Tools GmbH





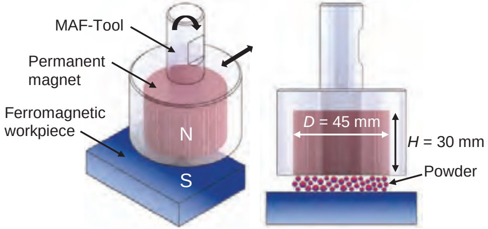


Magnetic abrasive finishing

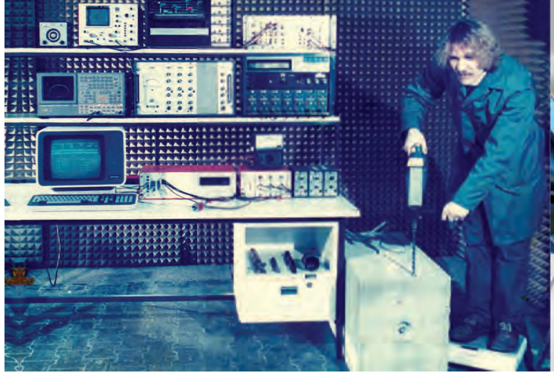
The production of highly smooth flat and free-form surfaces is a major challenge, for example in the fields of medical technology, optics and drive technology. Existing finishing processes often have a low productivity or require special equipment. Magnetic abrasive finishing using tools with standardized interfaces enables them to be integrated into process chains, for example after pre-machining by means of milling. Using an MAF tool with permanent magnets and a slurry of magnetic abrasive powder and oil, a surface roughness of Ra = 0.02 µm and Rz = 0.12 µm could be produced.
In MAF machining, a mixture of microscopic chips and worn magnetic abrasive powder is formed in oil, which is necessary for lubrication and cooling.

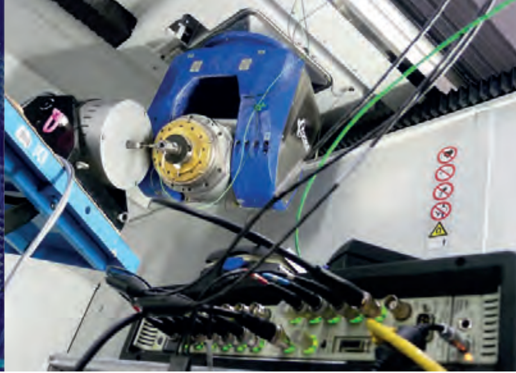
Process:

Material:	Structural steel 1.0037
Tool:	MAF-Tool with cylindrical permanent magnet
Parameters:	n = 900 min^{-1}; working gap a_p = 1.5 mm; v_f = 25 mm/min; powder FerroMAP 200/315 µm



Source: Jun.-Prof. Dr.-Ing. Andreas Wirtz
GFE Schmalkalden e.V.





Measurement and electronics lab

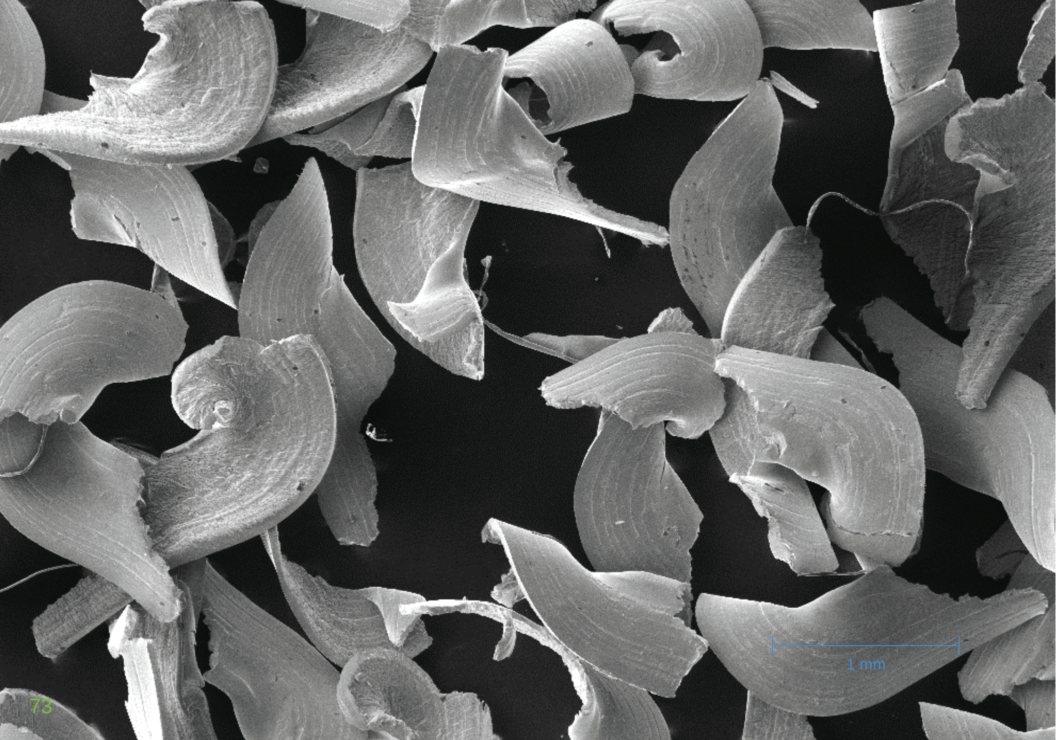
The equipment of the ISF includes systems for the measuring cutting forces, temperatures, deflections accelerations, modal and geometric properties and microscopy. The variety of complex systems has been managed for many years by the dedicated and competent team of the measurement laboratory, which provides support to the scientific colleagues. This includes system briefings, support with measurement setups and the analysis of measurement data.

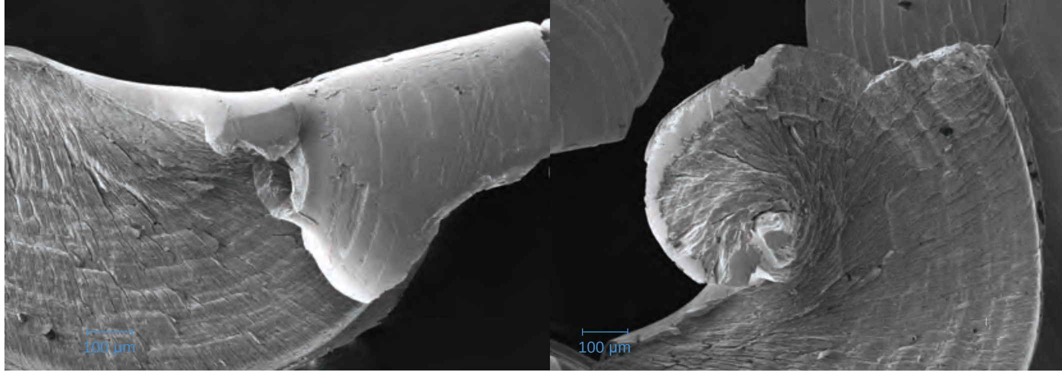
In addition, the electronics laboratory supports the maintenance of electrical components, measuring systems, machine tools and the facility infrastructure.

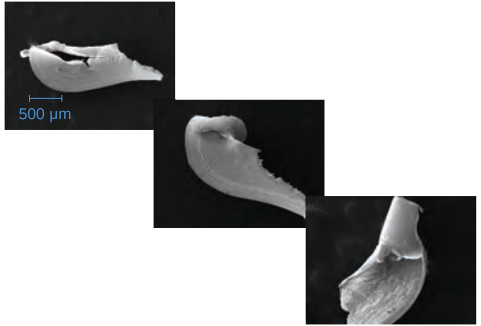
Provided equipment:

Number of Measurement systems:	122
Number of Sensors maintained:	463

Source: Tobias Hoffmann, Michael Kater
Institute of Machining Technology, TU Dortmund





