MOVE THE WORLD FORWARD MITSUBISHI HEAVY INDUSTRIES GROUP

# Machining Process Solutions to support the Reduction of Distortion in Ring Gears after Heat Treatment

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WZL | RWTH AACHEN UNIVERSITY

MITSUBISHI HEAVY INDUSTRIES MACHINE TOOL

# Agenda

- Introduction
- Topic and Motivation
- State of the Art
- Objective and Method
- Tool Wear Behavior
- Residual Stress Analysis
- Improvement Solutions for Finishing Processes
- Summary and Outlook

# Mitsubishi Heavy Industries

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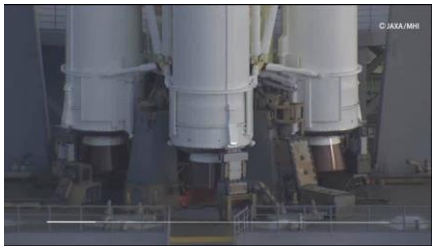



**Space Systems**


**Commercial Aircraft**

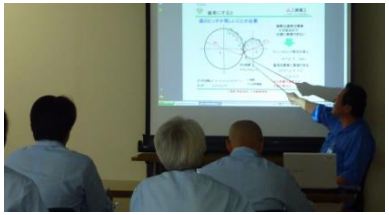
**Power Systems**

MITSUBISHI HEAVY INDUSTRIES MACHINE TOOL (MAT)

MITSUBISHI HEAVY INDUSTRIES GROUP

# We will create the future of “Monozukuri”

**“Monozukuri=Making things” -** the Japanese comprehensive concept of manufacturing to pursue creativeness and quality


# Business Portfolio

## Gear Machine System Business

### Gear Cutting Machine

### Gear Grinding Machine

## Total Solution Business

### Large Machine

### Special Purpose Machine

## Micro Machining Solution Business

### Room Temperature Wafer Bonding Machine

### Laser Micromachining System

### Micro Milling Machine

### 3D Printer

### Precision Position Feedback Detector

### Fiber Laser System

## Gear Cutting Tool Business

### Gear Cutting Tool

### Broach

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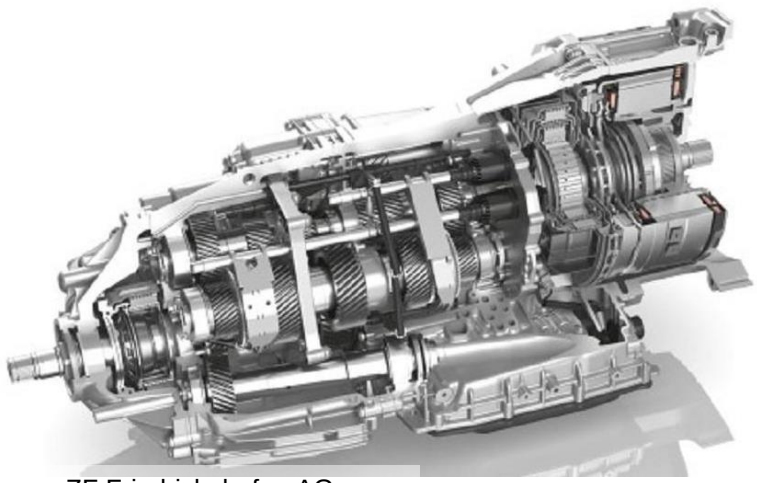
# What puts the ring gear in focus

Past & Present (Cars with Combustion Engine):



Source: ZF Friedrichshafen AG

**ZF 8-speed Dual Clutch Transmission:**

- many external gears
- manufacturing processes optimized
- internal (ring) gears already used, but quality not so critical

Present & Future (Electric Cars):

Source: Schaefller Technologies AG & Co. KG

**Schaeffler transmission for AUDI e-tron:**

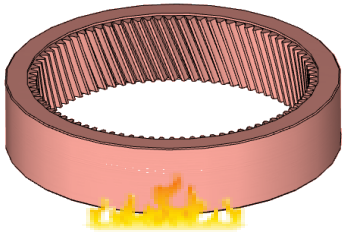
- Key component: planetary gearbox with **internal ring gear**
- Quality of **internal gear** after finishing very critical due to efficiency and high noise requirements
- manufacturing processes not yet clear within industry

# Ring Gear Production Process

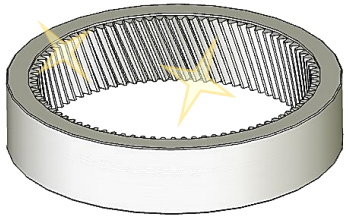
## Gear Machining Basics

Green Part

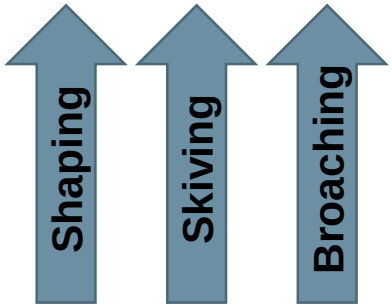
Gear Cutting (rough)

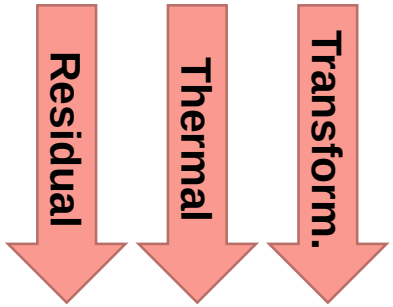


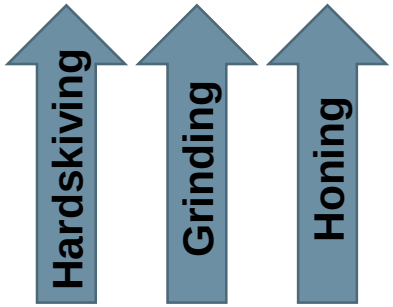
Hardening



Gear Finishing (fine)




Process Efficiency

Process Flexibility

Release of Stress cause plastic deformation

Restore intended geometric properties

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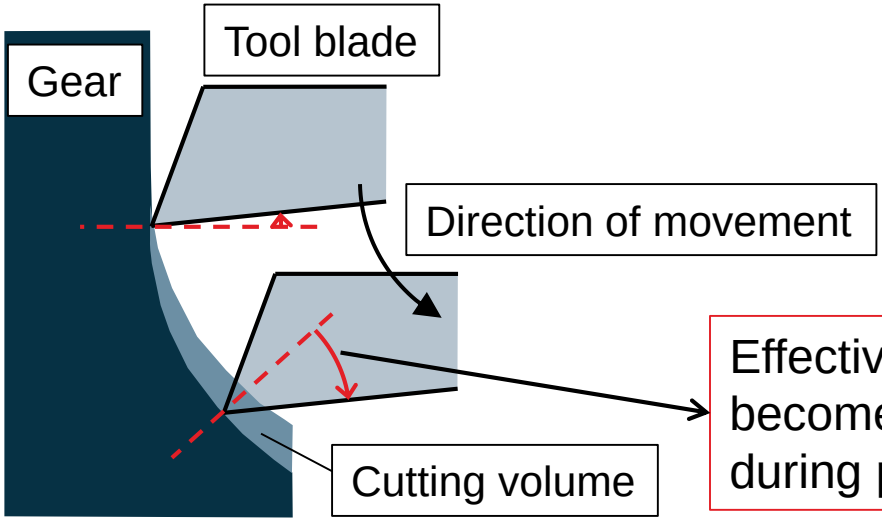
# Skiving Process

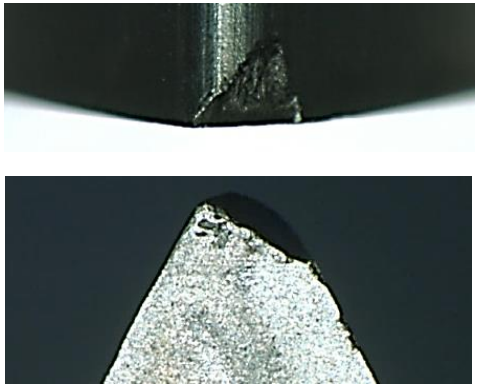
- Improvement of material and coating of tool
- Improvement of high stiffness and accuracy of machine

Highly accurate and efficient skiving processes is possible

However, the tool life is still a problem…




Effective rake angle becomes negative during process .

