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Experimental investigations on the machinability of tungsten carbides in orthogonal cutting with diamond coated tools

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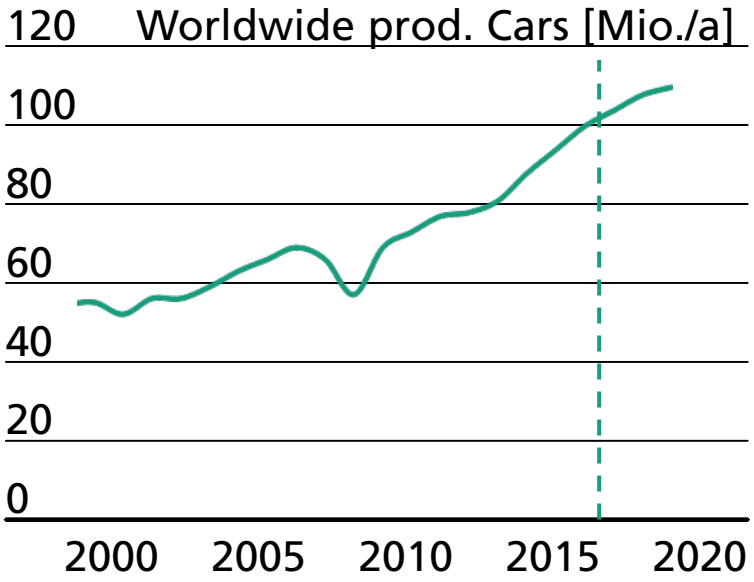
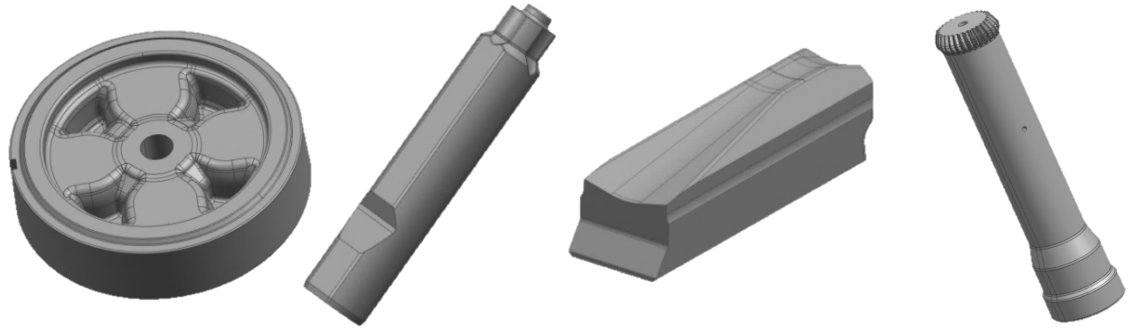
The market for forming dies will continuously increase…



Source: VW, Thyssen Krupp Presta, Hirschvogel, PWC

Single components made by massive forming/forging:

Relevant forming tools



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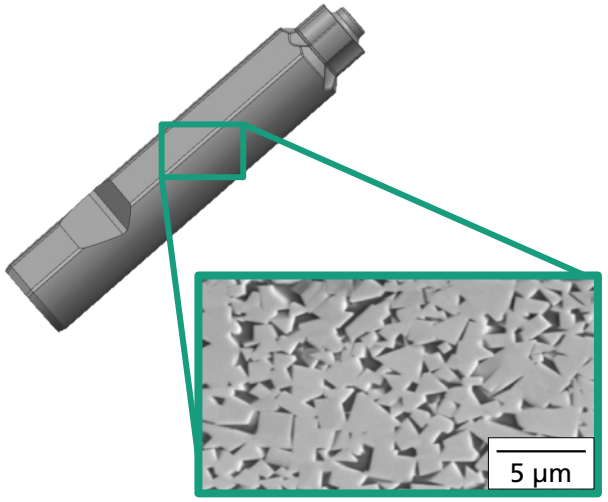
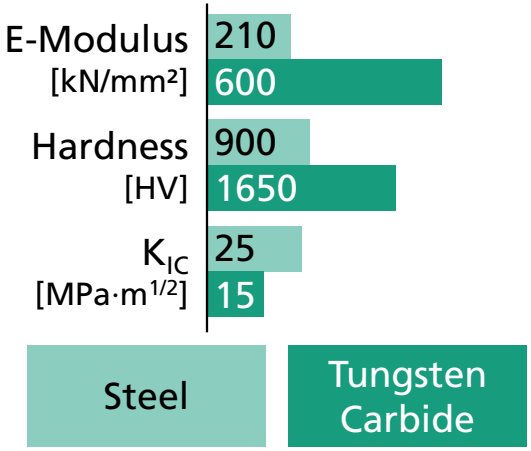
Tungsten carbides are very challenging for milling operations



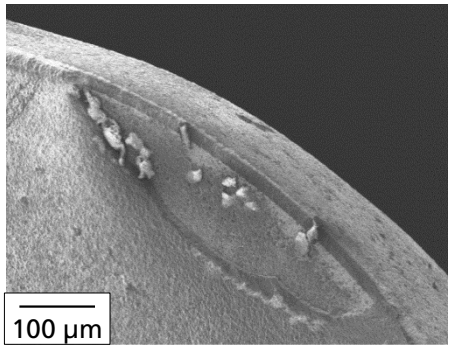


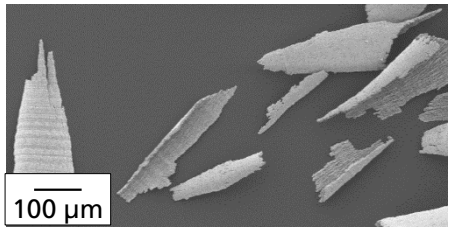
Source: Thyssen Krupp Presta, Fraunhofer IPT, WZL

Properties of tungsten carbides when milling lead to:

- Failure of coatings and cutting edges breakages
- Unreproducible and uneconomical machining processes

First investigations show the potentials of milling tungsten carbides, but…





…lack of knowledge lead to :

- Short tool life time
- Unreproducible machining processes
- Bad workpiece quality
- High tool and process costs

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Economical and scientific challenges

Economical question:

How to achieve reproducible and economical milling processes for forming tools made of tungsten carbides?