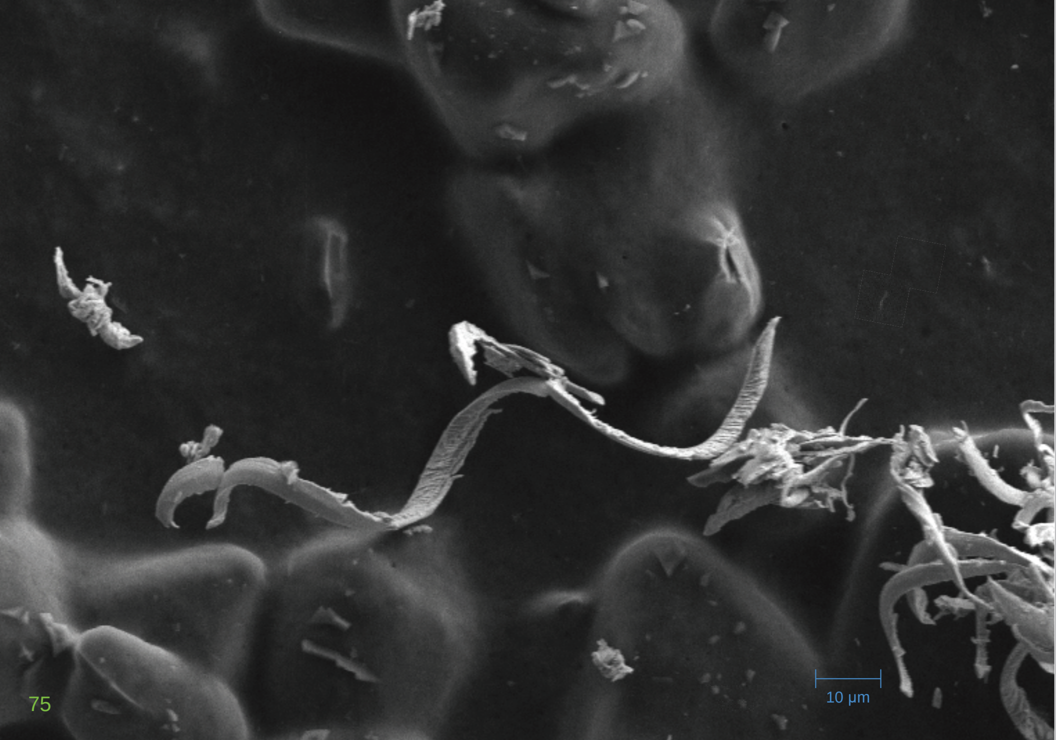


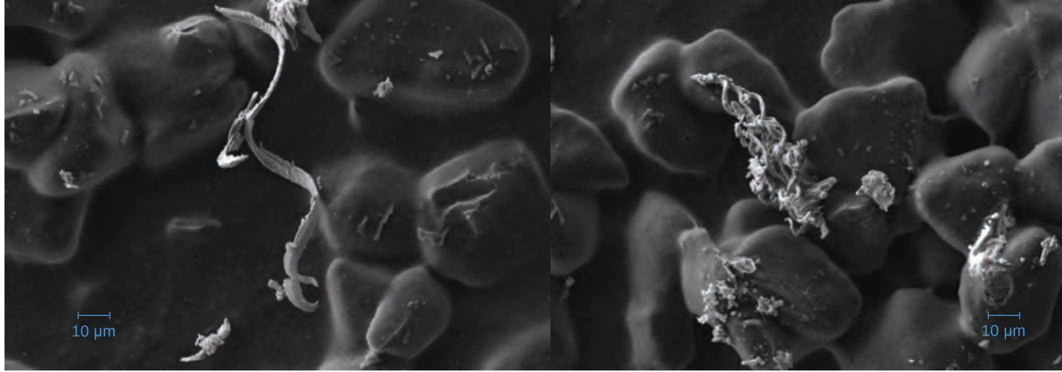
Microdrilling of quenched and tempered steel

Process: **Drilling**
Material: 42CrMo4+QT
Tool: micro helix drill, *d* = 1.5 mm
Parameters: v_c = 80 m/min; *f* = 0.06 mm

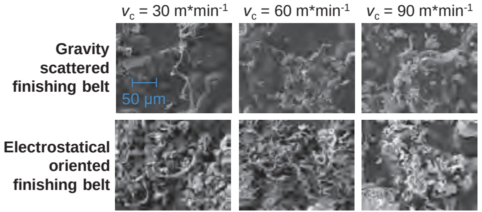
Microdrillings are found in a wide range of technical products, especially in the field of medical technology as well as tool and mold making. The requirements for drilling and drilling processes are diverse and include, among other things, a high precision of the drilling geometry, the reproducibility and the productivity of the process. Due to the small depths of cut and chip thicknesses, small chips are produced. The chip shape is not directly visible to the human eye.

Source: Laura Zieher M.Sc.
Institute of Machining Technology, TU Dortmund





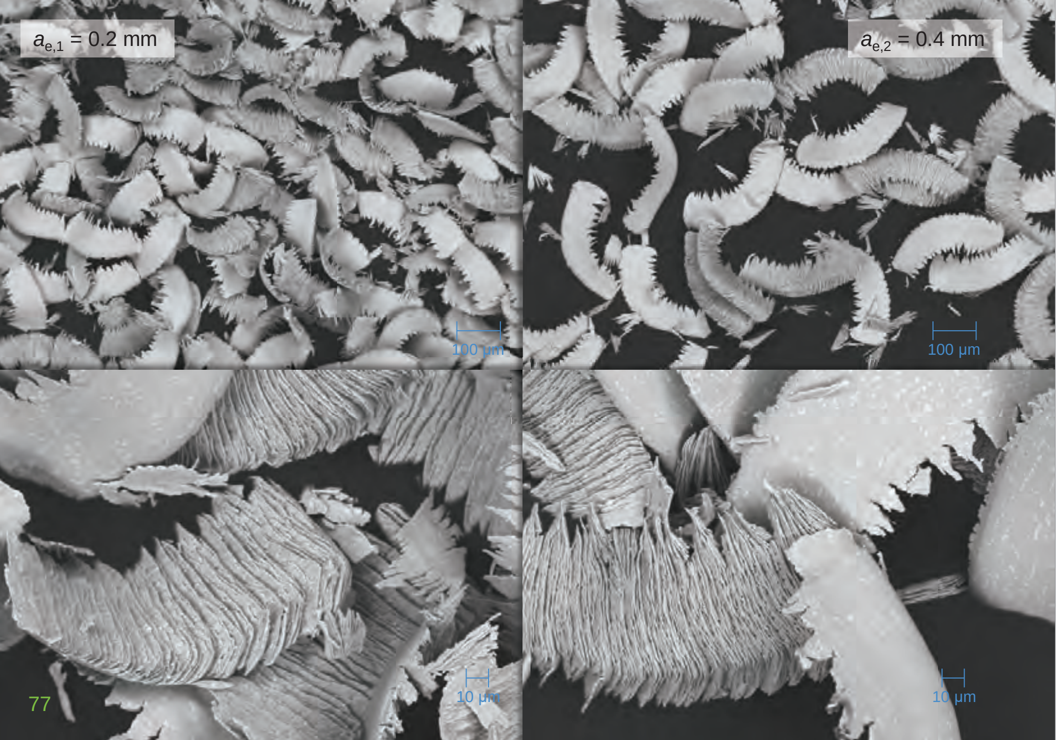
Process:
Material: 1.4404; Additively manufactured (PBF-LB/M); ground
Tool: SiC finishing belt, d_K = 30 µm; gravity scattered
Parameter: Normal force F_n = 140 N; Oscillation S = ±2 mm;
Cutting vel. v_c = 30 m*min^{-1}; Contact time t_p = 10 s;
Belt feed velocity v_{fb} = 0 mm*min^{-1}

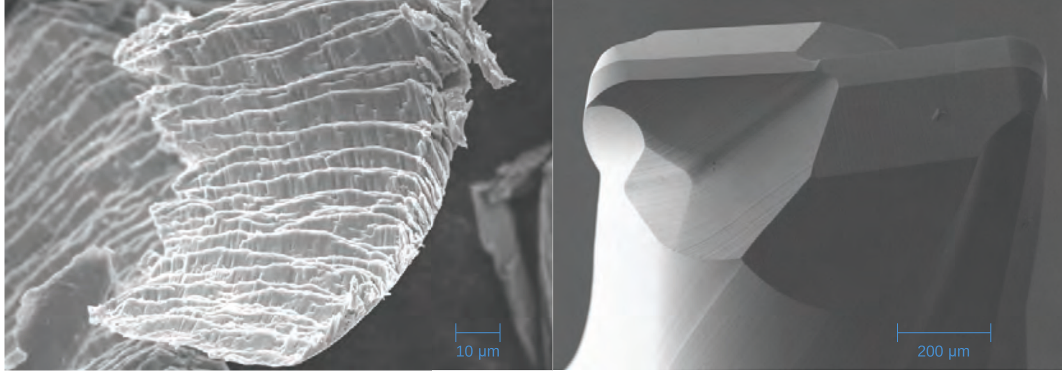


Microfinishing of additively manufactured steel parts

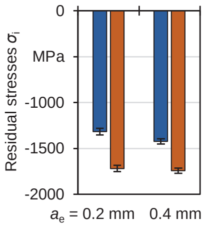
Due to their dimensional deviations and high surface roughness, additively manufactured components require post-processing to produce functional surfaces. The process chain of grinding and microfinishing is suitable for producing rotationally symmetrical functional surfaces with plateau character. Investigations into the influence of the process parameters on the wear of the finishing belt showed that different chip shapes dominate as a function of the cutting speed. From this, the influence of the cutting velocity on the material removal mechanisms can be deduced. **Micro-snarled chips** and micro-ribbon and micro-discontinuous chips are the most common chip shapes, but **micro-helical chips** also occur in some cases.

