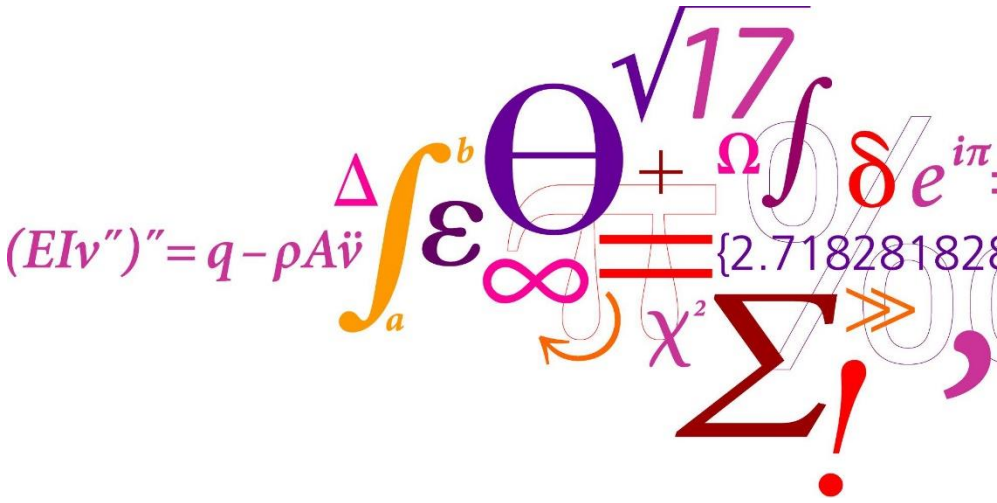
Manufacturing & testing of textured tool surfaces in strip reduction

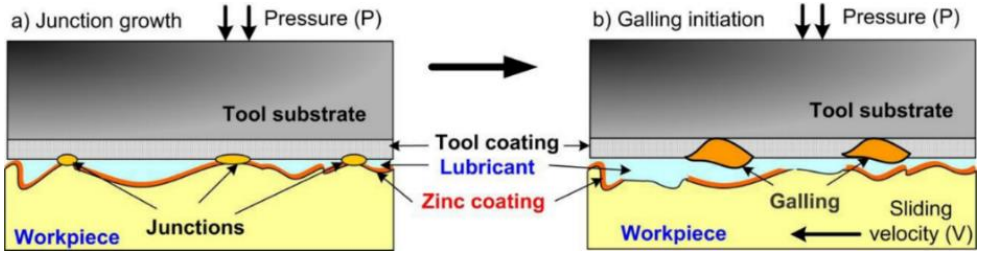
Mohd Hafis Sulaiman



DTU Mechanical Engineering
Department of Mechanical Engineering

Introduction

- Galling:
  - Breakdown of lubricant film can cause pick-up on the tool surface and scoring of subsequent workpiece surfaces.



- Galling lead to inferior surface finish.

H. Kim, 2008.
N Bay, E Ceron, 2014.

Introduction

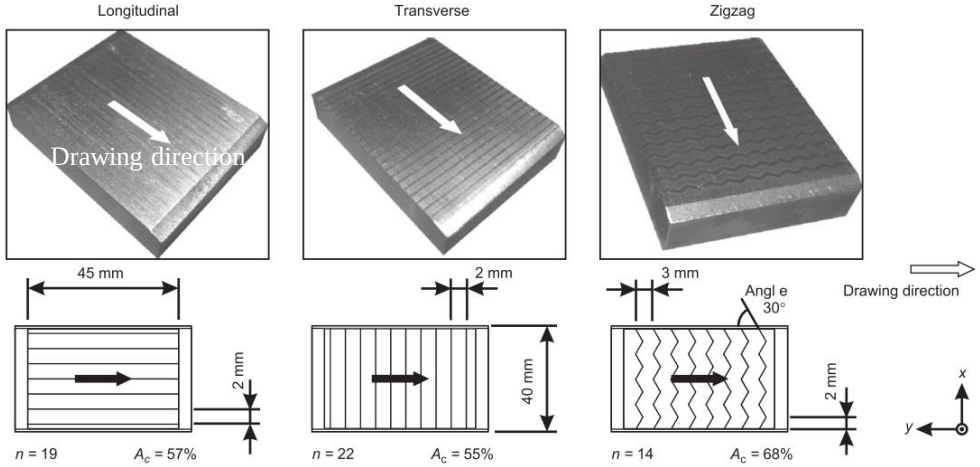
- Methods to prevent galling:
  - Special boundary lubricants, i.e. Extreme Pressure (EP) additives, etc.
  - Anti-seizure tool materials
  - Anti-seizure tool coatings
  - Tool surface treatment
  - Textured surfaces