Scientific questions:

1) What is the thermo-mechanical loading when milling tungsten carbides?
2) What are the influencing factors and what is their impact on the milling process performance?
3) How can milling processes of tungsten carbides be adjusted to become reproducible and economical?

Structure

1 Introduction and motivation

2 Scope of research

3 Experimental investigations

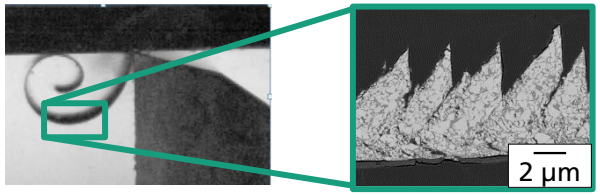
4 Results

5 Summary and future activities

Scope of research

Thermo-mechanical loadings / Machinability

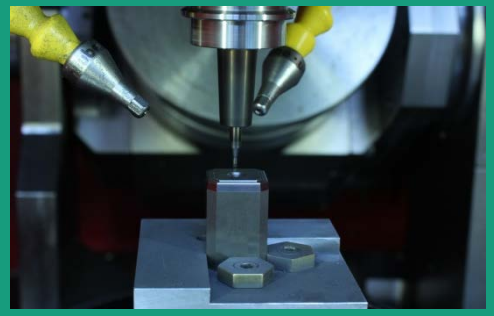
Chip formation



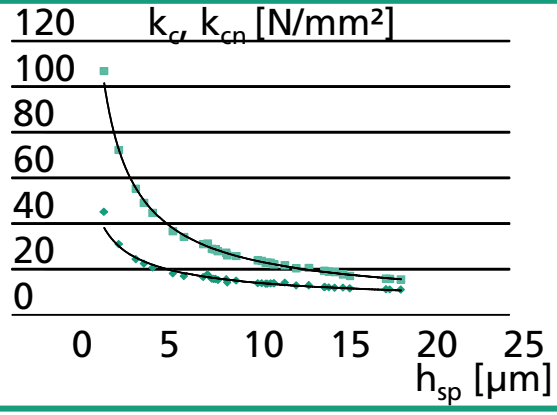
Key values:

G, l_{ch}, f_{seg}, λ_{ch}, φ

Thermo-mechanical loading/ Machinability



Cutting force



Systematical variation of machining process variables

Process parameters

Cutting velocity v_c:
70, 140 m/min

Uncut chip thickness h_{cu}:
3-30 µm

Workpiece

Variation of cobalt %:

WC-11,8Co; fine grain
WC-17,5Co; fine grain

Tool

Clearance angle α:
15° (const)
Rake angle γ:
0° (const)
Cutting edge rounding r_β:
5 µm, 19 µm, 29 µm

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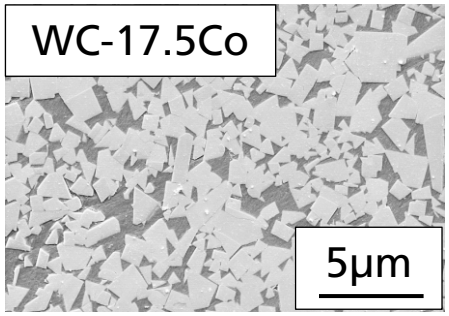
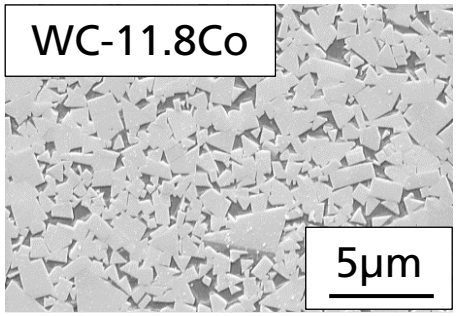
Fundamental qualification of work piece and tools