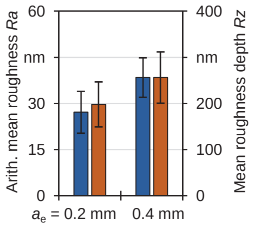
Source: Dipl.-Ing. Meik Tilger, Floris Weber M.Sc.
Institute of Machining Technology, TU Dortmund





Process: **Micromilling**
Material: Hardened high speed steel - ASP®2023 (63 HRC)
Tool: Micro end mill (TiAlSiN); d = 1.0 mm; r_ε = 0.2 mm
Parameters: n = 38 197 min^{-1}; v_f = 1 900 mm/min; a_p = 25 µm; $a_{e,1}$ = 200 µm; $a_{e,2}$ = 400 µm; f_z = 25 µm



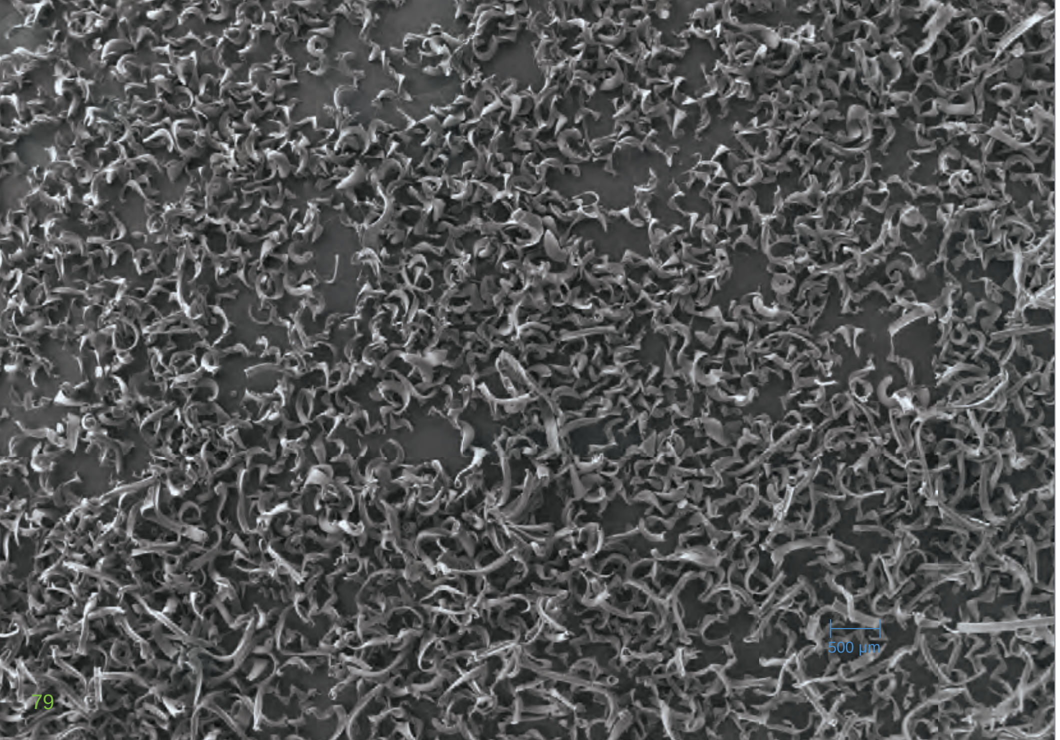


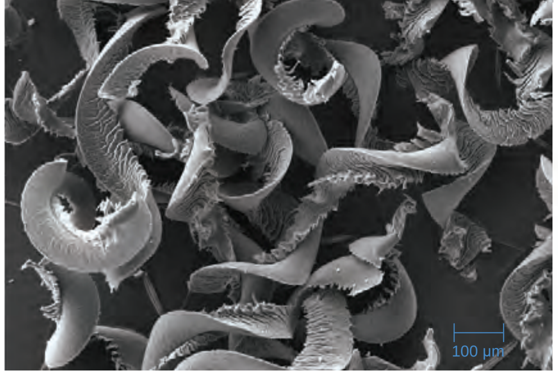
Micromilling of hardened HSS

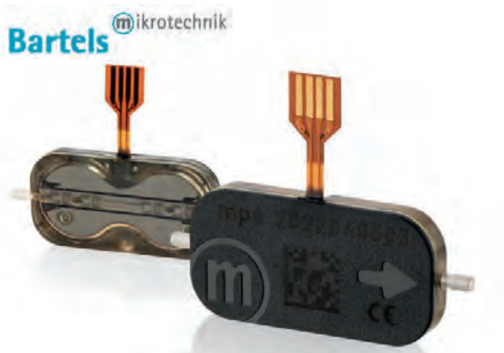
Micromachining of hardened powder metallurgical high speed steels is a great challenge due to the high hardness of the material as well as the resulting mechanical tool load. However, with optimized process settings, high surface qualities can be achieved under favorable conditions of the workpiece sub-surface. In particular, the significantly colder cutting process compared to conventional machining supports the induction of residual compressive stresses. Highly durable surfaces can thus be manufactured, which also provide favorable preconditions for a subsequent coating process.

The scanning electron micrographs show chips with different engagement widths. The surface quality achieved and the resulting residual stress state can be seen in the diagrams on the left.

Source: Alexander Leonard Meijer, M.Sc.
Institute of Machining Technology, TU Dortmund

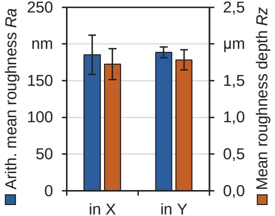


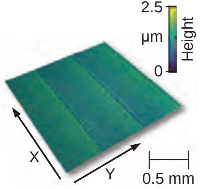




Micromilling of prototypes

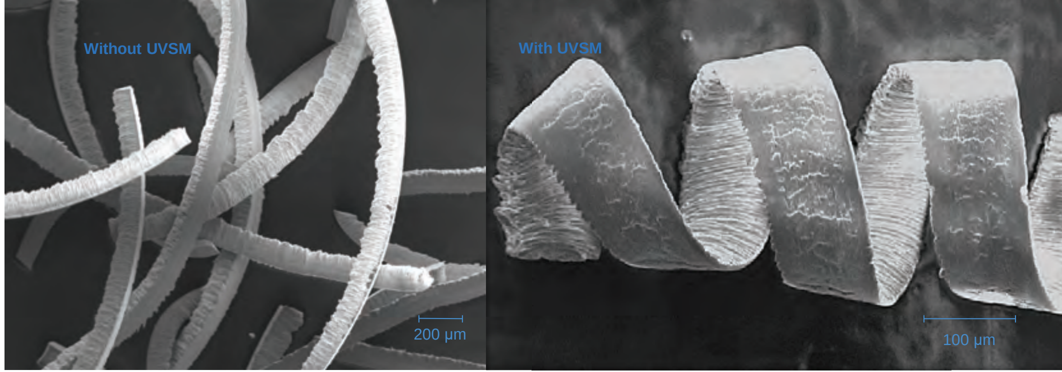
Process: **Micromilling**
Material: Polyphenylsulfone (PPSU)
Tool: Micro end mill; d = 3.0 mm
Parameters: n = 8 488 min^{-1}; v_f = 509 mm/min;
a_p = 65 µm; a_e = 600 µm; f_z = 20 µm





The development of components for microsystems technology is a demanding task due to the requirements for surface quality and manufacturing accuracy. In particular, the production of prototype components in the smallest dimensions can be a major challenge, as this usually has to be done using more flexible manufacturing processes. In this context, the ISF supported Bartels Mikrotechnik GmbH (Dortmund, Germany) in the manufacturing of components for a new generation of micropumps, which are used in medical applications, for example. The prototypes were micromilled from polyphenylsulfone (PPSU) in several process steps. The resulting surface finish of the roughing process step can be seen as an example. Within the scope of the project, all components for functional prototypes could be manufactured.