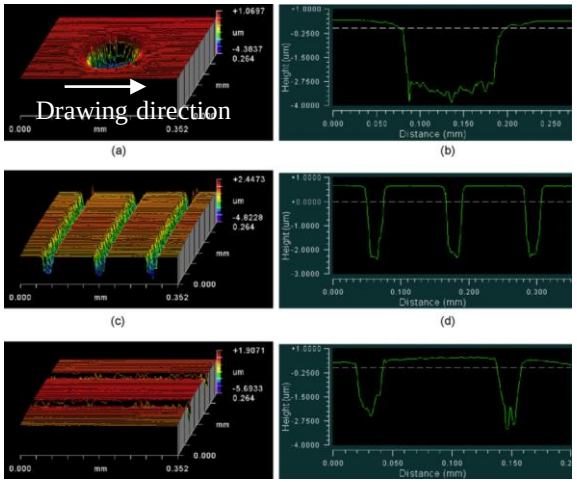
Introduction

- Methods to prevent galling:
  - Special boundary lubricants, i.e. Extreme Pressure (EP) additives, etc.
  - Anti-seizure tool materials
  - Anti-seizure tool coatings
  - Tool surface treatment
  - Textured surfaces – *permitting retention of adequate oil on contact region*.

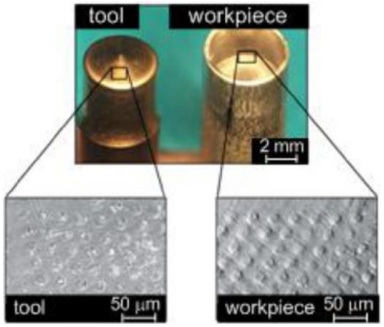
Introduction

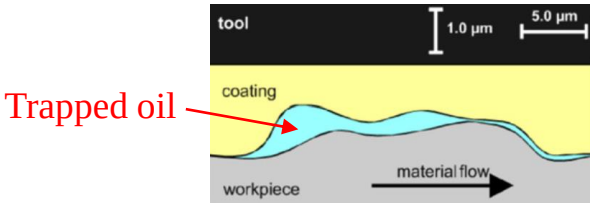
✓ Texture features for deep drawing tools





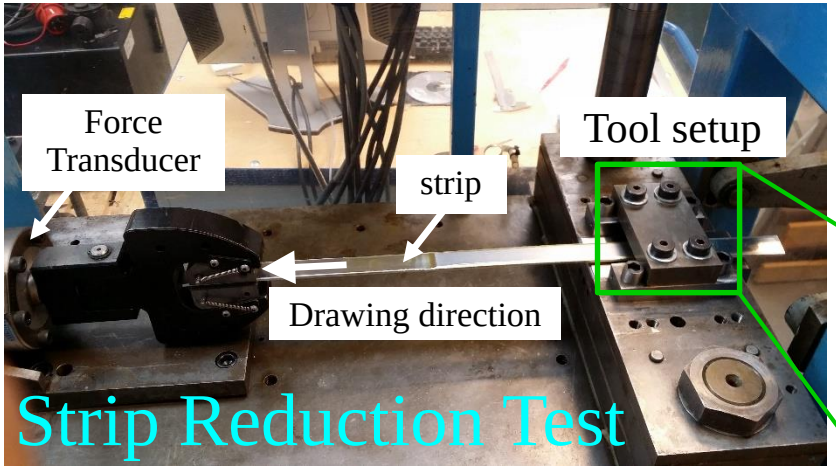
✓ Dimple-shaped pockets for enhanced lubrication in backward can extrusion