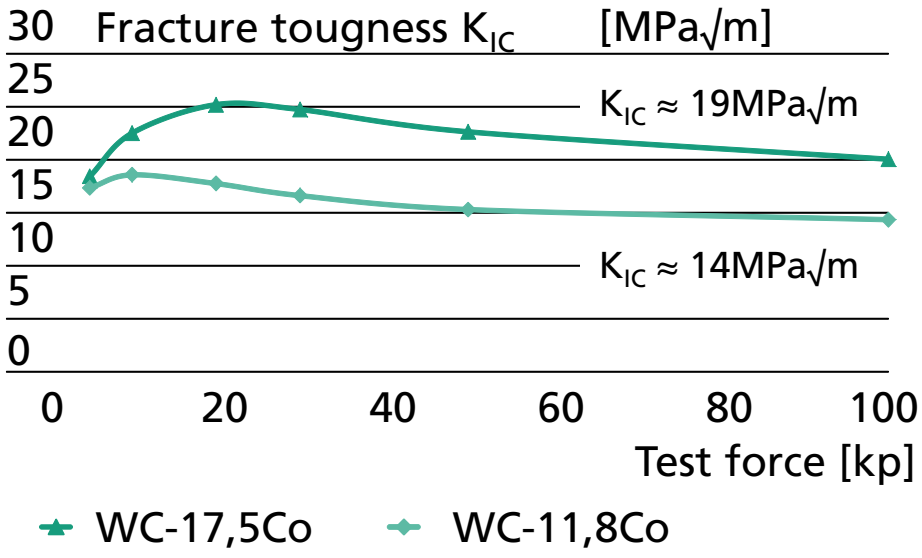
Work piece



Hardness: 1150HV10

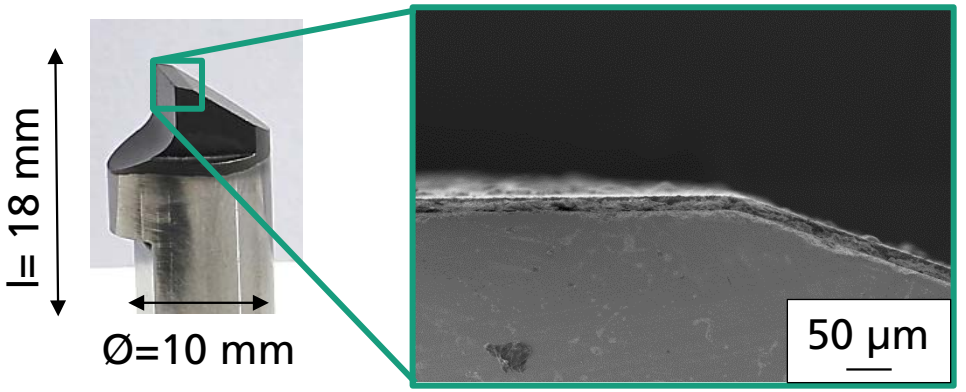


Hardness: 1400HV10

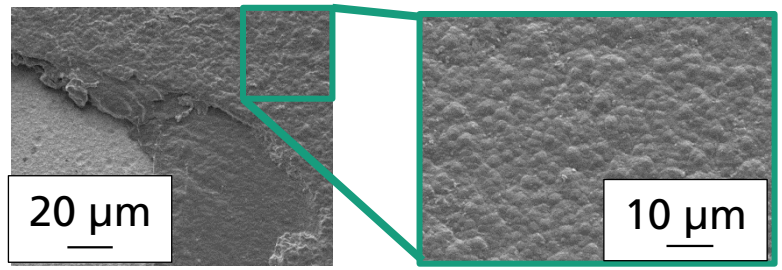


Tools

Substrate:	WC-6Co (Submicron)
Coating:	CVD Diamond Multilayer (Nano-/Microlayer)
Coating thickness:	17±1µm



Coating structure



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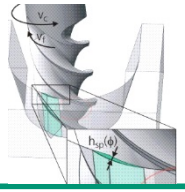
Analysis of Machining Behaviour – Analogy Process

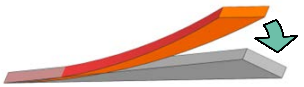
Transformation of uncut chip geometry

Real milling process

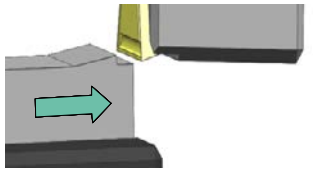


Real uncut chip geometry

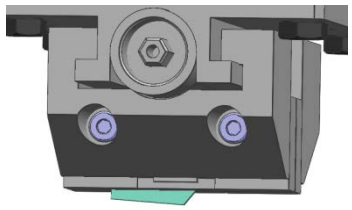
Simplified uncut chip geometry

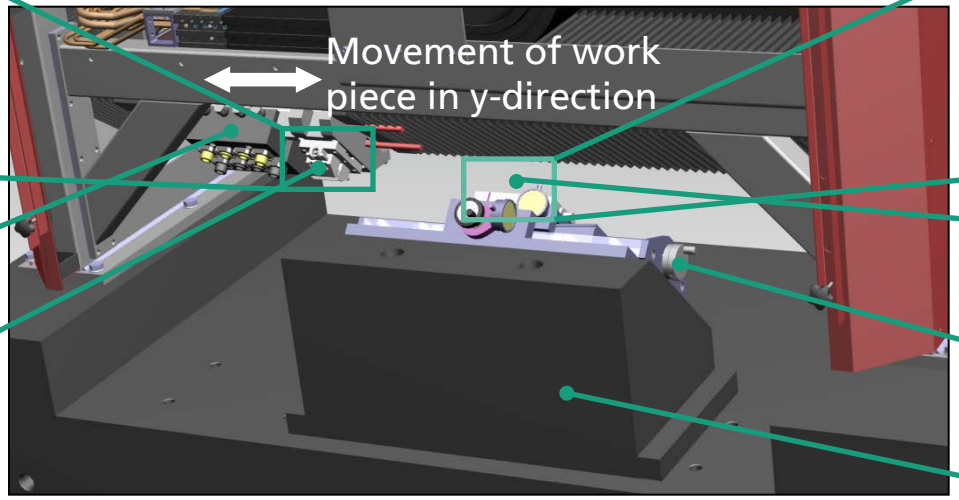


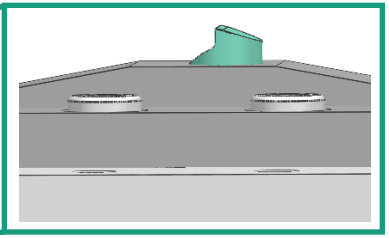
Analogy milling process



Isometric view on test bench







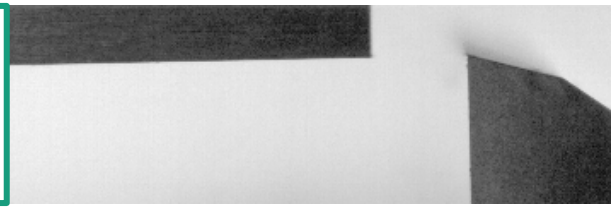
- Hydrostatic mounted slide
- Work piece in high precision bench vice
- Special tool on force sensor
- Hand wheel for tool infeed
- Granite bed

