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High efficient hard machining with new and innovative monolithic CBN end mills

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Agenda

- Introduction
- Machining of hardened mould inserts
  - Cutting material particularity
  - Prototype tools in monolithic cubic boron nitride
- Results
  - Cutting material characterization
  - Machining investigations
- Conclusion

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Introduction - Trend

- Increasing demands and high requirements on cutting tools have been prevailing lately, especially in the tool and die making industries.
- Trend in cutting applications is focused on new materials and hardened materials of up to 70 HRC.
- Hard machining enables flexible production of precisely shaped structural elements and component geometries in the µm range, improvement of accuracy and surface quality, functionalization of selected areas and extension of the lifetime of injection molding dies and other tool types.
- High-quality surfaces can be produced without subsequent grinding/polishing processes.

This only applies if the machining technology, milling tool, machine tool, lubrication strategy and control system are optimally matched with each other.


Example of injection mould insert (Source: IWU)

Introduction - Framework

- In hard machining with geometrically defined cutting edges high specific cutting forces occur at high cutting temperatures
- Wear resistance as well as edge stability and cutting edge geometry of the tools decide whether accuracy and surface requirements can be achieved.
- Reliable and repeatable machining of typical materials in this application field affords at least the use of coated tungsten carbide tools
- Tool wear and reduced feed rates decrease the achievable material removal rate while using tungsten carbide tools
- One solution to overcome these limitations lies in the use of alternative cutting materials such as cubic boron nitride (CBN)

Monolithic CBN end mills in the diameter range of 1 mm to 10 mm are commercially not or only limited available and developed.


Protoype of monolithic CBN ball nose milling tool (Source: IWU)

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Machining of hardened mould inserts – Requirement profile in tool and die making industries

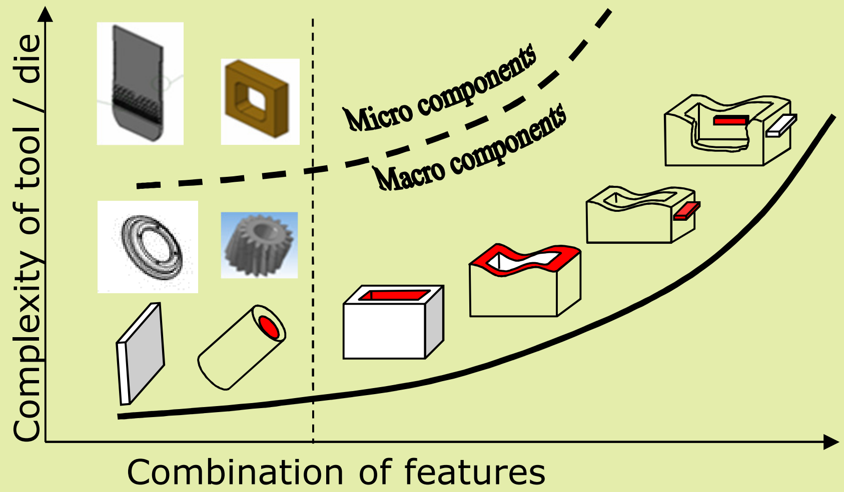
Type of component:		forming dies (for plastic or ceramic)	
Number of pieces	:	1 .. (10)	
Typical material	:	1.2767 1.2379 1.2343 powder steel MH430	55 HRC 60 HRC 55 HRC 56 HRC
Geometry	:	2 ½ D und 3-D	
Typical elements	:	pockets, channels, drill hole, fins	
Orientation	:	mostly recessed	

Minimal width of fins : 0,050 mm

Minimale width of channels : 0,100 mm

Maximal depth of structures : 2 mm .. (4mm)

Maximal aspect ratio	: 3 .. (20)
Minimal edge radii	: R 0,01mm
Roughness	: $R_z \leq 1$ µm
Min. tolerances on structures	: ± 0,005 mm
Structure edges	: burr-free, minimal chamfered



Machining of hardened mould inserts - Targets

- Adequate machining strategies under consideration of tool wear and selection of optimized cutting parameters are required to reach these challenging values of the requirement profile
- By development of new and innovative monolithic CBN end mills the following advantages in comparison to CBN cutting inserts are possible:
  - Increasing the number of cutting edges with small flutes which allow increased chip removal rates
  - Twisted chip geometries with constant rake angle for better chip removal / chip breaking possible (not possible for cutting inserts)
  - Special geometry features of solid carbide tools or new developed optimized cutting edge geometries can be transferred to monolithic CBN end mills to improve workpiece surface quality