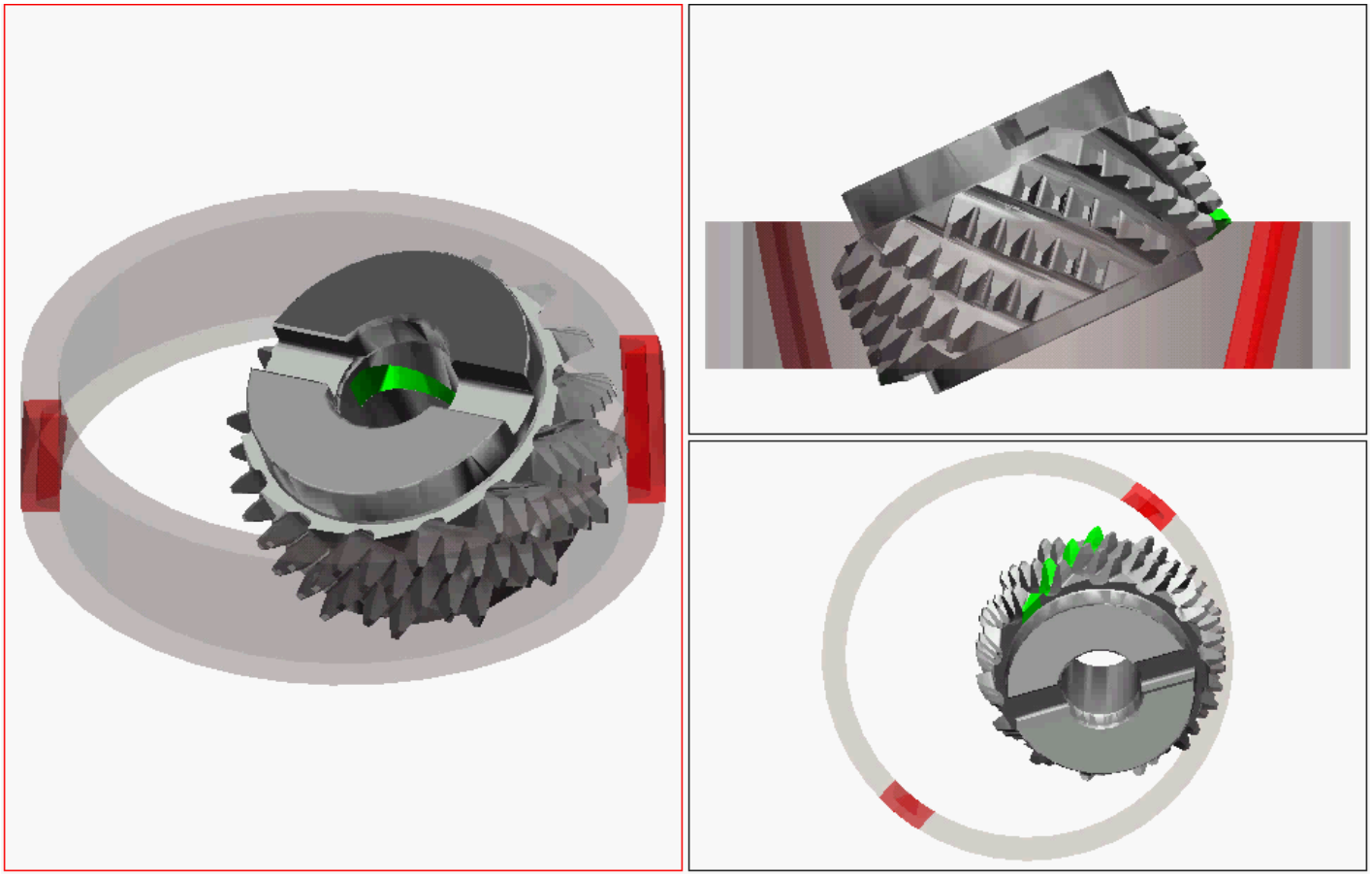


Large wear of tooth tip

# Super Skiving Process, Idea

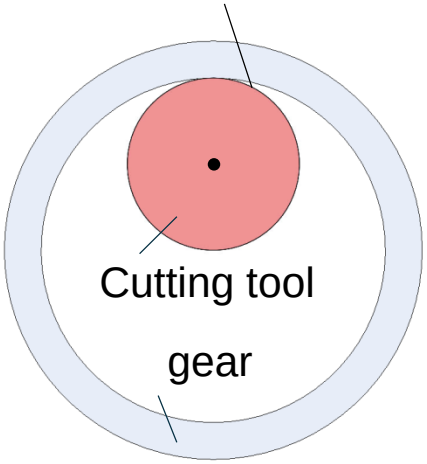
How to achieve both productivity and long tool life?

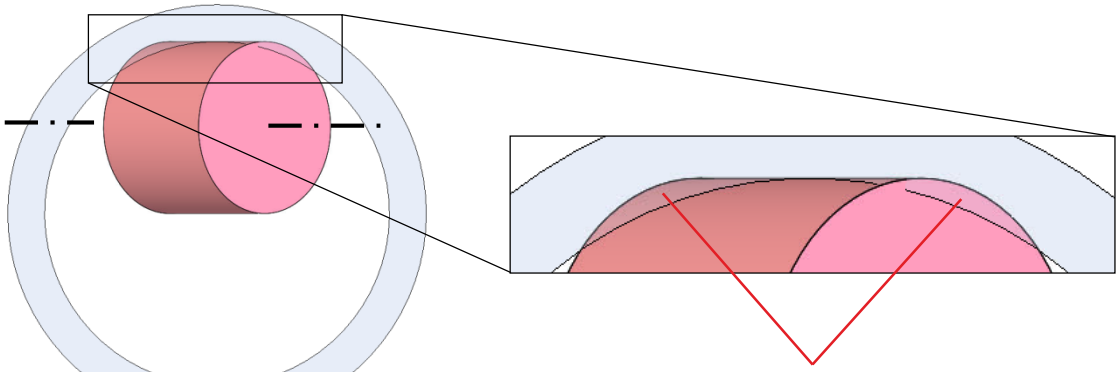
➡ Continuous cutting similar as hobbing



# Design of Super Skiving Cutter

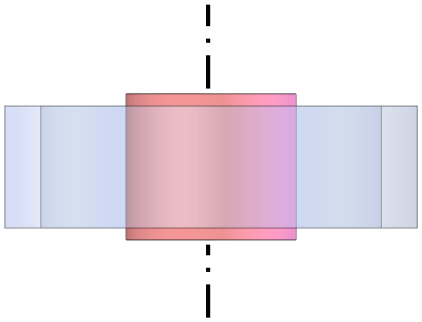
No interference
if cylindrical shape



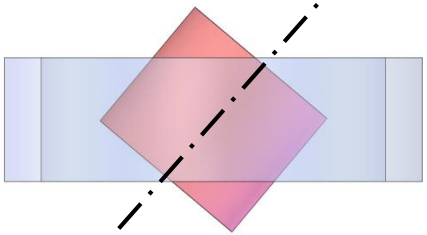



Interference

Barrel-shape is needed

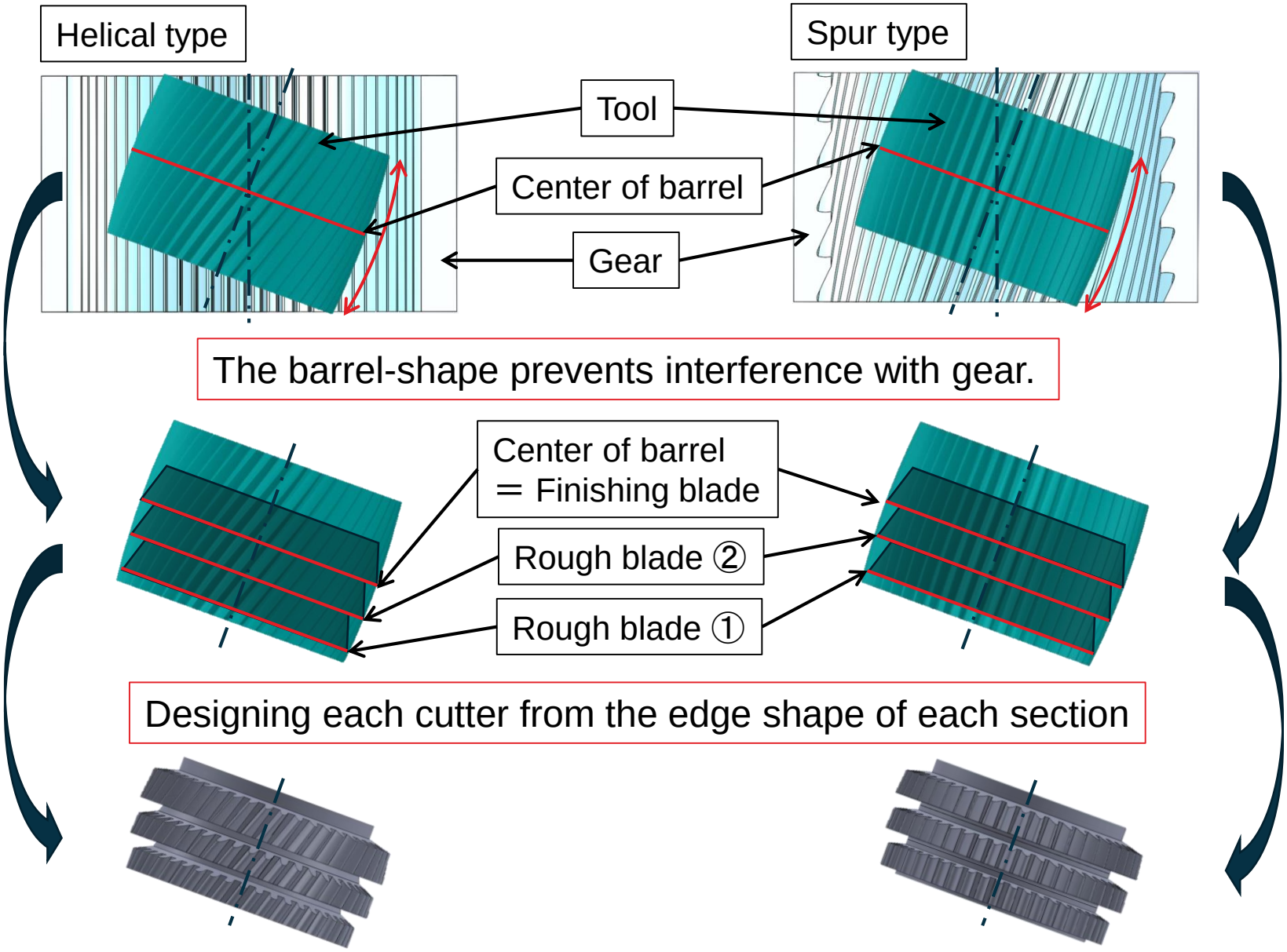


No crossed axes angle
(0° )