Structure

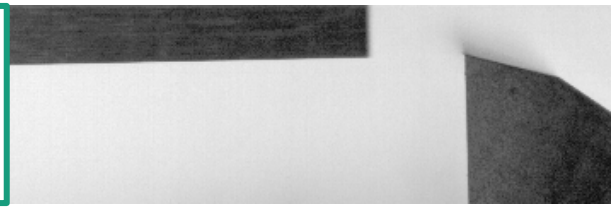
Chip formation of tungsten carbides

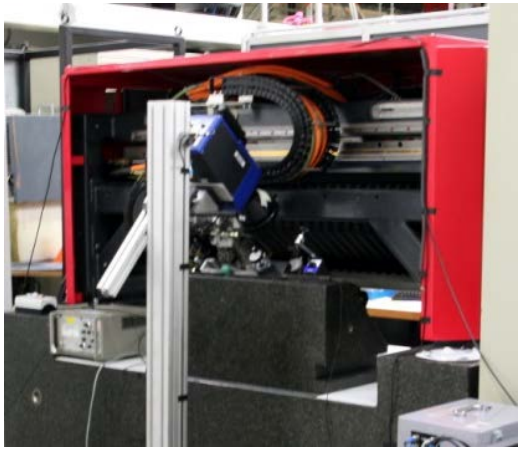
WC-17,5Co

v_c =70 m/min
r_β =19 µm



v_c =140 m/min
r_β =19 µm





Process setup

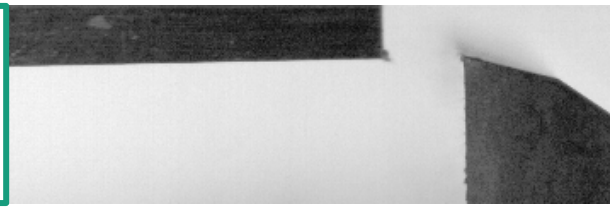
Orthogonal cutting

Uncut chip thickness:
h_{cu} = 10 µm

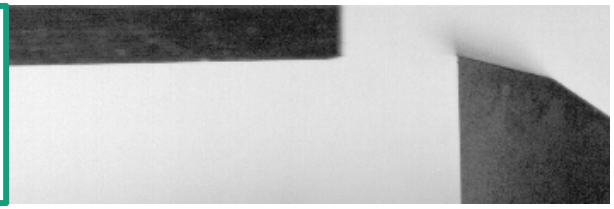
Tool geometry:
$\alpha = 15°; \gamma = 0°$