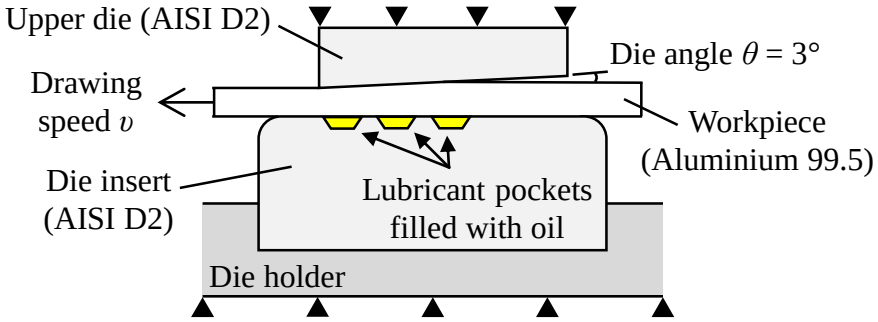


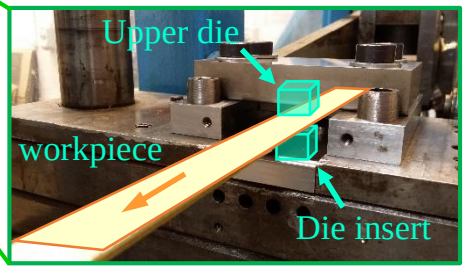


V. Franzen et al, 2010
H. Costa, I. Hutchings, 2009
Popp U, Engel U, 2006

Test Setup



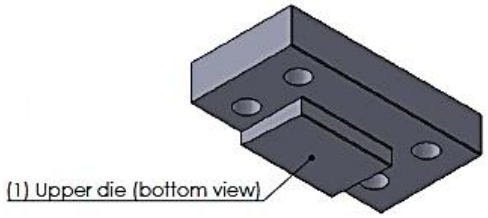


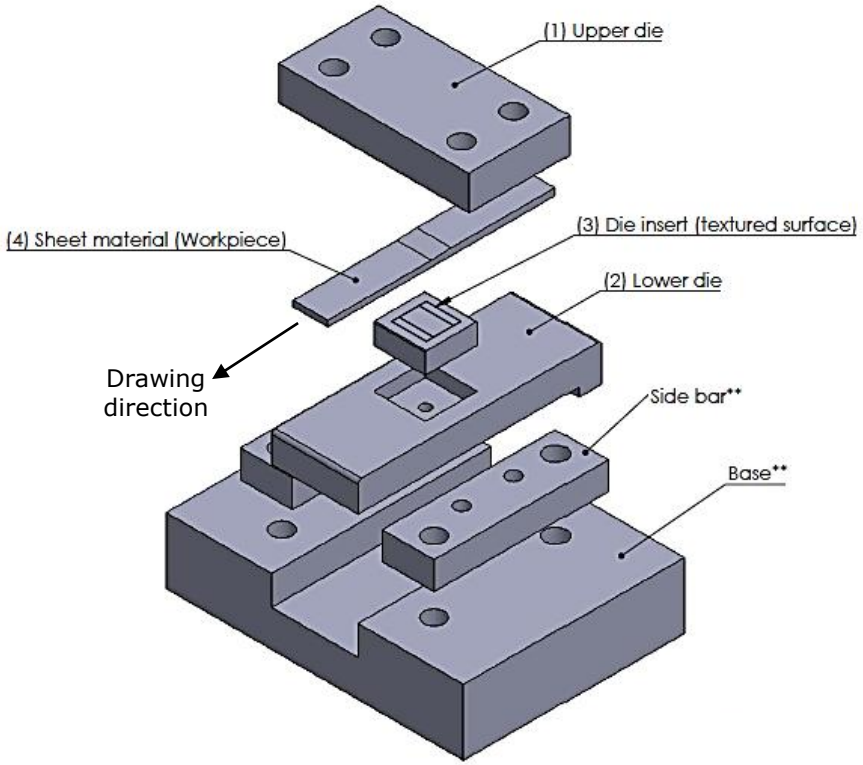


Die inserts with varying texture features

Smooth *Ra* 0.02µm	*x*=0.23mm	*x*=0.46mm	*x*=0.92mm
			

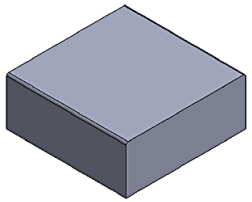
Test Setup