Example of milling head with CBN inserts (Source: Ceratizit)

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Machining of hardened mould inserts


CBN raw material (Source: Mitsubishi)

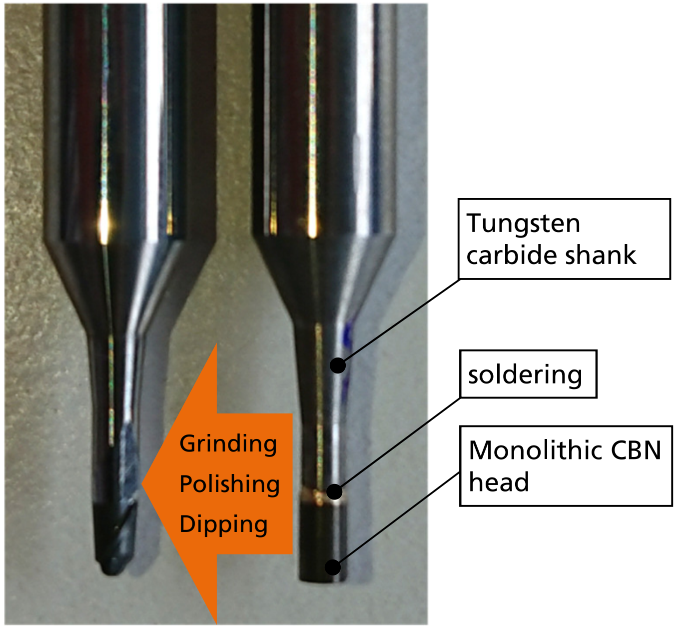
Cutting material particularity

- Cubic boron nitride (CBN) is advantageous due to its extreme thermal stability and significantly higher cutting and feed rates
- material is susceptible to mechanical alternating loads, especially at the cutting edges (e.g. damage by vibrations)
- available CBN base material must have a certain minimum thickness in order to work out the corresponding cutting edges (available up to 8 mm thickness)
- Base materials with about 90 % by volume of CBN content and primarily cobalt as the binding material are comparatively tough, have excellent thermal conductivity and are ideal for roughing operations.
- In the range of 50 to 90 % by volume of CBN, ceramic bonds such as TiN or AlN are frequently included. Ceramic-bonded base materials show greater hardness with less toughness and are suitable in particular for finishing operations with more constant cutting conditions and increased demands on the surface quality.

Machining of hardened mould inserts

Prototype tools in monolithic cubic boron nitride

- prototypes of monolithic cubic boron nitride tools delivered by the tool supplier
- tools based on tungsten carbide shanks in typical diameters e.g. 6mm with soldered pre-machined monolithic CBN heads in the required diameter
- Coaxiality of CBN cylinder and tungsten carbide shank is measured during the soldering process
- Following special tool grinding operations were done in several steps to realize the defined cutting edge geometries.
- Additional polishing and cutting edge dipping operations were done in dependency of the tool requirements

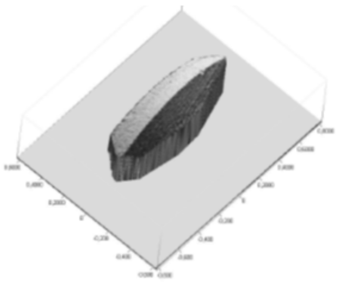


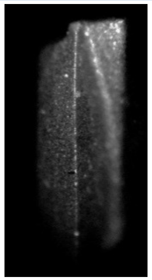
Tool preparation steps
(Source: IWU)

Results

Evaluation of prototype tools in monolithic cubic boron nitride

- Rating/Measurement with MikroCAD
  - Tool diameter
    - Ball nose milling tool D_{target}= 2,0mm -> $D_{current}$= 1,997mm
    - Toroid milling tool D_{target}= 6,0mm -> $D_{current}$= 5,991mm
  - Cutting edge evaluation



	D [mm]	Length of cut [mm]	Shank diameter [mm]	Overall length [mm]	Cutting edge radi [µm]	Cutting edge angle [°]	Chipping of cutting edge [µm]
	2.0	3	6	60	6.5	85	0.9

High constancy of cutting edge geometry for a number of tools and relatively low tool diameter deviation

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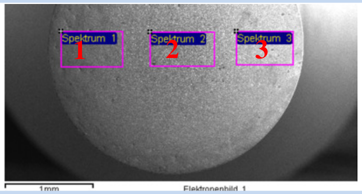
Results