WC-11,8Co

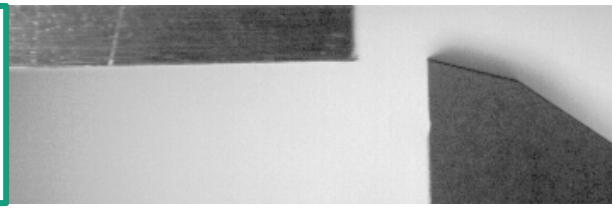
v_c =70 m/min
r_β =19 µm



v_c =140 m/min
r_β =19 µm

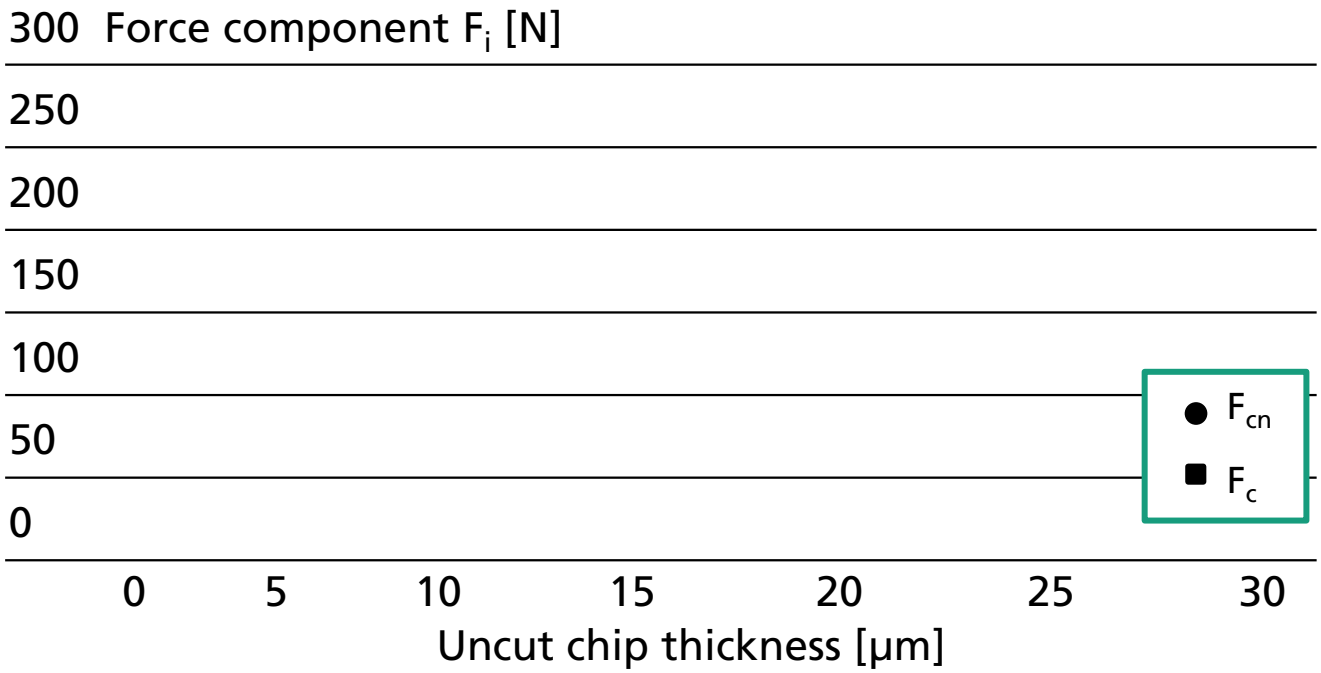


v_c =70 m/min
r_β =5 µm



v_c =70 m/min
r_β =29 µm

Evaluation of cutting force



Model-Equations: $F_i = K_{i,1.1} \cdot b \cdot {h_{cu}}^{(1-m_i)}$

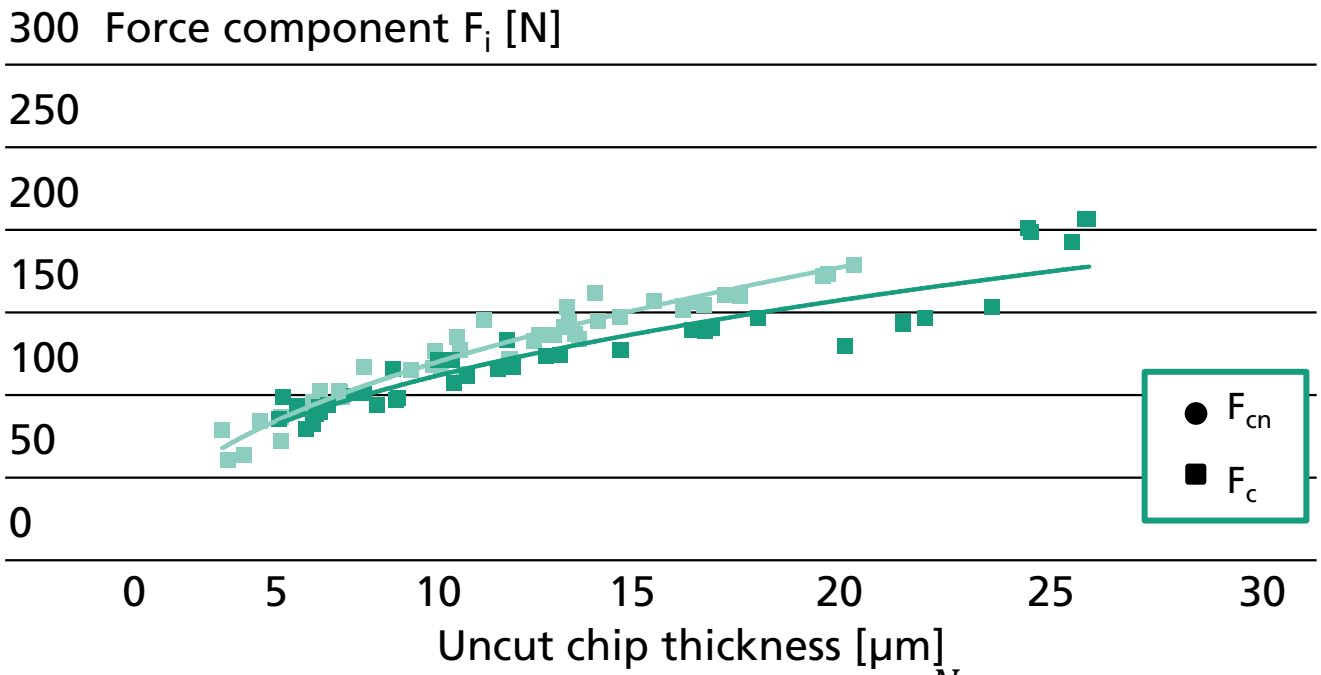
Cutting velocity
v_c = 70 m/min

Tool geometry
clearance angle: α = 15°
rake angle: γ = 0°

Cutting edge radius
r_β = 19 µm

Material and hardness
- WC-11,8Co;1400 HV10
- WC-17,5Co;1150 HV10

Influence of cobalt content on cutting force components



Model-Equations:

$$F_c\ (11{,}8\ \% - Co) = 1026 \frac{N}{mm^2} \cdot b \cdot {h_{sp}}^{0{,}4385}$$

$$F_c\ (17{,}5\ \% - Co) = 734 \frac{N}{mm^2} \cdot b \cdot {h_{sp}}^{0{,}3826}$$

Cutting velocity
v_c = 70 m/min

Tool geometry
clearance angle: α = 15°
rake angle: γ = 0°

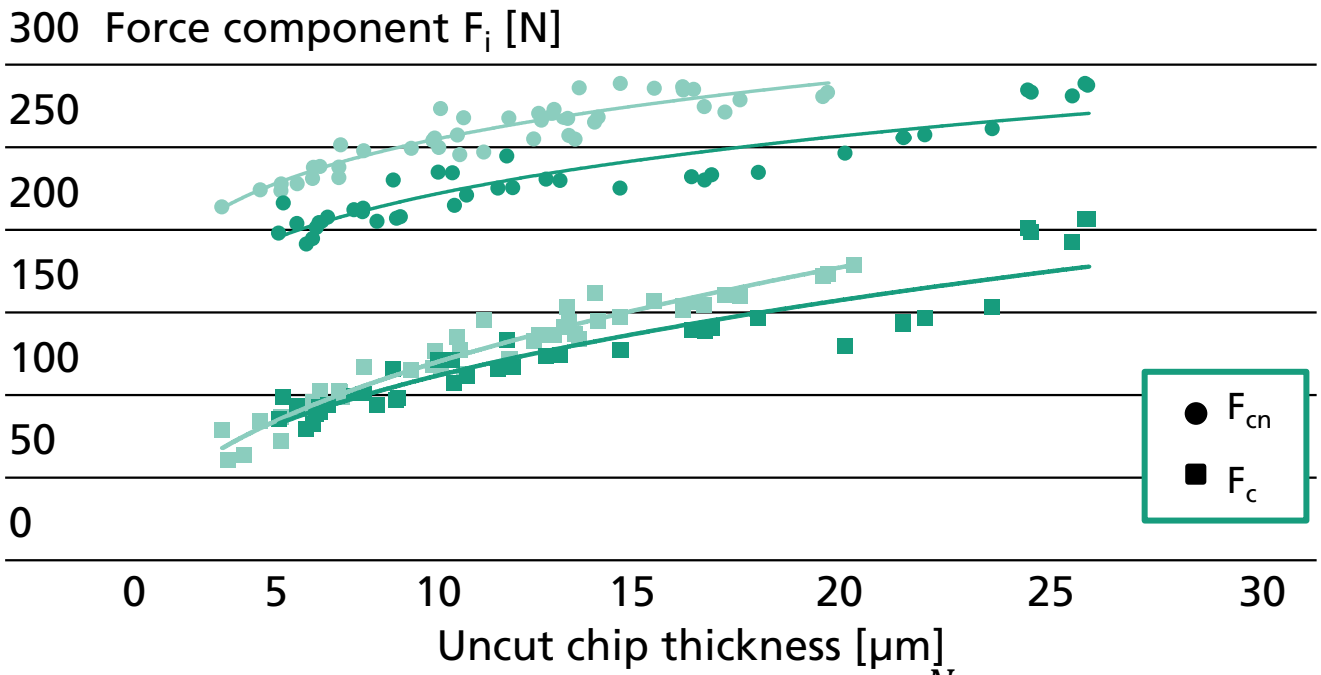
Cutting edge radius
r_β = 19 µm

Kienzle-Model

$$F_i = K_{i,1.1} \cdot b \cdot {h_{cu}}^{(1-m_i)}$$

Material and hardness
- WC-11,8Co;1400 HV10
- WC-17,5Co;1150 HV10

Influence of cobalt content on cutting force components



Model-Equations:

$$F_{cn}(11{,}8\,\%-Co) = 512\,\frac{N}{mm^2}\cdot b\cdot {h_{sp}}^{0{,}1477}$$

$$F_{cn}(17{,}5\,\%-Co) = 497\,\frac{N}{mm^2}\cdot b\cdot {h_{sp}}^{0{,}1688}$$

Cutting velocity
v_c = 70 m/min

Tool geometry
clearance angle: α = 15°
rake angle: γ = 0°

Cutting edge radius
r_β = 19 µm

Kienzle-Model

$$F_i = K_{i,1.1}\cdot b\cdot {h_{cu}}^{(1-m_i)}$$

Material and hardness
- WC-11,8Co;1400 HV10
- WC-17,5Co;1150 HV10

An increasing cobalt content effects decreasing force components

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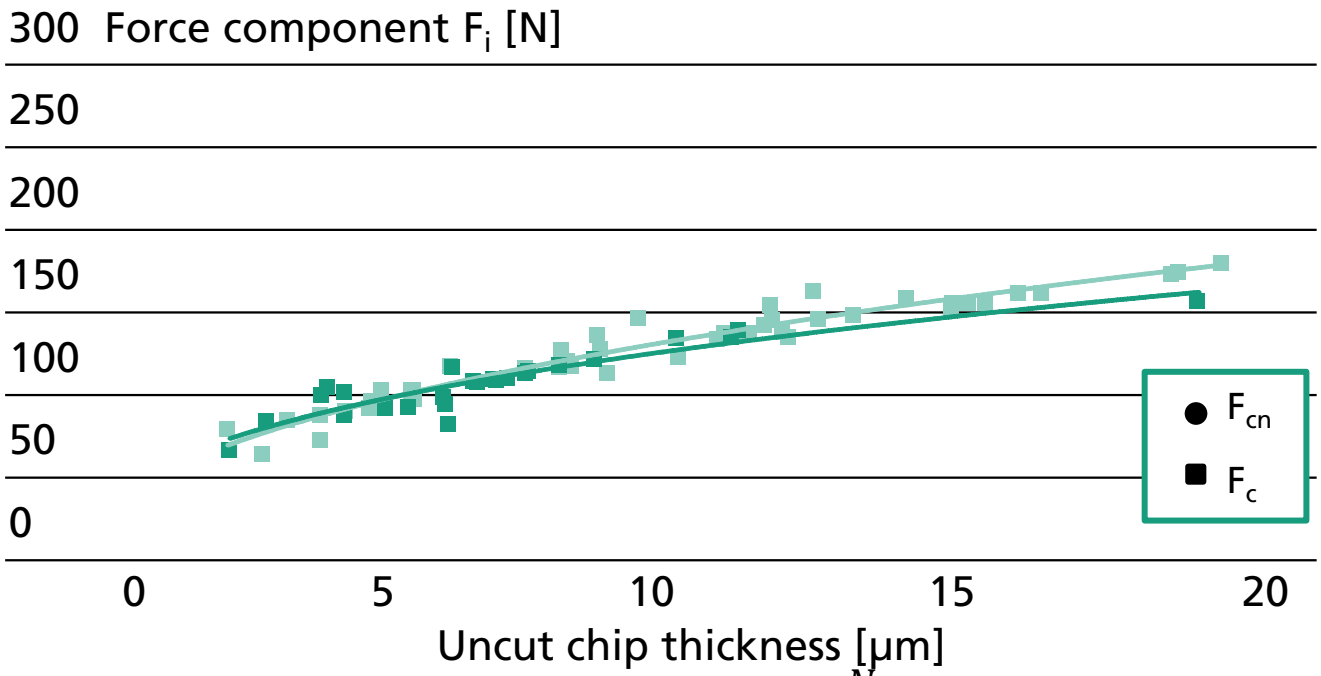
Influence of cutting velocity on cutting force components



Model-Equations:

$$F_c\left(70\frac{m}{min}\right) = 972\frac{N}{mm^2}\cdot b\cdot {h_{sp}}^{0{,}4267}$$

$$F_c\left(140\frac{m}{min}\right) = 691\frac{N}{mm^2}\cdot b\cdot {h_{sp}}^{0{,}3618}$$