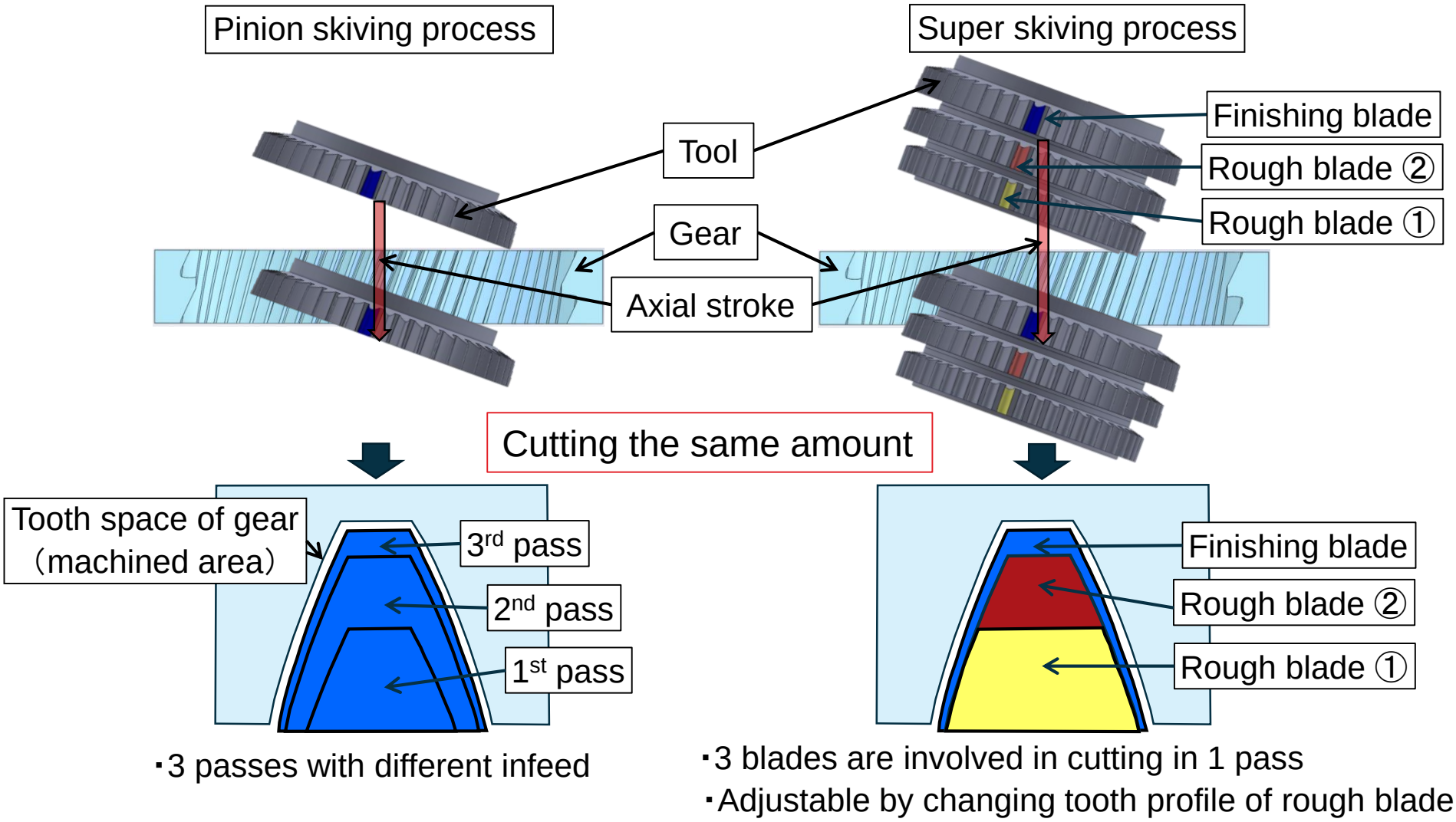


Crossed axes angle
(20° )

# Design of Super Skiving Cutter



# Advantage of Super Skiving Cutter




・3 passes with different infeed

・3 blades are involved in cutting in 1 pass
・Adjustable by changing tooth profile of rough blade

⇒ Adjustable rough blade profile, shared cutting process by 3 layer blades with the aim to establish longer tool life and higher productivity.

# Super Skiving Process

## Final Process Design

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# Objective and Method

- analyze how Super Skiving approach can be a solution to cut harder materials (>HRC30) while improving tool life compared to conventional skiving methods.
- whether using Super Skiving cutter has an effect on residual stresses

Tempered steel

DIN 42CrMo4
JIS SCM440

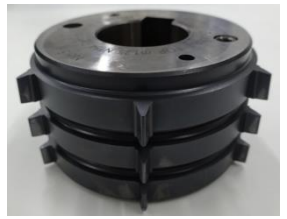

- Cutter design,
  Pinion Skiving Cutter (PSC) vs Super Skiving Cutter (SSC)
- Cutter material,
  High Speed Steel (HSS) vs Carbide
- Test pieces hardness,
  HRC 30-35 vs 35-40
- Cutting conditions
  Number of cuts 7 vs 13

# Dimensions

| Test Piece dimensions | | |
|---|---|---|
| Module | 1.25 | mm |
| No. of teeth | 85 | |
| Pressure angle | 20 | deg |
| Helix angle | 20 (RH) | deg |
| Root dia. | 116.920 | mm |
| Inside dia. | 111.170 | mm |
| Face width | 30 | mm |
| Material | 1.7225 (42CrMo4) | |
| Hardness | 30-35 and 35-40 | HRC |

| Tool dimensions | |
|---|---|
| Type | PSC and SSC ※1 |
| No. of teeth | 54 (real blade 6) ※2 |
| Helix angle | SPUR |
| Material | High Speed Steel and Carbide(K30-40) |
| Coating | AlCrN |

Test tool (SSC)



| Cutting Conditions | | |
|---|---|---|
| Cutting speed | 120 | m/min |
| Axial feed | 0.18 (roughing)<br>0.09 (finishing) | mm/rev |
| Cuts ※3 | 7 and 13 | times |

※1 PSC: Pinion Skiving Cutter
SSC: Super Skiving Cutter

※2 Test cut was carried out with 6 real blades

※3 7 cuts = 7 machine strokes for Pinion Skiving Cutter,
3 machine strokes for Super Skiving Cutter
13 cuts = 13 machine strokes for Pinion Skiving Cutter,
5 machine strokes for Super Skiving Cutter

# MSS300 Super Skiving Machine

- Optimized design for Super Skiving
- Pinion Skiving & Super Skiving available


| Technical data of MSS300 | | |
|---|---|---|
| Max. workpiece diameter | Ø300 | mm |
| Max. module | 4 | mm |
| Spindle motor power | 33 | kW |
| Max. RPM of spindle | 5,000 | $min^{-1}$ |
| Max. RPM of work table | 2,000 | $min^{-1}$ |
| Max. swivel angle of spindle | ±30 | deg |
| Mass | 20,000 | kg |
| Size | W 4,550<br>D 3,345<br>H 2,990 | mm |

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# PSC vs SSC (HRC30-35), HSS