Source: Alexander Leonard Meijer, M.Sc.
Institute of Machining Technology, TU Dortmund

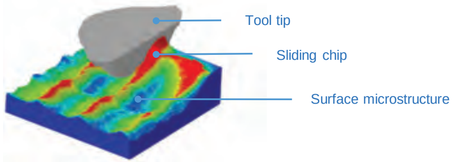


Microstructuring by Ultrasonic Vibration Superimposed Milling (UVSM)

To improve the adhesion of the CVD diamond coating, ultrasonic vibration superimposed machining (UVSM) is applied by face milling. The relative motion in tool axis direction and perpendicular to specimen surface is implemented by ultrasonic vibrations on the workpiece side. Due to its defined cutting edge geometry and kinematics, UVSM represents a suitable method for a sustainable generation of surface microstructures.

The time-dependent varying undeformed chip width resulting from the alternating depth of cut may lead to a helical shape of the "UVSM chips" in contrast to the slightly curved chips when milling without ultrasonic vibration assistance.

Process:
Material: Martensitic stainless steel (X46Cr13)
Tool: SPGW 1204; ultrafine-grained WC-Co with coating
$r_\varepsilon = 30$ µm, $r_\beta < 5$ µm, $\alpha_o = 40°$, $z = 1$
Parameters: $v_c = 50$ m/min; $f_z = 40$ µm; $a_p = 30$ µm
Medium: Oil (MQL)
US Vibration: $A_{US} = 4$ µm, $f_{US} = 19.6$ kHz



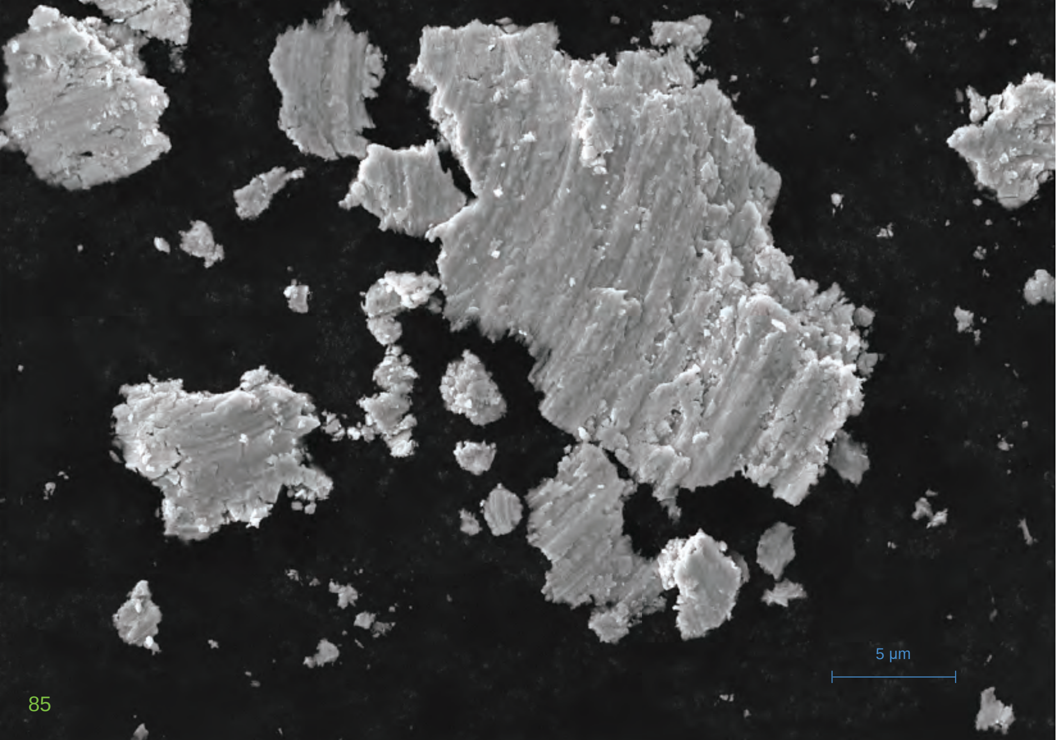
Source: Dipl.-Ing. Richard Börner; Professorship Micromanufacturing Technology, Chemnitz University of Technology

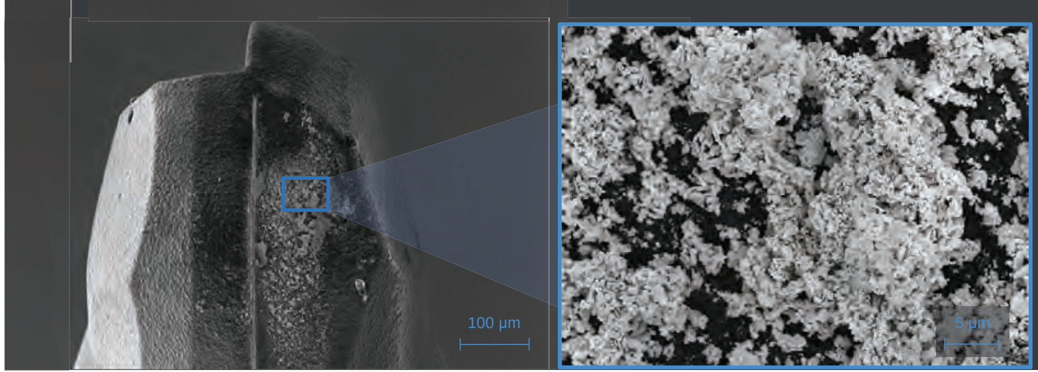
Milling of silicon tombac

New possibilities in high pressure die casting: Silicon tombac is the construction material with the highest strength that can be economically cast using the high-pressure die casting process. This alloy is very suitable for thin-walled and heavy-duty structural parts. Pressure die casting using silicon tombac is more economical than the very complex steel investment casting process. High-pressure die casting using silicon tombac achieves significantly greater strength compared to aluminium or zinc high pressure die casting. In addition, it enables series production of thin-walled and heavy-duty construction parts. Tolerance ranges of ±0.05 mm are achievable in casting. Narrower tolerance ranges can be achieved in-house using subsequent fine blanking or CNC processing.

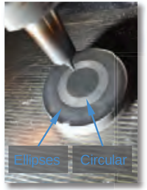
	SILICON TOMBAC	ALUMINIUM	ZINC	UNALLOYED STEEL
Process	High pressure die casting (HPDC)			Investment casting
Tensile strength Rm in N/mm^2	>500	240-310	280-350	410-450
Yield point Rp 0,2 in N/mm^2	>300	140-240	220-250	200-210
Density in kg/dm^3	8.3	2.7	6.7	7.9
Hardness in HB	160-180	80-120	85-105	140

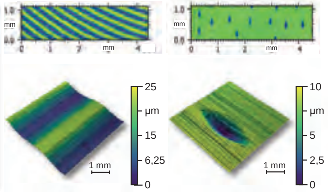
Source: Breuckmann GmbH & Co. KG





Process:
Material: Varied WC-Co Coatings (HVOF sprayed)
Tool: CVD-D ball end milling cutter; $z = 2$; $d = 0.7$ mm
Parameters: $f_z = 4.2$ µm; $v_c = 24$ m/min;
$a_{p\ max} = 20$ µm; $n = 32754$ min^{-1} (Circular paths)
$a_{p\ max} = 10$ µm; $n = 45984$ min^{-1} (Ellipses)





Milling of WC-Co coatings

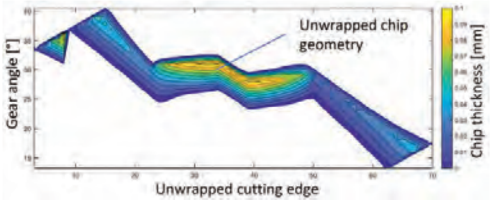
Tungsten Carbide (WC) based coatings applied using HVOF-spraying are well established in the field of surface technology to enhance wear resistance of tribologically stressed surfaces. By applying bionic and technical micro textures to coatings, the tribological properties of these surfaces can be further improved. However, these composites, consisting of both hard and ductile components, present a major challenge for milling, making it necessary to optimize the coatings for machinability.