Material and hardness
WC-11,8Co;1400 HV10

Tool geometry
clearance angle: α = 15°
rake angle: γ = 0°

Cutting edge radius
r_β = 19 µm

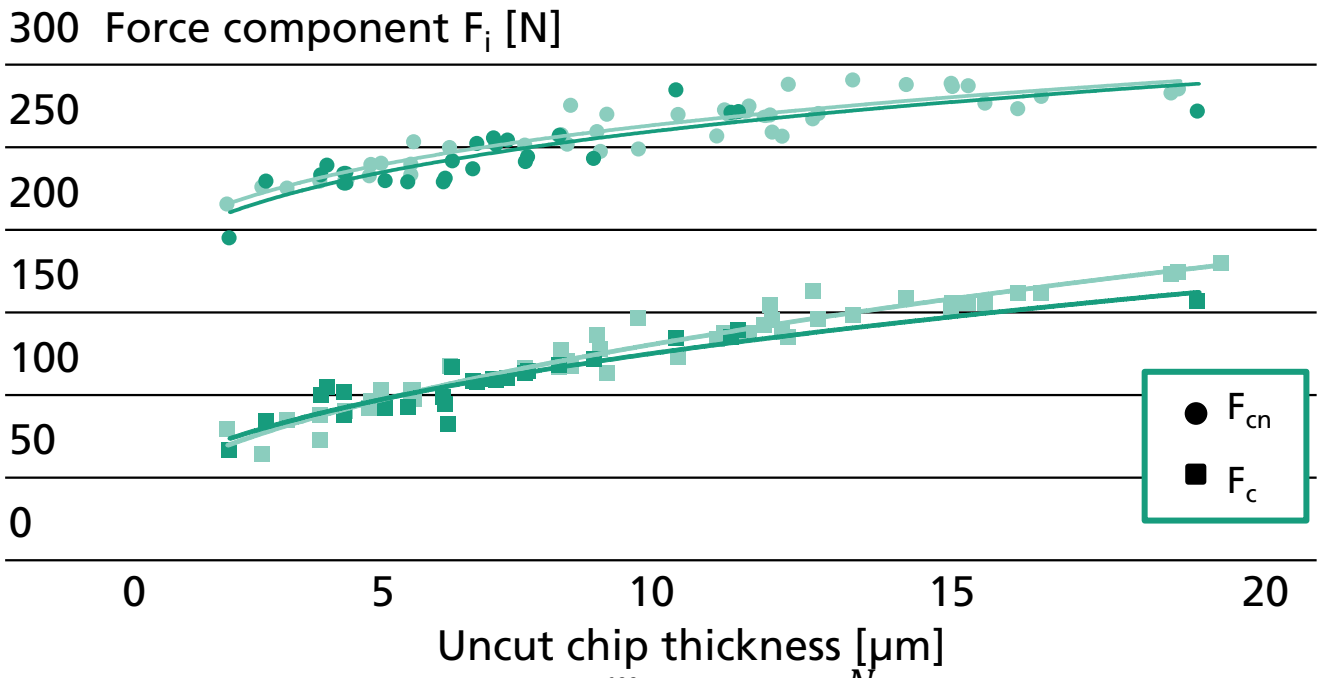
Kienzle-Model

$$F_i = K_{i,1.1}\cdot b\cdot {h_{cu}}^{(1-m_i)}$$

Cutting velocity
- v_c = 70 m/min
- v_c = 140 m/min

Results

Influence of cutting velocity on cutting force components



Model-Equations:

$$F_{cn}\left(70\frac{m}{min}\right) = 517\frac{N}{mm^2}\cdot b\cdot {h_{sp}}^{0{,}1526}$$

$$F_{cn}\left(140\frac{m}{min}\right) = 504\frac{N}{mm^2}\cdot b\cdot {h_{sp}}^{0{,}1442}$$

Material and hardness
WC-11,8Co;1400 HV10

Tool geometry
clearance angle: α = 15°
rake angle: γ = 0°

Cutting edge radius
r_β = 19 µm

Kienzle-Model

$$F_i = K_{i,1.1}\cdot b\cdot {h_{cu}}^{(1-m_i)}$$

Cutting velocity
- v_c = 70 m/min
- v_c = 140 m/min

An increasing cutting velocity effects slightly decreasing force components

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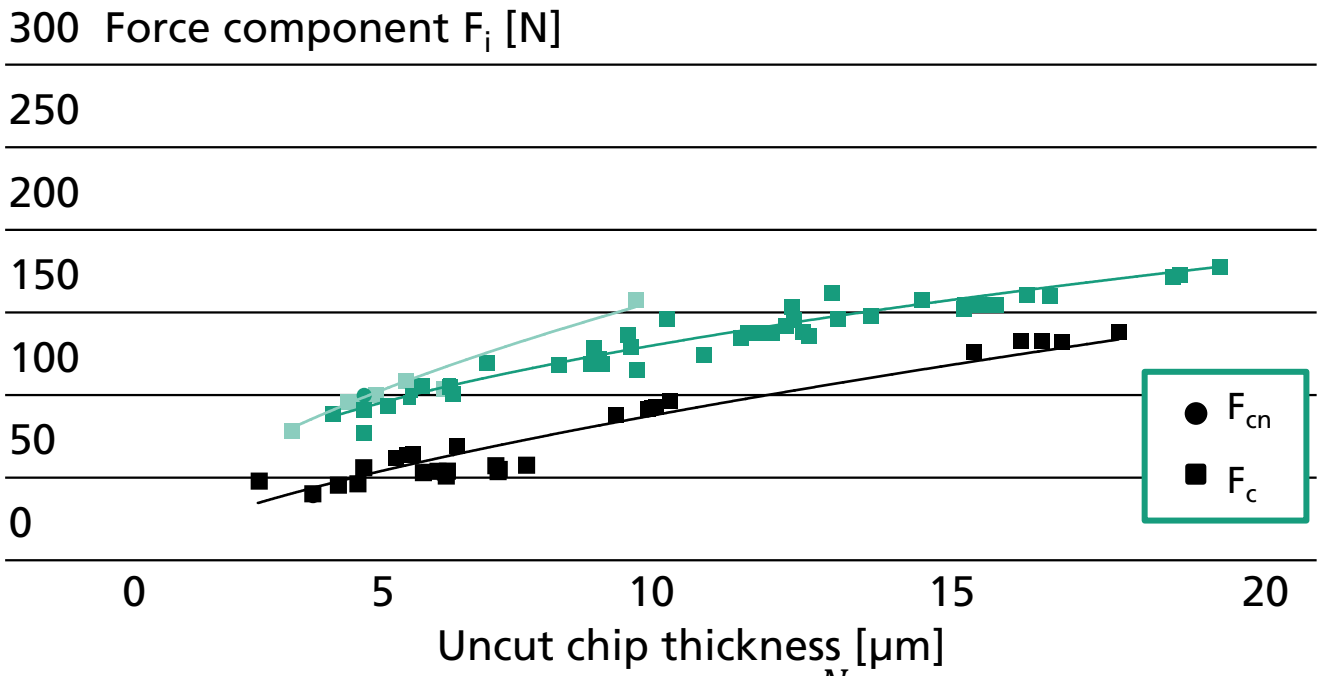
Influence of tools' micro geometry on cutting force components