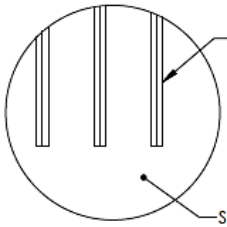


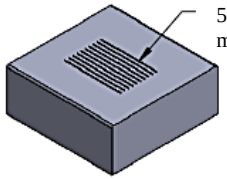


Tailored tool surfaces

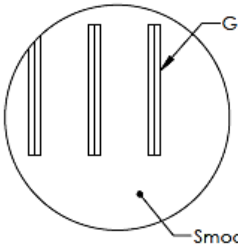
A smooth, plain tool surface, *Ra* 0.02 µm

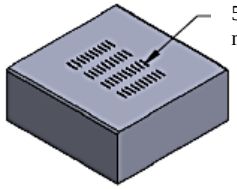






Grooves:
- 1 row.
- 25, 16 and 10 columns.

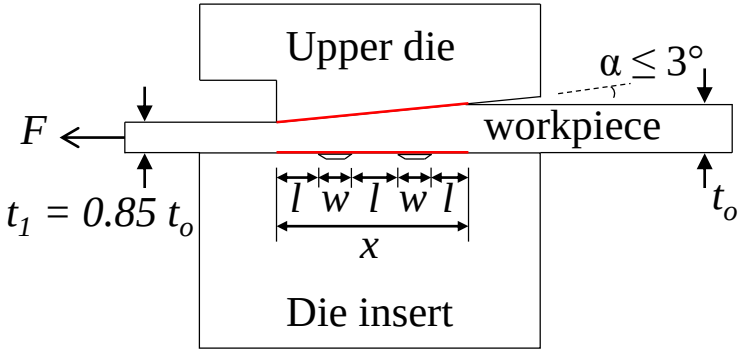




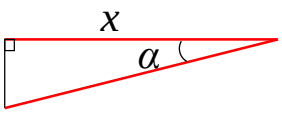
Grooves:
- 4 row.
- 25, 16 and 10 columns.