During the texturing of the surface, microchips of different sizes result from the varying engagement situations and the inhomogeneous material. Tiny particles of individual carbides, which can be described as powder-like chips, also accumulate on the tool.

Source: Christoph Jäckel M.Sc., Nils Schmidt M.Sc.
Institute of Machining Technology, TU Dortmund

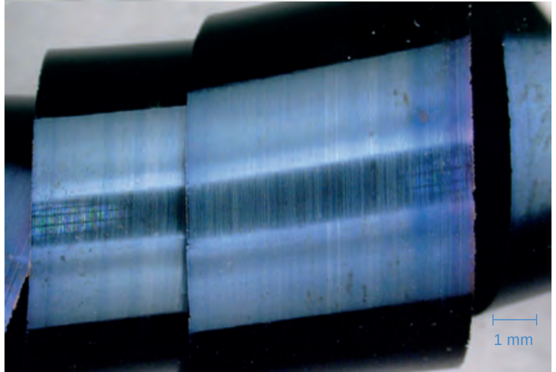
Process design of power skiving

Process:	**Power skiving**
Material:	16MnCr5
Tool:	Conical power skiving tool, full carbide, AlCrN coating
Technology:	8 Cut strategy, a_p = 0.38 mm, f_z = 0.44 mm/U, v_c = 200 m/min



Power skiving has been gaining popularity in recent years due to the changing component demand in the field of gears. However, due to its complex kinematics, this highly productive process has large variations in the process values (e.g. clearance angle) between extreme values, which can lead to a short tool life. To reduce the extreme values in the process values, the gear is produced in several strokes (e.g. 8 strokes). This leads to different chip geometries in each stroke, which are shown here. Mathematical modeling is indispensable for the optimized design of tool, process and each individual cut.

Source: Alexander Wenzel M.Sc.
Fraunhofer Institute for Machine Tools and Forming Technology IWU, Chemnitz

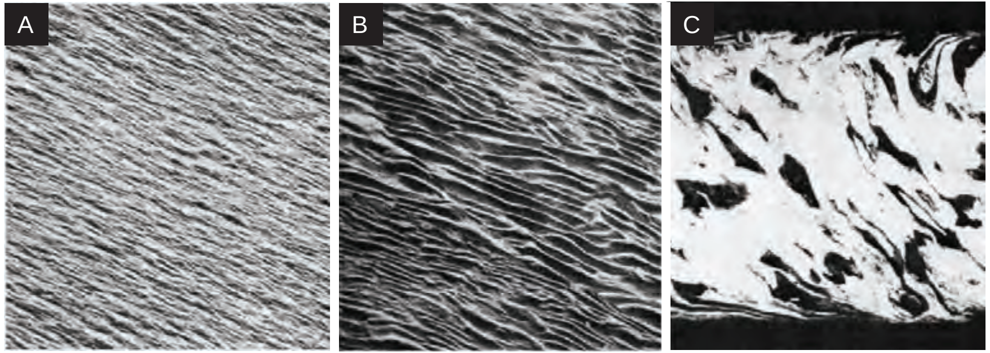


Strip edge trimming

By using special strip edge trimming machines, it is possible to produce different contour shapes on the edges of sheet metal strips. Several sets of tools are used, which are arranged one after the other. With strip thicknesses ranging from 0.15 to 8 mm, the geometry of the processed strips varies considerably.

The illustrated chips, removed by the first set of tools, already show that a high material removal rate is possible. The corresponding chips show a large chip cross-sectional area.
Depending on the cutting parameters and used materials, various chip sizes are produced. The homogeneous chips formed are long and have a cylindrical, helical shape.

Source: Dr. Andreas Groß
Heinz Berger Maschinenfabrik GmbH & Co. KG



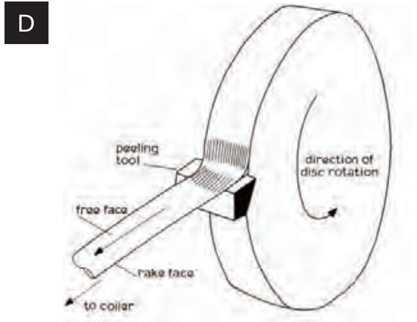
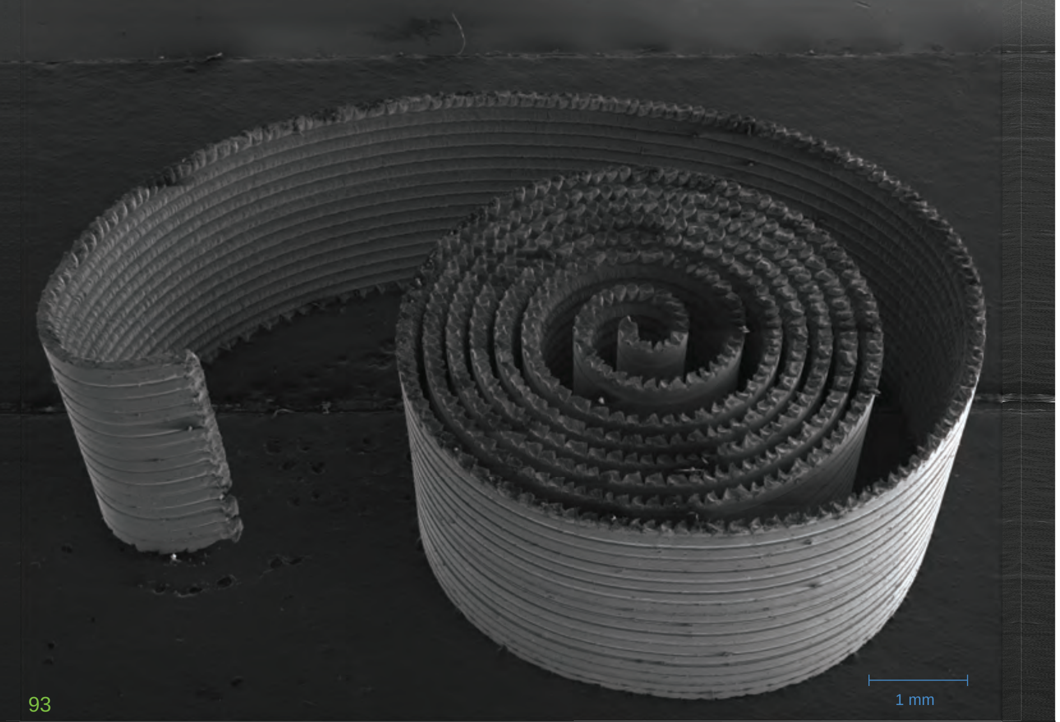


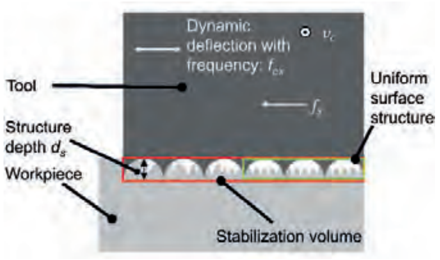
Fig. [A-D]: Middlemiss et. al., DOI:10.1179/030716982803286322

Strip production by peeling

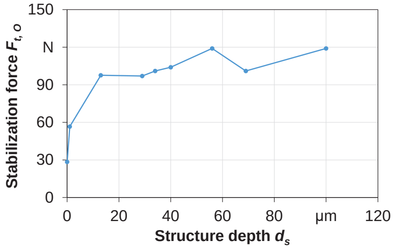
The strip peeling process enables efficient strip production. The process involves the machining of a strip separated from the surface of a rotating bar or disc, which is coiled under tension (Fig. D). By setting suitable machining parameters for the cutting speed, the rake angle of the tools, and also the lead-off angle of the finished strip, acceptable metallurgical properties are obtained. A variation of the strip surface depending on the material composition can be shown. The free surface consists of a series of corrugations over the entire strip width, the spacing between the corrugations being much greater for austenitic stainless steel (Fig. B) than for low carbon steel (Fig. A). The metallurgical examination over the entire thickness (Fig. C) showed no evidence of internal discontinuity.