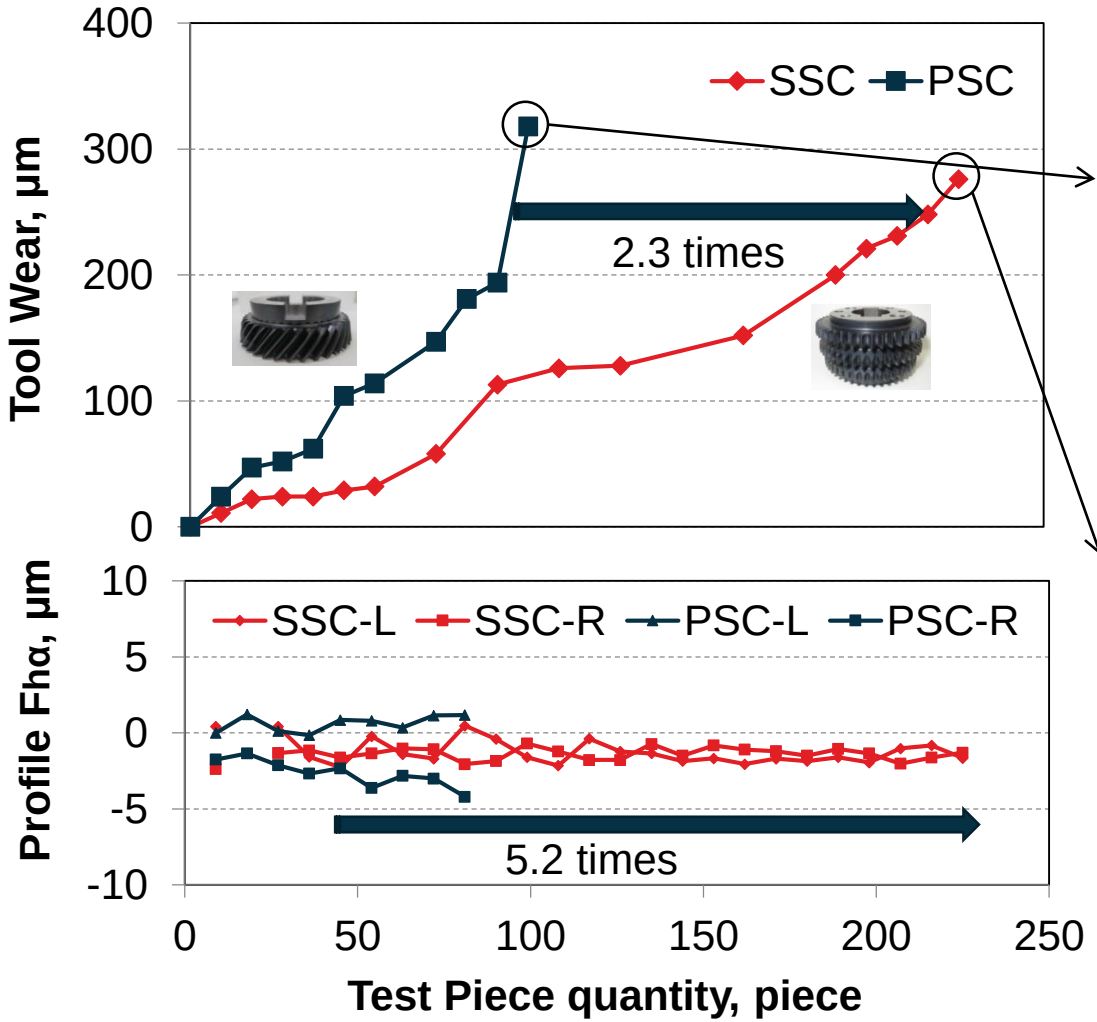
## Test Conditions

Test Piece
- Hardness
  HRC 30-35

Tool
- Tool type
  PSC and SSC
- Material
  High Speed Steel

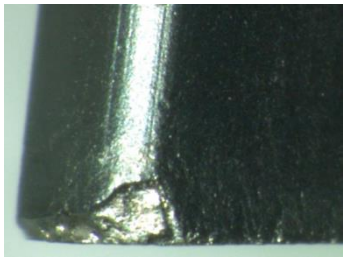
Cutting Conditions
- Cutting speed
  120 m/min
- Cuts
  13
- Cycle time
  245 sec (PSC)
  145 sec (SSC)

PSC: Pinion Skiving Cutter
SSC: Super Skiving Cutter

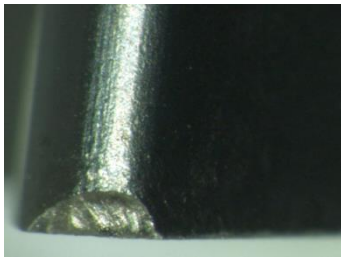



Tool wear

PSC



SSC



Super Skiving Cutter has longer tool life while reducing cycle time by 40%.
2.3 times, by 0.25 mm tool wear
5.2 times, by profile slope variation

# PSC vs SSC (HRC35-40), HSS

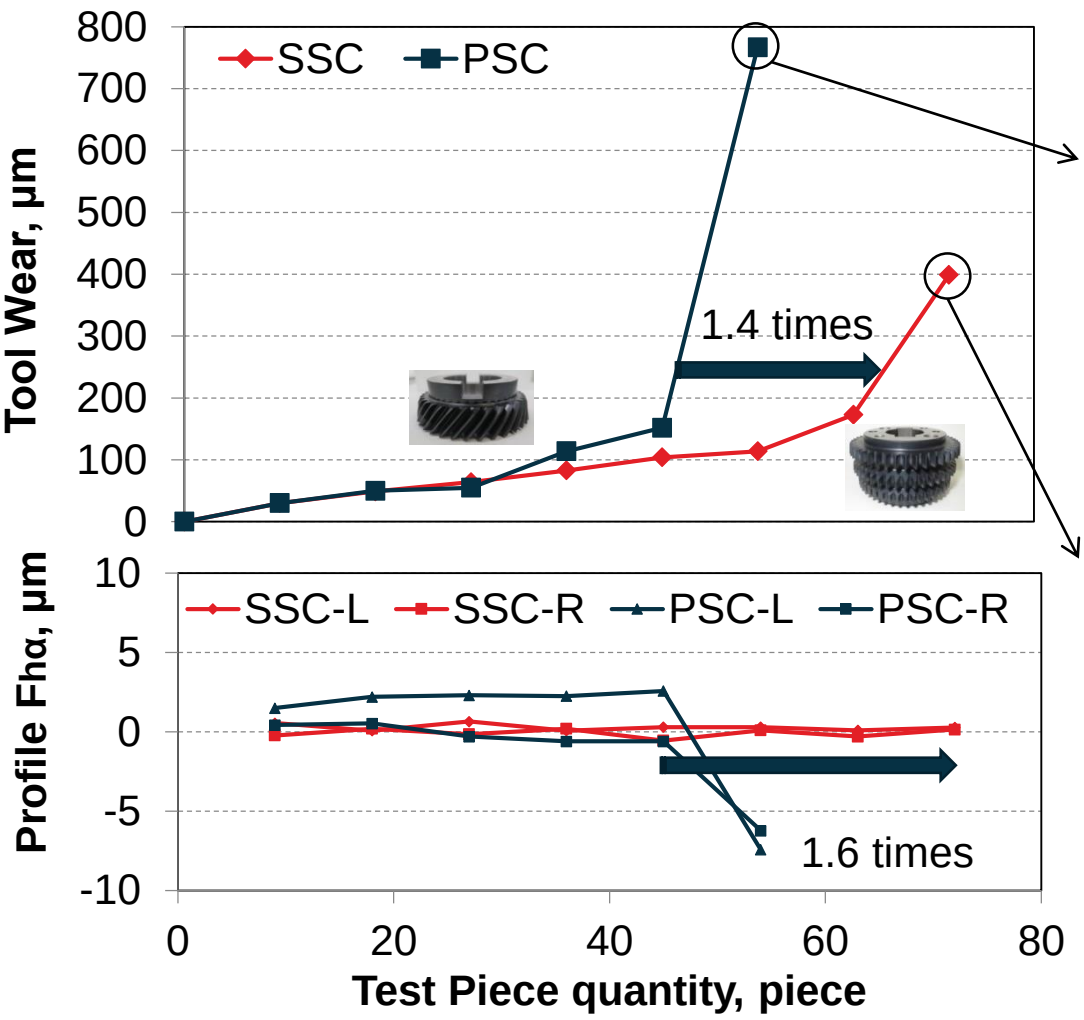
## Test Conditions

Test Piece
- Hardness
  HRC 35-40

Tool
- Tool type
  PSC and SSC
- Material
  High Speed Steel

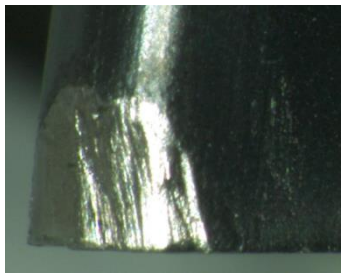
Cutting Conditions
- Cutting speed
  120 m/min
- Cuts
  13
- Cycle time
  245 sec (PSC)
  145 sec (SSC)

PSC: Pinion Skiving Cutter
SSC: Super Skiving Cutter

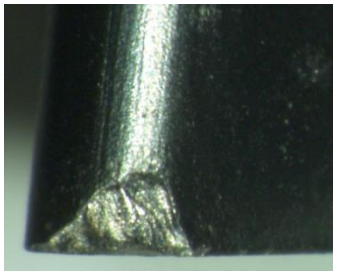



Tool wear

PSC



SSC



Super Skiving Cutter has longer tool life.
1.4 times, by 0.25 mm tool wear
1.6 times, by profile slope variation