Cutting material characterization with SEM/EDX

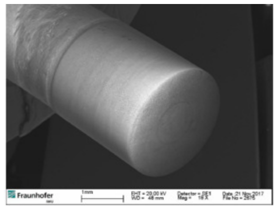
- Fluctuation of mass percentage between different suppliers of CBN basic material and different delivery batches of identical suppliers

	B	N	Al	Ti	Co	Ni	W
Probe 1	31,47	**40,36**	**3,51**	**1,79**	**15,38**	**2,37**	5,11
Probe 2	26,60	29,91	5,66	36,53	0,13	0,02	1,52
Probe 3	28,27	32,39	10,07	28,60	0,15	0,04	**0,49**
Probe 4	25,28	33,78	10,22	25,35	0,13	0,11	5,14
Probe 5	**11,66**	**22,45**	**12,53**	**45,31**	0,92	**0,00**	**7,14**
Probe 6	28,65	34,01	8,78	27,90	**0,04**	0,13	**0,49**
Probe 7	**34,74**	40,16	9,63	14,88	0,08	**0,00**	0,51

- Example of analyzed CBN blank offers discrepancies in homogeneity



Area	B	N	Al	Ti	Co	Ni	W
1	27.07	31.35	11.18	29.89	0.18	0.01	0.33
2	31.02	34.11	8.79	25.44	0.21	0.11	0.33
3	26.71	31.72	10.25	30.46	0.05	0.00	0.82



Guarantee of identical basic material and homogeneity is vitally important for high tool quality especially tool life

Results

Machining investigations

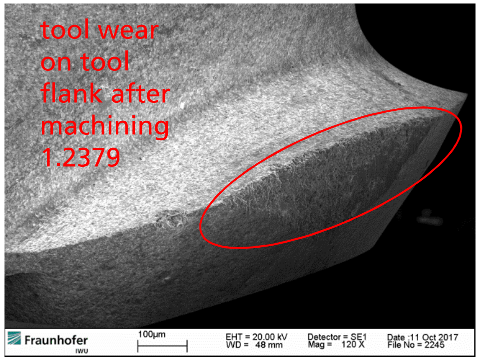
- Realization of milling operations on 5-axis micromaching center Kugler MM3
  - Ball nose cutting tools in diameter 2.0 mm (with setting angle 45°), cutting material cubic boron nitrite (CBN) and cemented carbide (CC)
  - Machining of a square pocket were done using different cutting parameters
  - The modifications in the cutting parameters were related to cutting speed, feed rate and cutting depth, the cutting width were kept constant.
  - Measurement of roughness was realized with confocal microscope

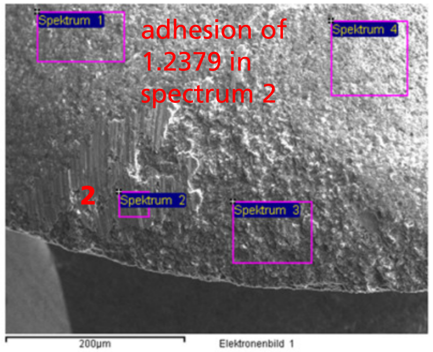
material	tool-type	RPM [min^{-1}]	Cutting speed [m/min]	Feed rate [mm/min]	Feed per tooth [mm]	Cutting depth [mm]	MQL	Ra [µm]	Rz [µm]
1.2379	CBN	13,000	60	675	0.025	0.25	no	1.48	9.05
1.2379	CBN	13,000	60	675	0.025	0.1	yes	0.25	1.39
1.2379	CBN	18,000	80	900	0.025	0.1	yes	0.34	1.66
1.2379	CBN	22,500	100	1,125	0.025	0.1	yes	0.26	1.53
1.2379	CBN	27,000	120	1,350	0.025	0.1	yes	0.28	1.58
1.2379	CC	27,500	120	1,350	0.025	0.1	yes	0.52	1.92
M340	CBN	22,500	100	1,125	0.025	0.1	yes	0.5	2.36

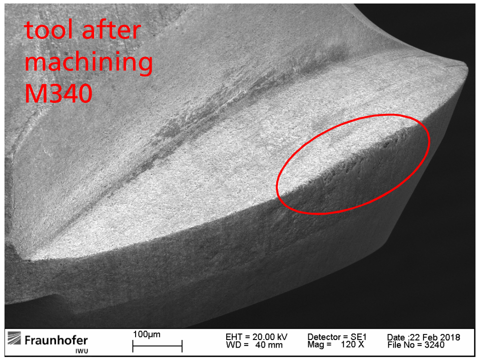
Results

Machining investigations

- Results and tool wear behaviour
  - The reached values on surface quality are close to the described target sector and better than while using tungsten carbide tools
  - Identified problem was the relatively high tool wear (flank wear) and adhesion of workpiece material especially in 1.2379 machining.
  - Problem was not present in machining of M340, but roughness value was higher than in 1.2379 machining and while using tungsten carbide tools.