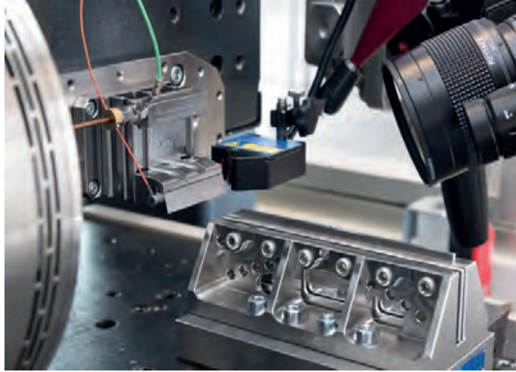
Source: Prof. em. Thomas H.C. Childs





Process: **Cutting operation with a linear cutting motion**
Material: EN AW-7075
Tool: HSS cutting element with modified flank face
Parameters: v_c = 120 m/min; a_p = 0.1 mm; f_{ex} = 1200 Hz



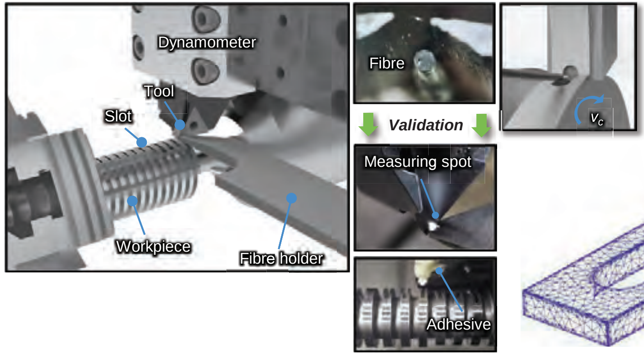


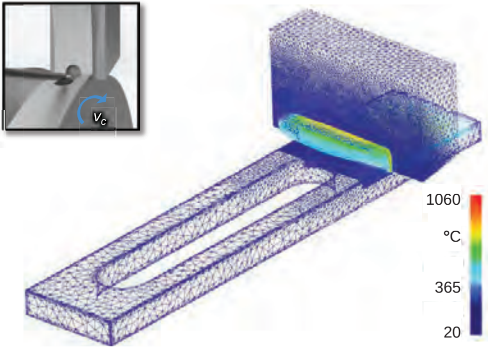
Structured tools in orthogonal cutting

The productivity of machining processes is often limited by the occurrence of dynamic effects. The investigated approach intends to counteract tool deflections, and thus to damp and disrupt chatter vibrations by using functional structures on the flank face.

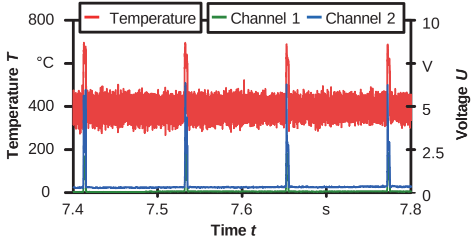
To fundamentally investigate the correlation between structural geometric properties and the tool-workpiece interaction, the engagement situation was validated experimentally in analogy tests with linear cutting motion. In these cutting experiments, dynamic deflections were induced by an external excitation of the specifically compliant modular tool system. A correlation between the structure depth and the stabilization force could be demonstrated.

Source: Rafael Garcia M.Sc., Simon Jaquet M.Sc.
Institute of Machining Technology, TU Dortmund





Material:	AISI 316L	Coating:	TiN
Witdh of cut:	b = 2 mm	Cutting speed:	v_c = 175 m/min
Rake angle:	γ = 6°	Uncut chip th.:	h = 0.1 mm
Tool:	TPUN 160305	Cutting fluid:	dry



Temperature measurement

In machining, the accurate determination of tool temperatures is a major challenge. At the Institute of Machining Technology, an innovative experimental setup has been developed that allows an in-situ measurement of the rake face temperature of the tool during orthogonal turning.

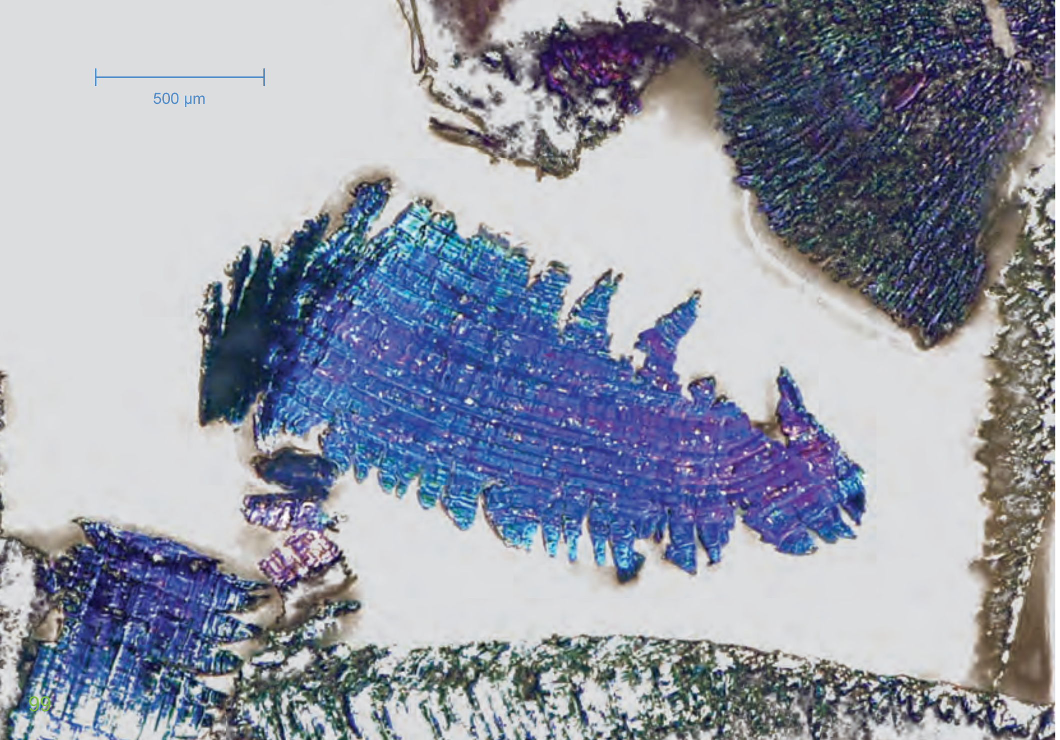
By preparing the workpieces with a milled slot, it is possible to access the rake face of the tool by temporarily opening the chip without interrupting the chip flow (**grooved ribbon chip**). To measure the temperatures, a ratio pyrometer with a glass fiber was used, with the measuring spot focused on the rake face of the tool. The results are used to validate chip formation simulations designed to predict the wear evolution of coated carbide tools.

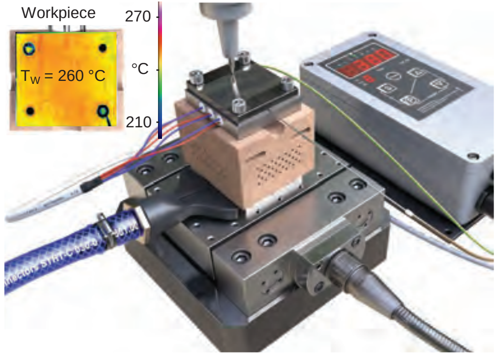
Source: Pascal Volke, M.Sc.
Institute of Machining Technology, TU Dortmund

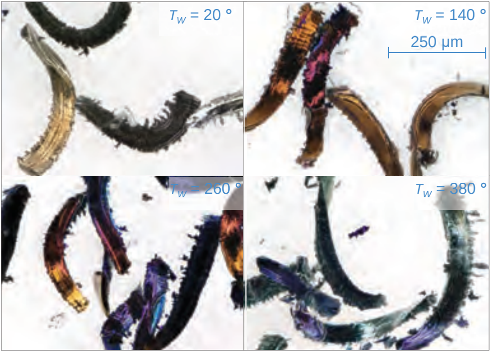
Testing machine tools' limits

Within the scope of preliminary investigations for a DFG Major Research Instrumentation proposal, machining tests were carried out at the Institute of Production Engineering and Machine Tools (IFW) of Leibniz University Hannover to investigate the performance of machine tools. Milling tests were performed on Ti6Al4V to investigate the stiffness and damping behavior of the machines. Using a solid carbide tool (D = 25 mm), a cutting depth of up to $a_p = 20$ mm was stably achieved in a full-slot cut at a cutting speed of $v_c = 50$ m/min and a tooth feed of $f_z = 0.05$ mm on a HELLER machine tool. In order to check the machine performance and torque, a cutter head (D = 160 mm) was used milling 42CrMo4. At a cutting speed of $v_c = 180$ m/min and a tooth feed of $f_z = 0.3$ mm, a cutting width of $a_e = 50$ mm and a cutting depth of $a_p = 40$ mm could be achieved.