Model-Equations:

$$F_c\ (29\ \mu m) = 2349 \frac{N}{mm^2} \cdot b \cdot {h_{sp}}^{0{,}5750}$$

$$F_c\ (19\ \mu m) = 970 \frac{N}{mm^2} \cdot b \cdot {h_{sp}}^{0{,}4261}$$

$$F_c\ (5\ \mu m) = 1994 \frac{N}{mm^2} \cdot b \cdot {h_{sp}}^{0{,}6627}$$

Material and hardness
WC-11,8Co;1400 HV10

Tool geometry
clearance angle: $\alpha = 15°$
rake angle: $\gamma = 0°$

Cutting velocity
$v_c = 70$ m/min

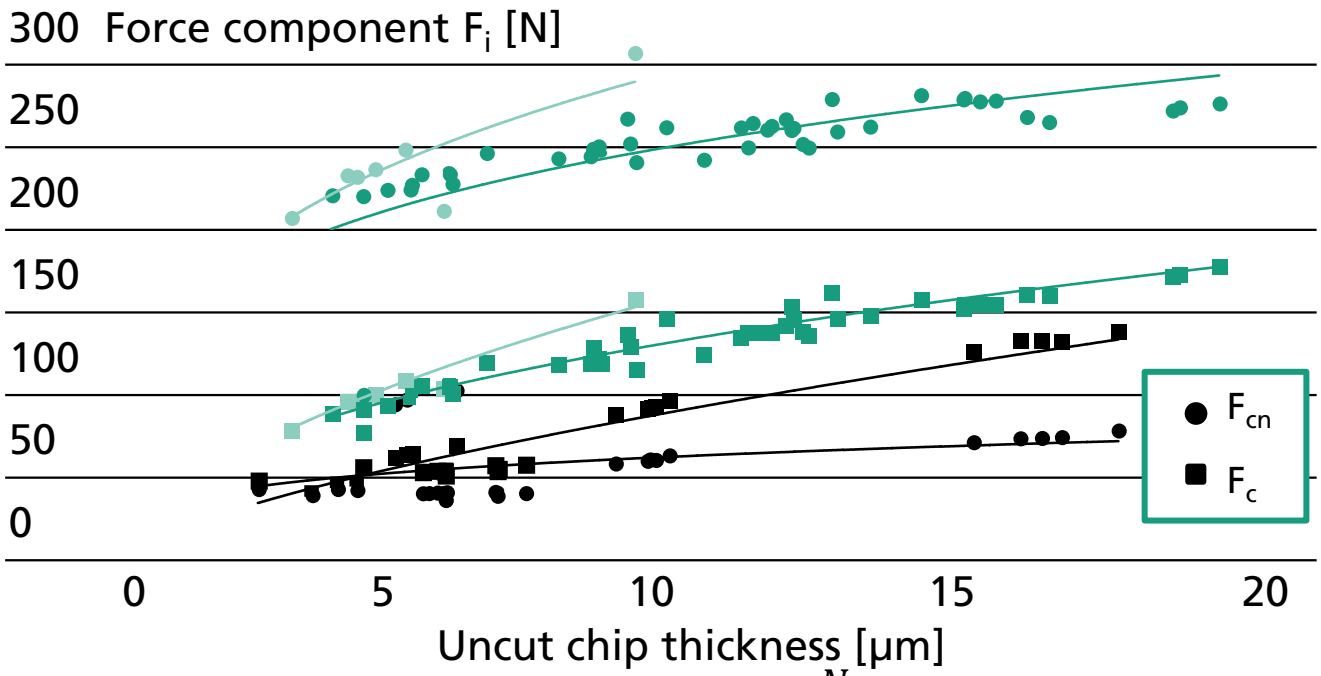
Kienzle-Model

$$F_i = K_{i,1.1} \cdot b \cdot {h_{cu}}^{(1-m_i)}$$

Cutting edge radius
- $r_\beta = 29$ µm
- $r_\beta = 19$ µm
- $r_\beta = 5$ µm

Results

Influence of tools' micro geometry on cutting force components



Material and hardness
WC-11,8Co;1400 HV10

Tool geometry
clearance angle: $\alpha = 15°$
rake angle: $\gamma = 0°$

Cutting velocity
$v_c = 70$ m/min

Kienzle-Model

$$F_i = K_{i,1.1} \cdot b \cdot {h_{cu}}^{(1-m_i)}$$

Model-Equations:

$$F_{cn}(29\ \mu m) = 1117 \frac{N}{mm^2} \cdot b \cdot {h_{sp}}^{0{,}2946}$$

$$F_{cn}(19\ \mu m) = 725 \frac{N}{mm^2} \cdot b \cdot {h_{sp}}^{0{,}2268}$$

Cutting edge radius
- $r_\beta = 29$ µm
- $r_\beta = 19$ µm
- $r_\beta = 5$ µm

A decreasing cutting edge radius effects significant decreasing force components but higher sensitivity against tool failures

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Structure

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5 **Summary and future activities**

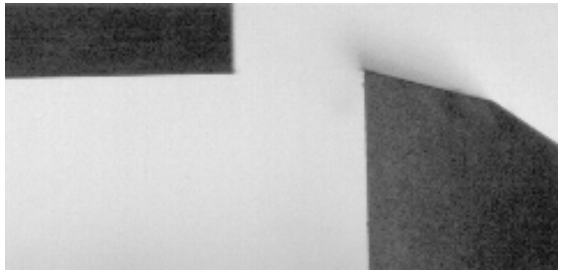
Main results

- Ductile cutting with continuous chips of tungsten carbides up to h_{cu} = 25 µm is possible with diamond coated tools
- An increase of cobalt of the workpiece material shows longer chips with a high chip curvature
- Smaller cutting edge radii result in short chips and brittle fracture of the workpiece material
- A significant decrease of the cutting force is seen when using a tool with small cutting edge radius
- High sensitivity for tool failures when using tools with high cutting edge radii
- The cutting velocity just has a slight influence on the cutting forces but significantly influences the chip formation towards more brittle chips

Future work

- Evaluation of the influence of grain size on the machinability
- Variation of the tool's macro geometry
- Evaluation of thermal loads while machining tungsten carbides
- Analysis of surface integrity of the workpiece
- Transfer of fundamental knowledge to milling applications
- Verification and evaluation of achieved manufacturing process chain

Milling of tungsten carbides becomes possible



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