# PSC vs SSC (HRC35-40), Carbide

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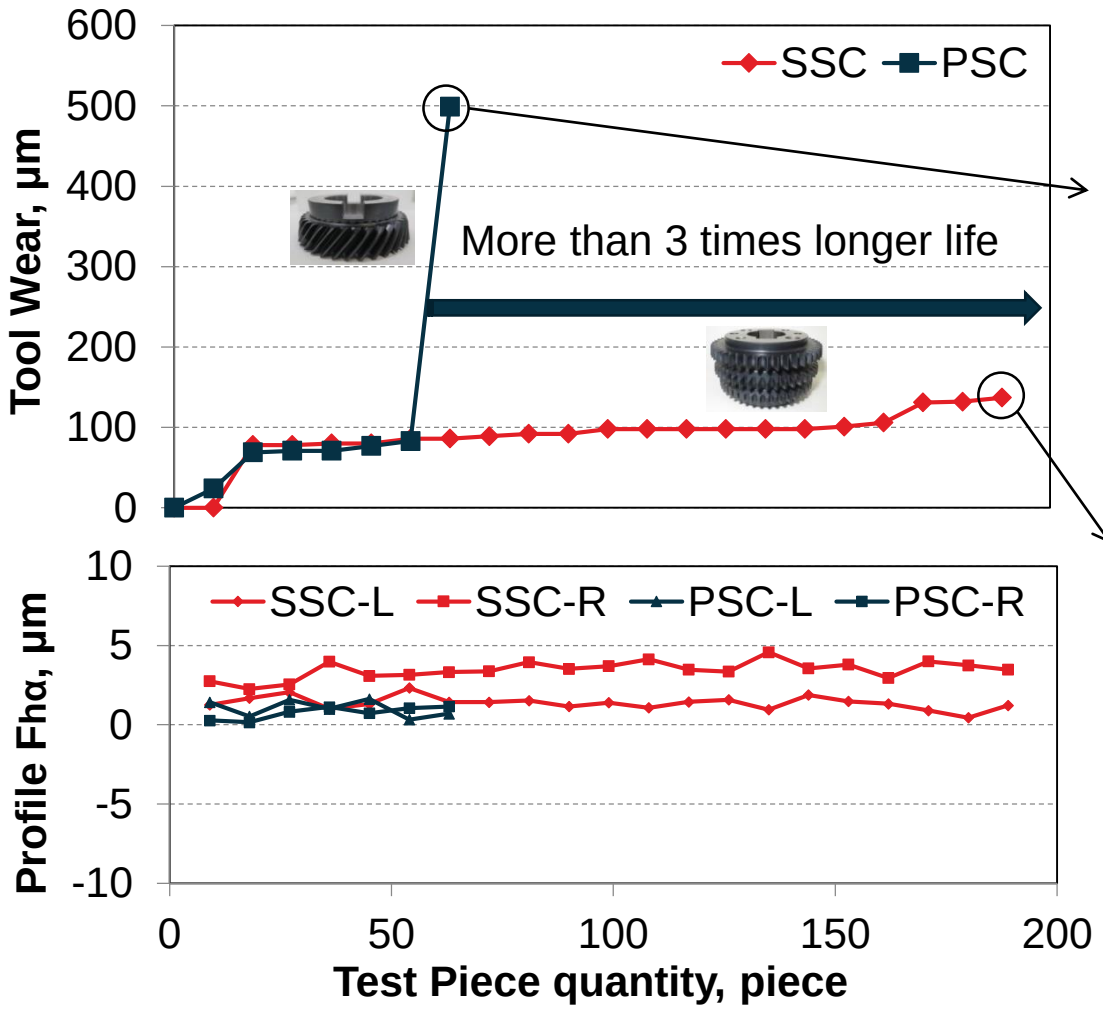
## Test Conditions

**Test Piece**
- Hardness
  HRC 35-40

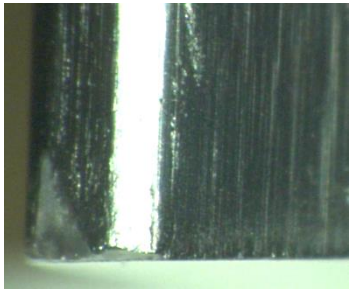
**Tool**
- Tool type
  PSC and SSC
- Material
  Carbide

**Cutting Conditions**
- Cutting speed
  120 m/min
- Cuts
  13
- Cycle time
  245 sec (PSC)
  145 sec (SSC)

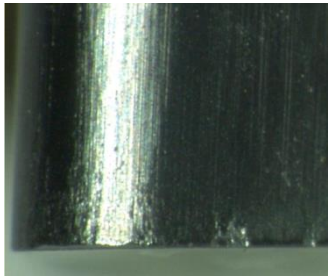



Tool wear

PSC



SSC



PSC: Pinion Skiving Cutter
SSC: Super Skiving Cutter

Super Skiving Cutter is more than 3 times longer tool life

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# Residual Stress Analysis

Tool

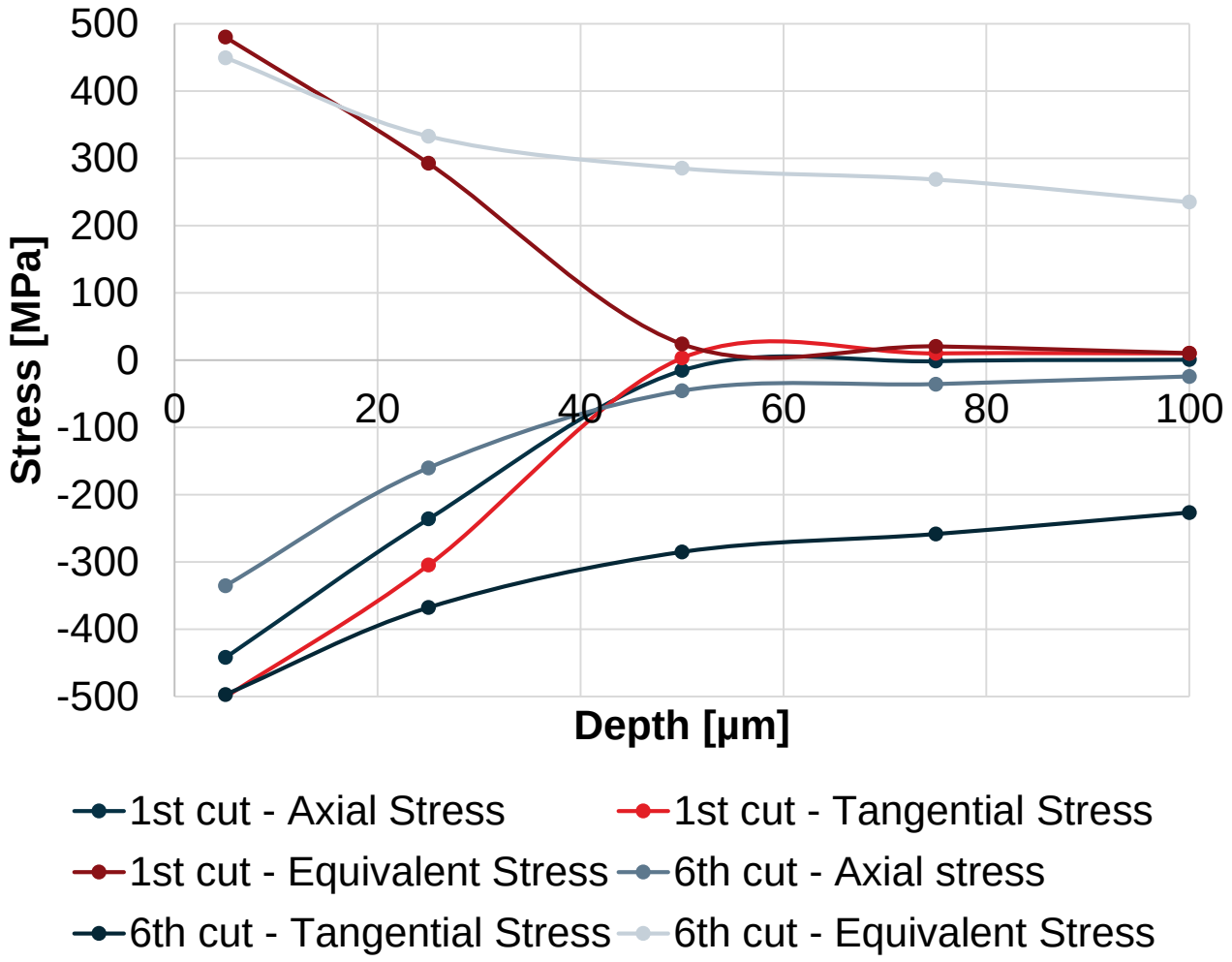
- **Pinion Skiving Cutter**
- Material: **HSS**
- $z_0$ = 54