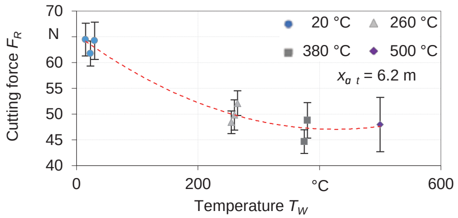
Source: IFW, Leibniz University Hannover
Gebr. Heller Maschinenfabrik GmbH







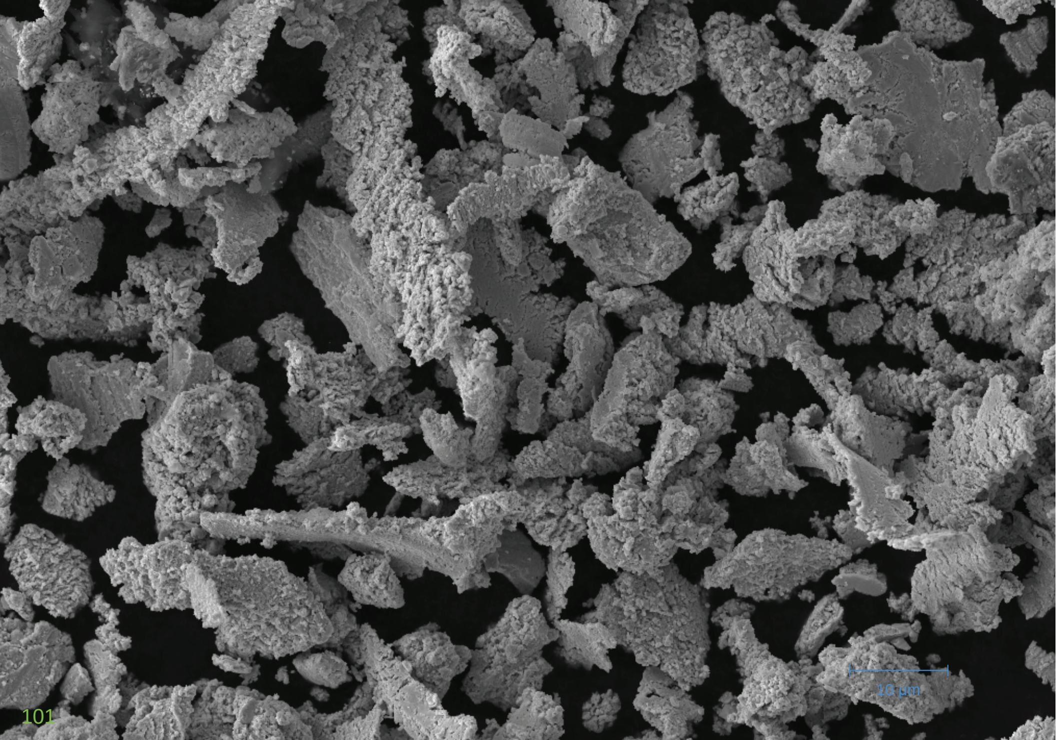
Process:	**Micro-end milling**	Strategy:	Downmilling
Tool diameter:	d = 1 mm	Coating:	TiAlN
Cutting speed:	v_c = 120 m/min	Feed per tooth:	f_z = 0.05 mm
Width of cut:	a_e = 0.4 mm	Lubrication:	-
Depth of cut:	a_p = 0.05 mm	Workpiece:	AISI H11

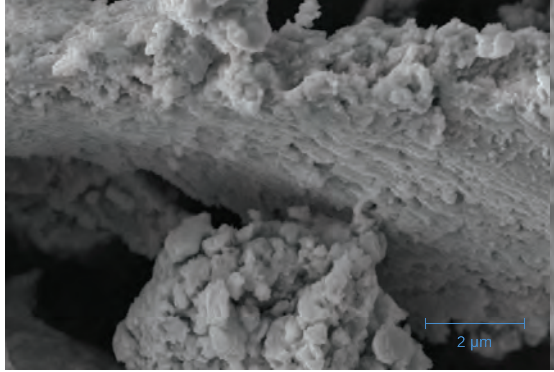


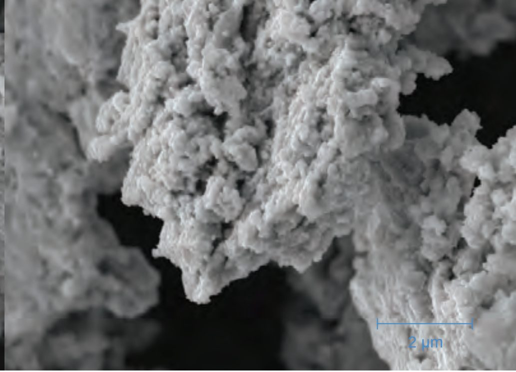
Thermally assisted micromilling

Difficult-to-machine materials such as high-strength tool steel require innovative manufacturing processes to increase the performance. Thermally assisted micromilling is a hybrid process using a prototype device to homogeneously heat the entire workpiece. By varying the workpiece temperature 20 C < T_W < 500 C, a hot-work tool steel (HWS) AISI H11 (51 HRC) was machined with PVD-coated micro end mills (d = 1 mm). The temporary thermal softening of the material led to a reduction in the cutting forces and thus in the resulting tool wear for specific configurations of the thermal assistance. The chips presented differ in length and color depending on the workpiece or the process temperature, which led to a certain thickness and appearance of the oxidation layer.

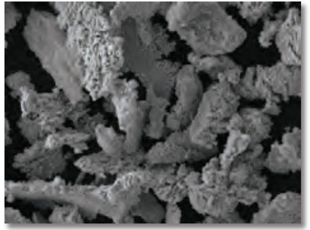
Source: Timo Platt M.Sc.,
Institute of Machining Technology, TU Dortmund







Process: **Tool Grinding**
Material: cemented carbide
Tool: diamond grinding wheel (D54)
Coolant: none

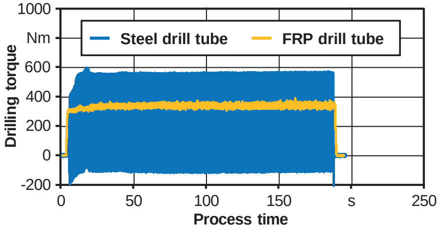


Tool Grinding

The tool grinding of cemented carbide tools is a challenging task. Typically, diamond grinding wheels are used as tools for the grinding of cemented carbide. Chips occur on a microscopic scale and are difficult to collect. The SEM-images show the variety of chips generated in a grinding process of cemented carbide. The tool used was a diamond grinding wheel with grain size D54, whereas the process was conducted without the use of coolant.

Source: Uwe Thiede
Hufschmied Zerspanungssysteme GmbH

Process:	**Single tube system (STS) deep hole drilling**
Material:	Quenched and tempered steel 42CrMo4+QT
Tool:	STS drill head d = 60 mm
Parameters:	v_c = 60 m/min; f = 0.225 mm; $\dot{V}_{\text{Öl}}$ = 275 l/min

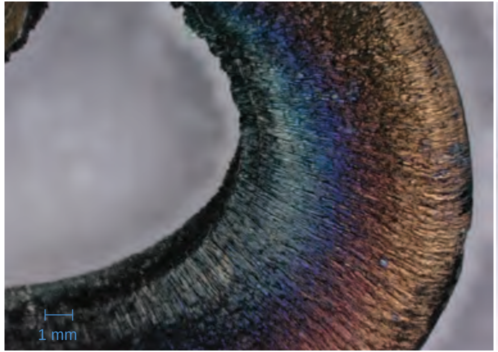


Torsional vibrations during drilling

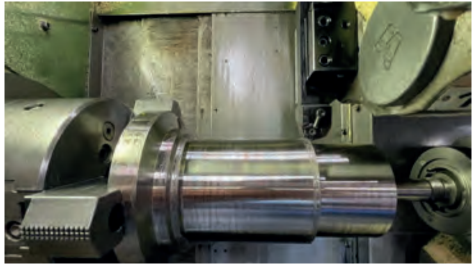
Due to the long tool lengths, the dynamic tool behavior in deep hole drilling processes has a significant effect on tool wear and machining results. The engagement of the asymmetrically arranged cutting edges on the drill head can lead to excitation of the tool system in the circumferential direction and to strong torsional vibrations.