Manufacture of Surface Textures

Tool-workpiece deformation zone

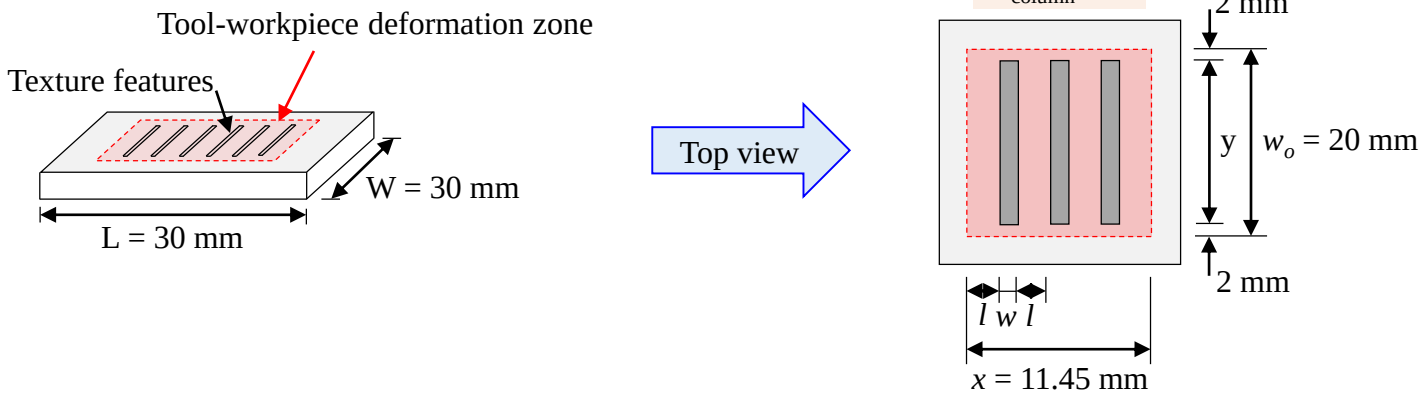


$\Delta t = t_1 - t_o$

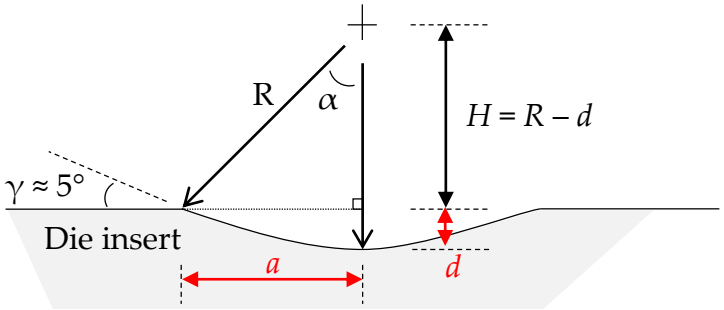


The **initial sheet thickness t_o = 4 mm** and **die angle α = 3°**,

- Total textured die-strip contact length x is:
  - If reduction is 10 %, thus $t_1 = 0.9t_o$, so x = 7.63 mm.
  - If reduction is 15 %, thus $t_1 = 0.85t_o$, so **x = 11.45 mm**.



Manufacture of Surface Textures



$$\tan\gamma = \frac{d}{a} \longrightarrow \text{Eqn. (1)}$$

$$R^2 = a^2 + H^2 = a^2 + (R-d)^2 \longrightarrow \text{Eqn. (2)}$$

Surface texture parameters for enhanced lubrication:

- Pocket angle $\gamma \leq 5°$.
- Pocket width w = 0.01-0.1 mm.
- Pocket depth d = 0.001-0.015 mm.
- Ratio depth d to width w, d/w = 0.05-0.15
- Distance between pockets, l = 0.02-0.05 mm.

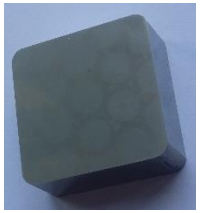
Parameters	Value		
Pocket angle γ (°)	5		
Pocket width w = 2a (mm)	0.23		
Pocket depth d (mm)	0.01		
Pocket ratio d/w	0.05		
Distance between pockets l (mm)	1 x w	2 x w	4 x w
Number of pockets - row n_{row}	25	16	10
Number of pockets - column n_{column}	1	1	1
Initial pocket volume V_o (mm^3)	0.61	0.39	0.24
Contact area ratio ($A_{r,o}/A_o$) (%)	60	74	84