Workpiece

- $d_a$ = 111.17 mm
- $z_2$ = 85
- $m_n$ =1.25

Process

- Cutting Speed: **120 m/min**
- No. of Strokes: 7



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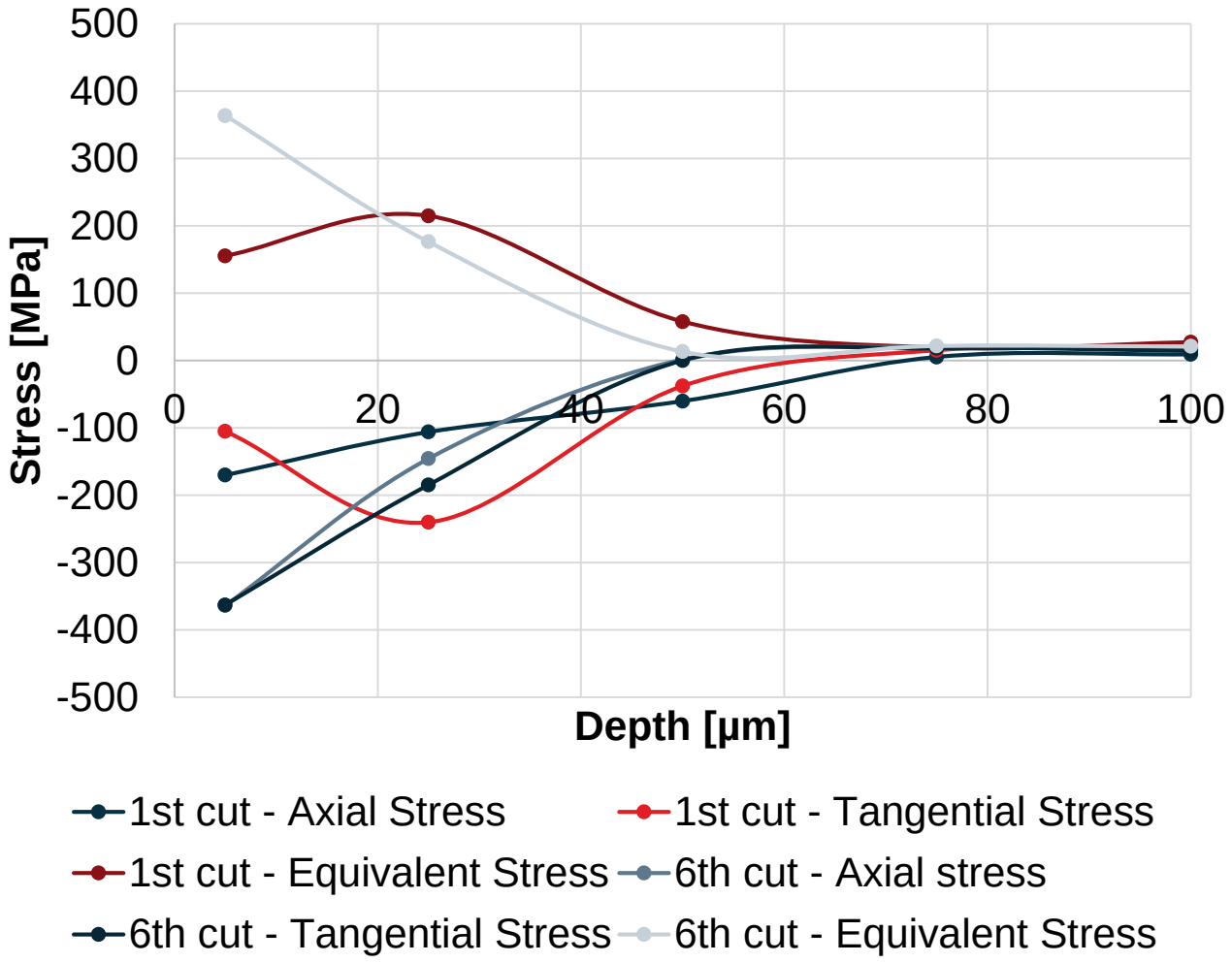

# Residual Stress Comparison

Tool

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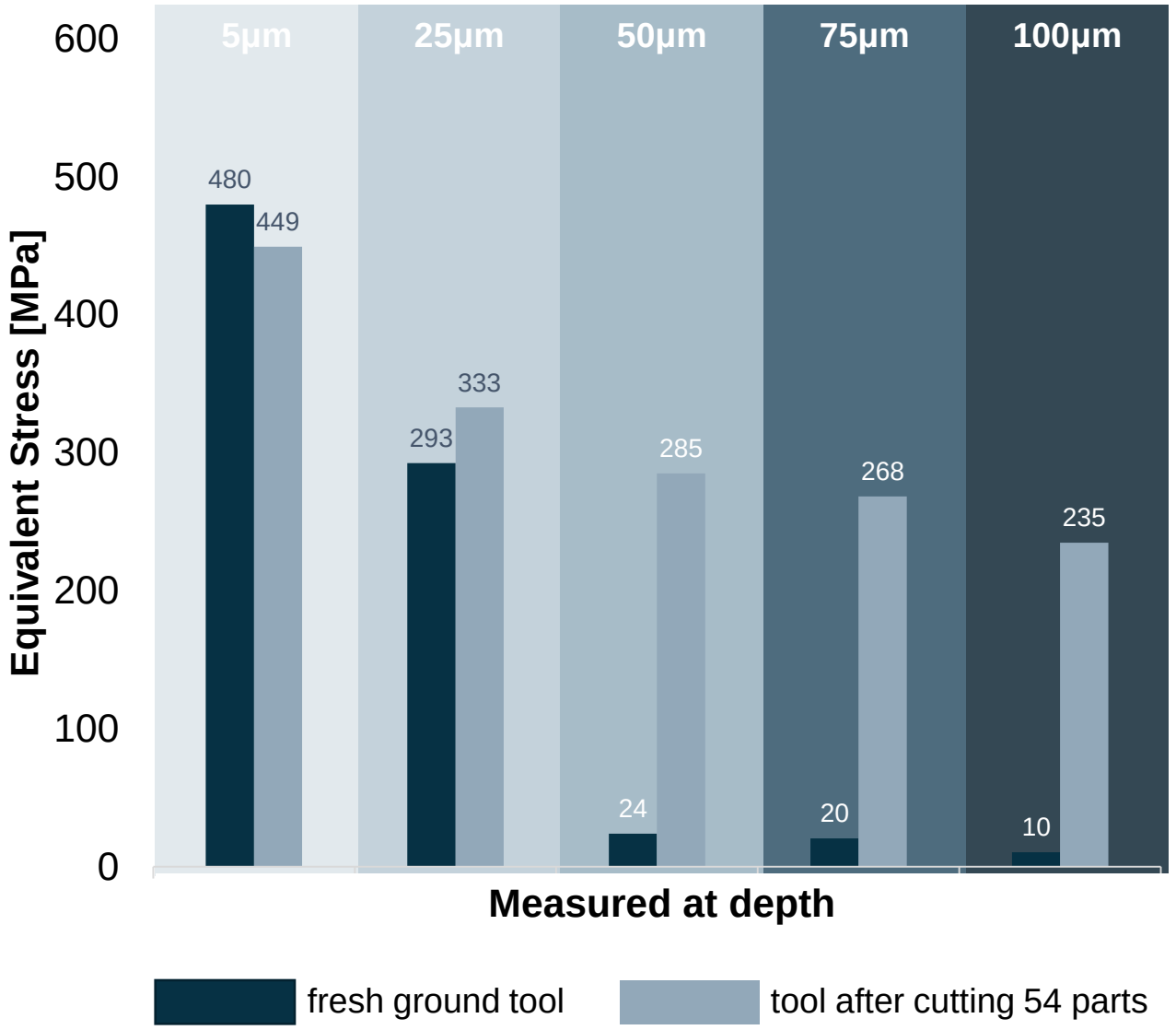

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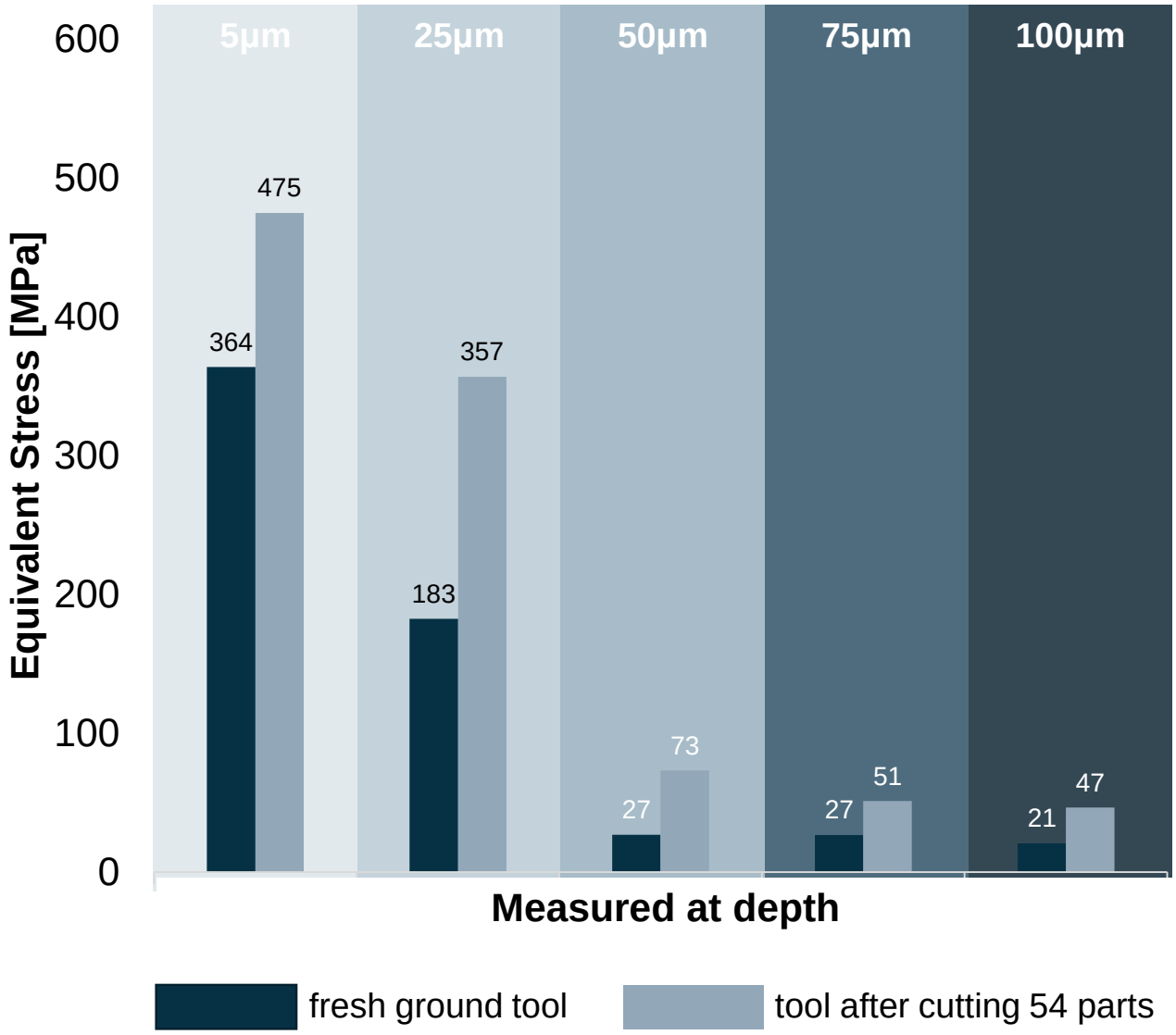