Fiber-reinforced plastics (FRP) have excellent damping properties due to their inhomogeneous material structure of highly rigid fibers and polymeric matrix material and can significantly reduce the torsional vibrations that occur. While the chip from the process with the FRP drill tube has a smooth surface, with the conventional steel drill tube the vibrations are transferred to the chip surface.

Source: Sebastian Michel M.Sc.
Institute of Machining Technology, TU Dortmund



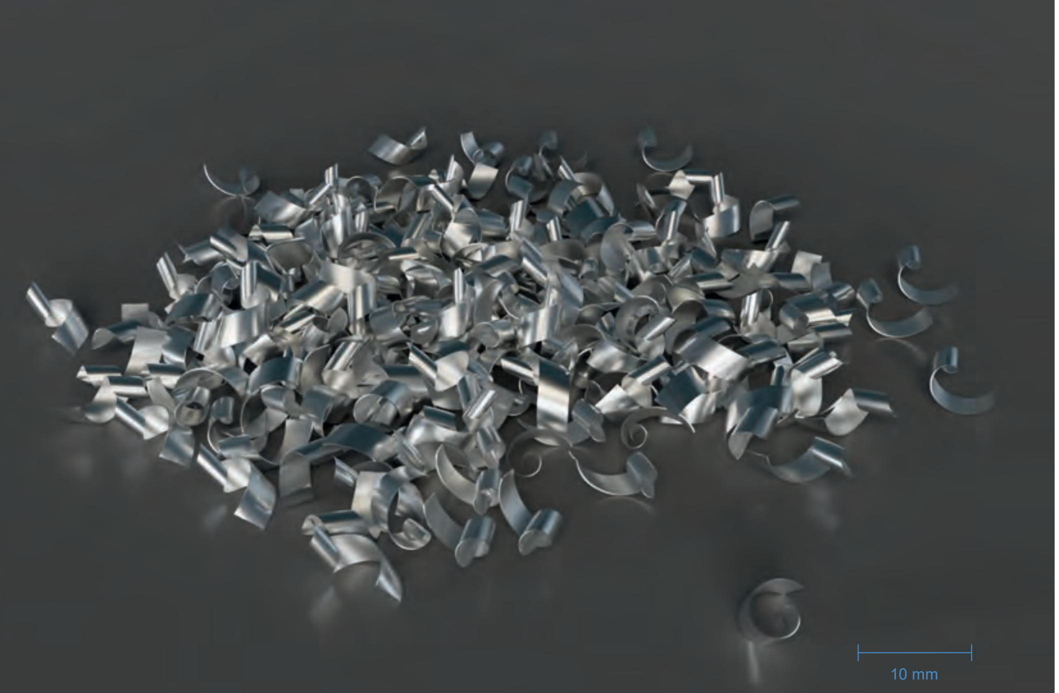
Process:	**Rough turning**	Cutting Speed:	v_c = 70 m/min
Material:	Alloy 42, 1.3917	Feed:	f = 0.3 mm
Tool:	SNMG 190616	Depth of cut:	a_p = 6 mm

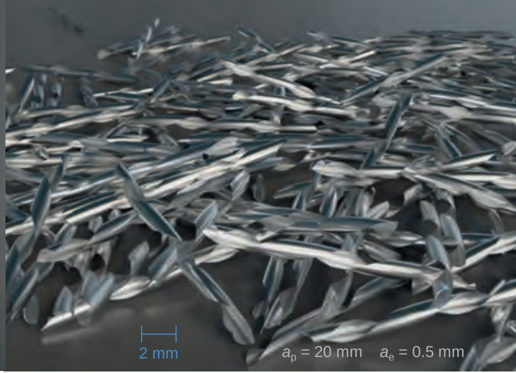


Turning of nickel-base alloys

Due to their high tensile strength and low thermal conductivity, machining of nickel-base alloys is challenging and associated with rapid tool wear as well as affected surface integrity of the workpiece. The helical chip shown was machined in a turning process of a forged semi-finished product of Alloy 42, which is characterized by high-temperature resistance as another central property of nickel-base alloys.
The application of a high depth of cut results in an increased cross-section of the undeformed chip, which implies high mechanical forces and also high process temperatures due to increased friction conditions in the shear zones. Signs of thermal load are visualized on the chip surface, and also the friction-related material buckling is displayed in the chip cross section.

Source: Timo Rinschede M.Sc., Tobias Wolf M.Sc.
Institute of Machining Technology, TU Dortmund





Virtual chips

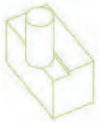
The *Virtual Machining* research group at TU Dortmund University develops geometric physical-based simulation systems for the analysis and optimization of milling processes. Based on the geometric engagement situations of the milling tools and the resulting undeformed chip shapes, process forces and vibrations can be predicted using empirical models of these physical effects. In this example, the undeformed chip shapes of two different milling processes were determined with a process simulation. The deformation of these virtual chips was simulated using an empirical model of material behavior. The comparison of two processes with different depths of cut shows a significant influence on the resulting chip shapes, which can be relevant for the optimization of material removal in complex engagement conditions.

Source: Dr.-Ing. Dipl.-Inf. Tobias Siebrecht,
Virtual Machining, TU Dortmund

Process: **Milling**

Tool: $d = 12$ mm
$z = 2$
$\lambda = 30°$

Process: $n = 8000$ RPM
$f_z = 0.1$ mm



	Example 1	**Example2**
a_p:	2 mm	20 mm
a_e:	8 mm	0.5 mm

vm
virtual machining
Prof. Dr.-Ing. Petra Wiederkehr

Process:
Material: Wood
Tool: Taper face milling cutter; wedge angle β = 18°;
Parameters: Inclination angle λ = 8°; set angle κ = 15°; spindle speed n = 4000 min^{-1}; feed velocity v_f = 12 m/min

Wood chips for composite insulation

The depicted chip geometry made of wood is suitable for composite insulation materials due to its improved specific properties and behavior. The resilient wood chips form a low-density matrix for loose-fill insulation to insulate wooden spaces in buildings (gaps in stud construction, roof beams). The structure of the insulation mixture formed by these elastic chip geometries gives rise to a lightweight bulk insulation (ρ = 40 kg/m3). Compared to the conventional bulk insulation comprising wood fibers (ρ = 55 kg/m3) at equivalent compaction levels, this alternative exhibits both superior performance and reduced weight. The taper face milling cutter for chip production had a diameter of 450 mm and a total weight of 18.6 kg.

Source: Hans-Christian Möhring, Matthias Schneider
IfW, Universität Stuttgart

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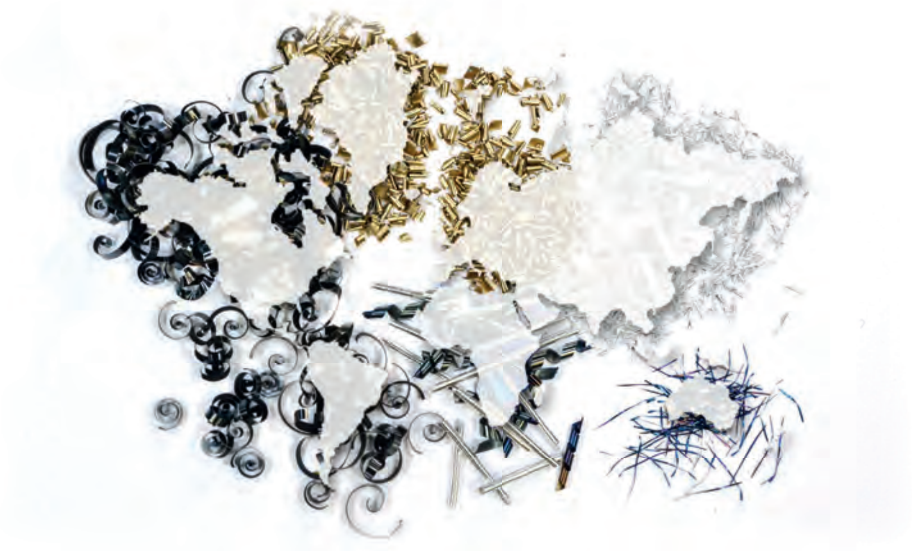
ISF



Under the constraints of what is possible and the requirements for
efficiency and quality of the remaining residual, they are the direct result of our efforts.
To illustrate their diversity in shape and formation is the intention of the presented Atlas of Chips.