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Results

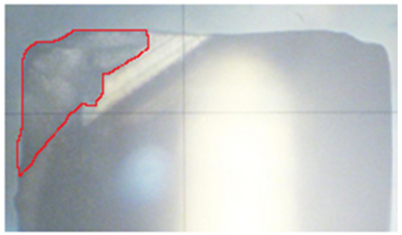
Machining investigations

- Comparison to commercial available tools in smaller dimensions
  - Toroid cutting tools in diameter 0.5 mm, cutting material cubic boron nitrite (CBN) and cemented carbide (CC)
  - Machining of a pocket were done using different cutting parameters

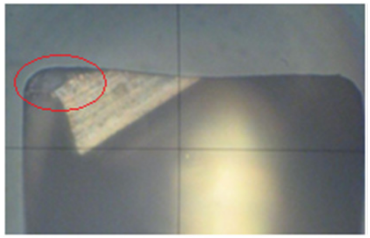
material	tool-type	RPM [min^{-1}]	Cutting speed [m/min]	Feed rate [mm/min]	Feed per tooth [mm]	Cutting depth [mm]	MQL	Ra [µm]	Rz [µm]
1.2379	CC	26,000	40	220	0.004	0.01	no	0.11	0.85
1.2379	CC	26,000	40	220	0.004	0.01	yes	0.09	0.69
1.2379	CBN	37,000	58	1490	0.02	0.01	no	0.15	1.1
1.2379	CBN	37,000	58	1490	0.02	0.01	yes	0.12	0.9

  - Tool wear behaviour

CC dry

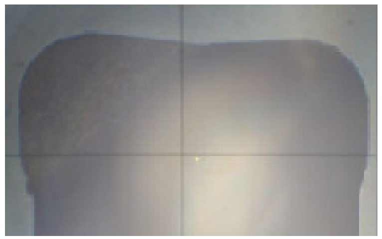


CC MQL



CBN dry

CBN MQL



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Results

Machining investigations

- Intermediate results based on previous investigations for high efficient hard machining

	Cutting material	Tool wear	Roughness	
			Parallel to feed direction	Across to feed direction
Dry machining	CC	--	++	--
	CBN	-	o	o
MQL	CC	o	++	o
	CBN	++	+	+

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Conclusion

- currently reached surface quality is already on the target corridor for the investigated workpiece material 1.2379 and better than in tungsten carbide machining
- Further comprehensive investigations are required and scheduled within the project to understand also for other workpiece materials the chip formation, tool wear systematics and relevant influencing variables while using monolithic CBN tools
- The next investigations will focus on other types of basic CBN material for tool preparation, alternative tool types and the development of cooling and lubrication strategies adapted to the requirements.
- The R&D project is founded by:

European Union
European Regional Development Fund
European Social Fund

Europe funds Saxony.
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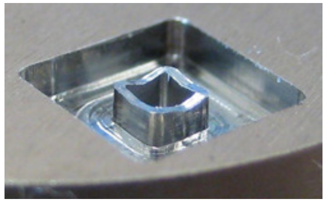
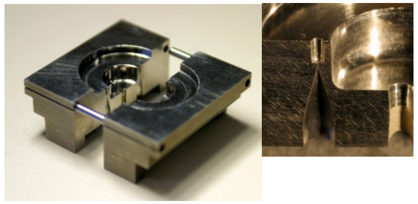
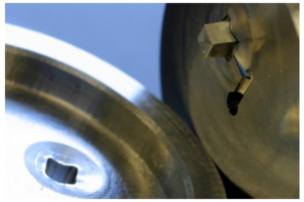
Thank you for your attention!

- Innovative processes for effective cost reduction and process reliable production
- Focus on process chains with forming, cutting and ablating technologies
- R&D based on industry demands
- Participation in national und international projects

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