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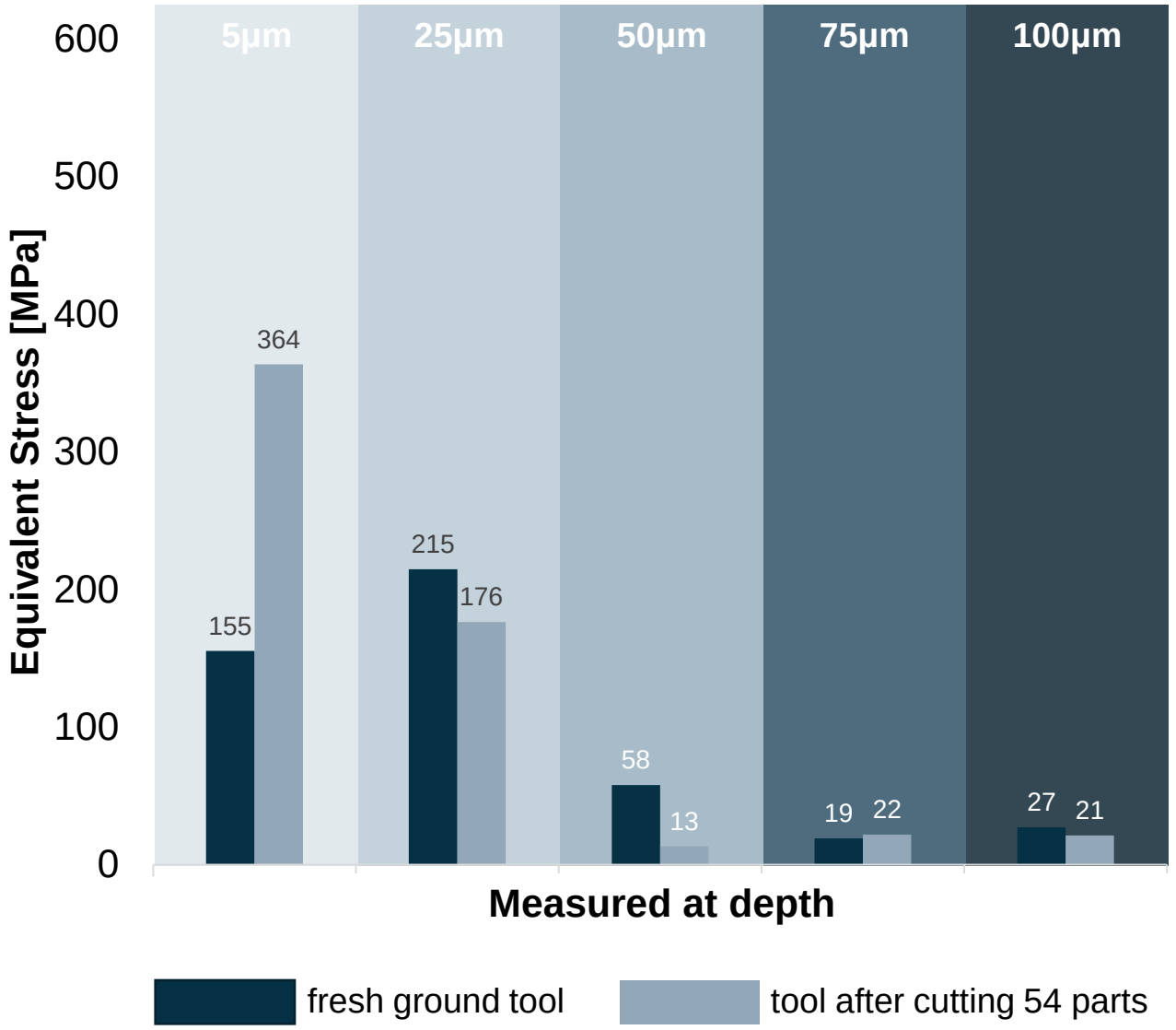

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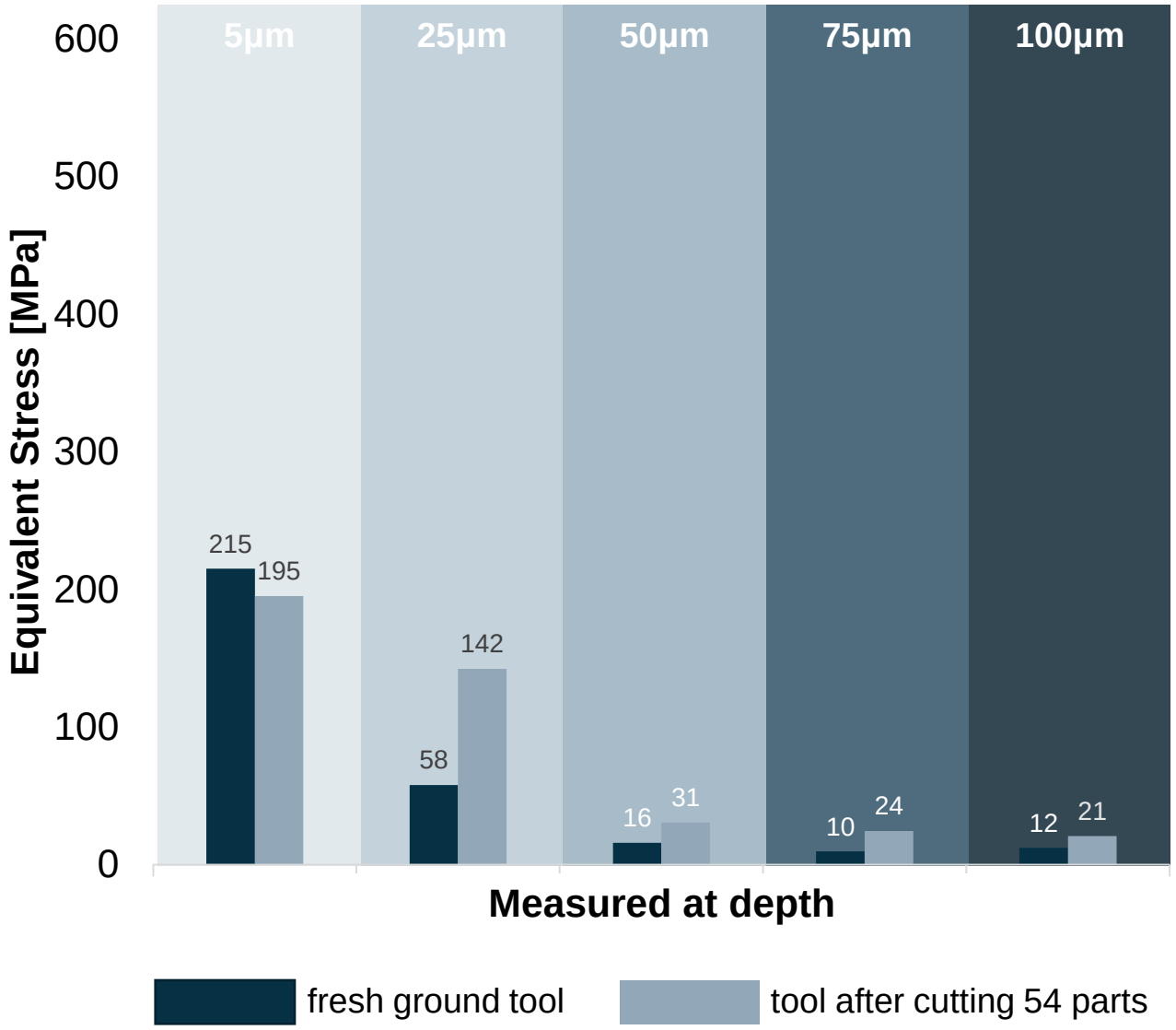
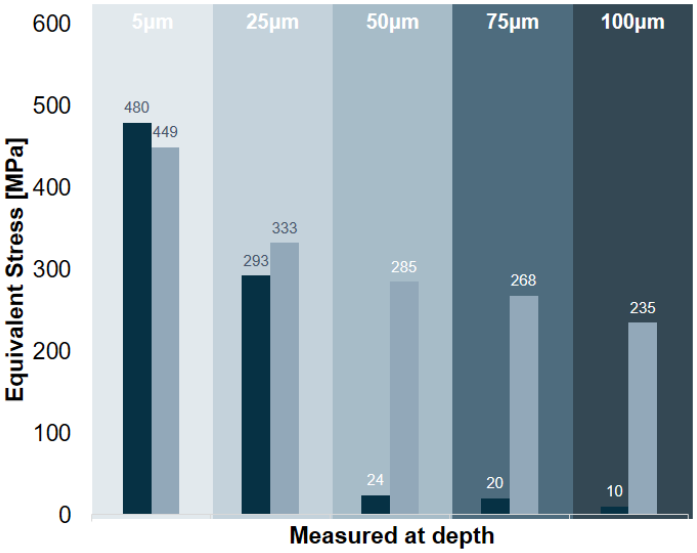
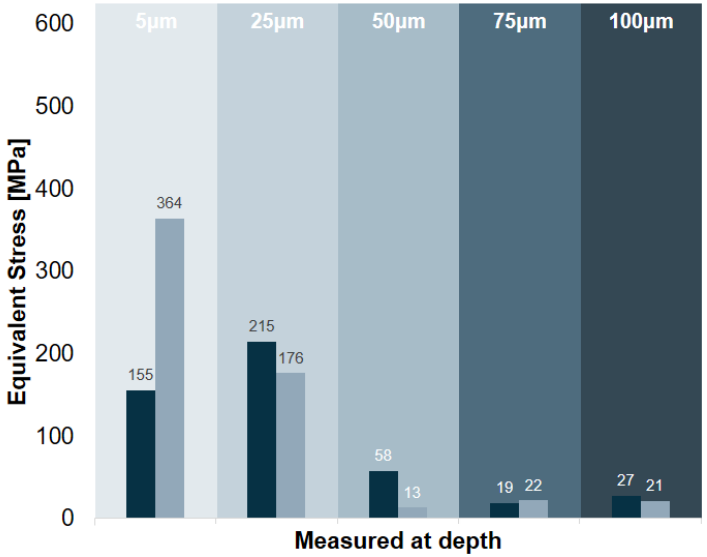


# Residual Stress Summary

- By using the Super Skiving cutter less residual stress was induced into the material by the cutting process
- This can reduce the negative effects of heat distortion on the parts geometry if further heat treatment is necessary




Pinion Skiving Cutter at 7 strokes




Super Skiving Cutter at 7 strokes

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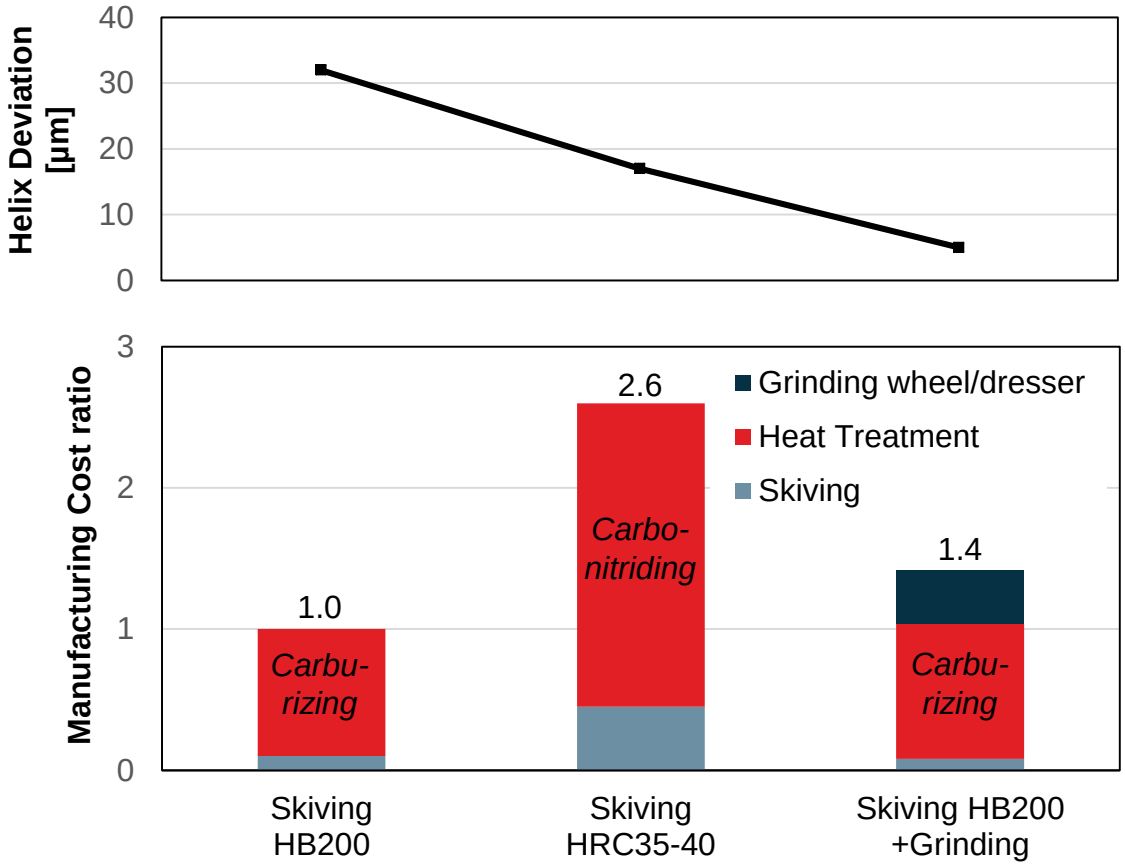
# Finishing Processes

- Internal Generating Gear Grinding is a solution to reach the highest ring gear requirements by hard finishing process
- Soft Skiving in combination with hard grinding can provide a competetive alternative
- Internal Generating Gear Grinding Process

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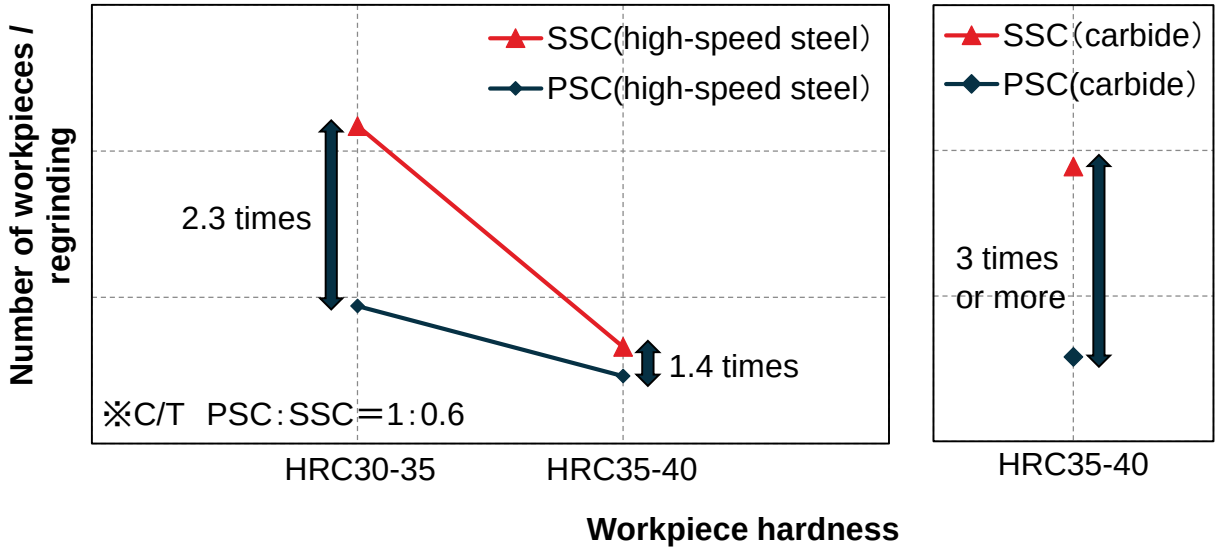
# Summary

- Tool life improvement by process difference (pinion or super skiving) depend on test piece hardness

- Super Skiving can provide better performance by choosing proper cutting materials



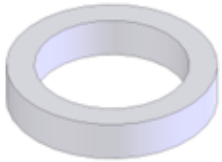

- By using Super Skiving Cutter, less residual stress was induced into the material, which most likely reduces the negative effects of heat distortion

- Super Skiving can enables economical soft machining after initial tempering which can help to reduce heat distortions in finished parts

# Outlook

- To continue the effort to optimize Super Skiving Technology for continuous improvement of process performance.
- Internal Generating Gear Grinding was introduced as competitive soft-/hard-machining alternative
- To establish the best ring gear manufacturing solutions with our skiving, and internal generating gear grinding we are currently focusing our industrial research on internal generating gear grinding as collaboration project with WZL
- Results will be shown at the Hard Finishing Seminar on 6. November 2019

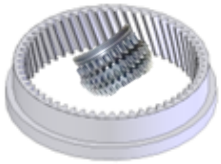
Case hardened steel
DIN 16MnCr5
JIS SCr415



Material

Turning

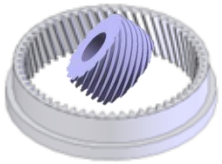
Done



Super Skiving
HB<230
(≒HRC20)

Carburizing/
Carbonitriding
HRC60

In Progress



Generating
Gear Grinding
(Hard Skiving
in 2020)

MOVE THE WORLD FORWARD

WZL | RWTH AACHEN UNIVERSITY

MITSUBISHI HEAVY INDUSTRIES GROUP