J. Bech, et al, 1999.
H. Costa and I. Hutchings, 2015.

Manufacture of Surface Textures

5-axis high speed milling machine,
Mikron HSM 400U LP

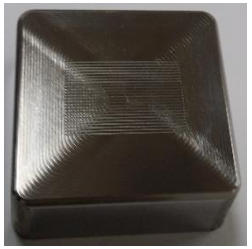
Process sequence



Milling surface

2 flutes solid carbide ball-nose milling cutter at 42,000 rpm and 600 mm/min

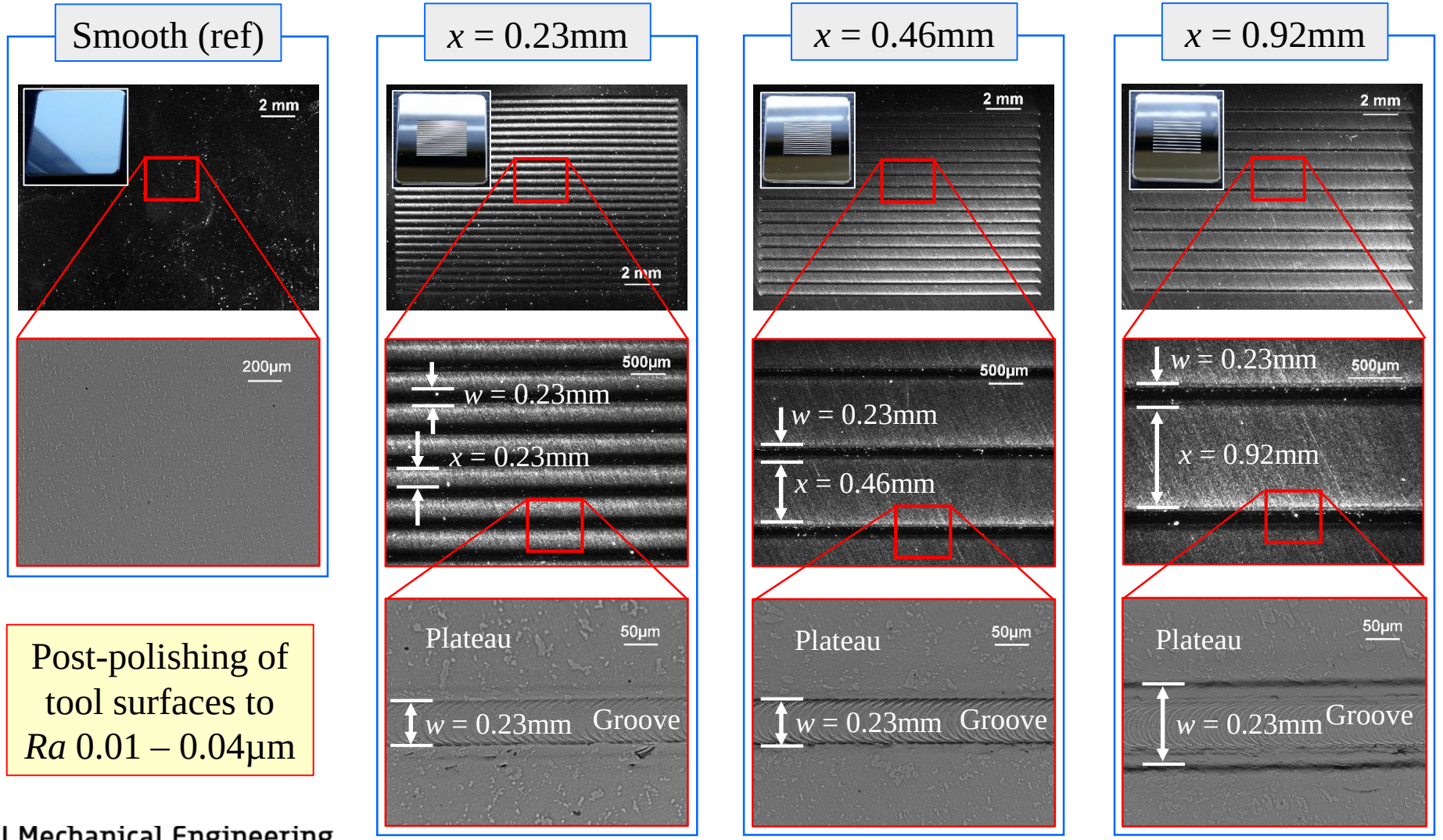
Milling pockets



Polish surface

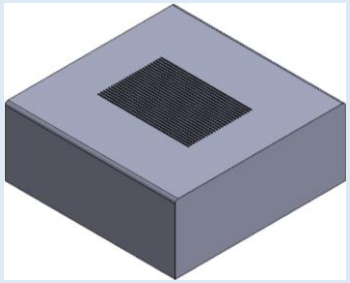
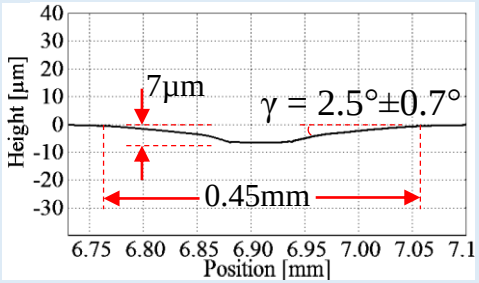
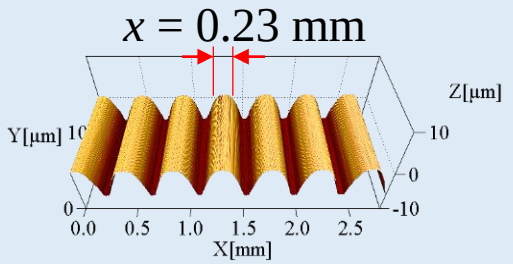
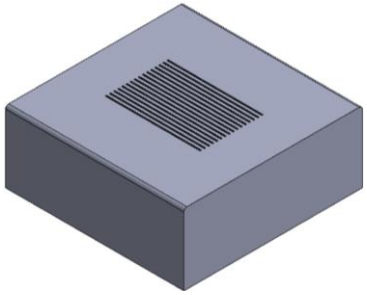
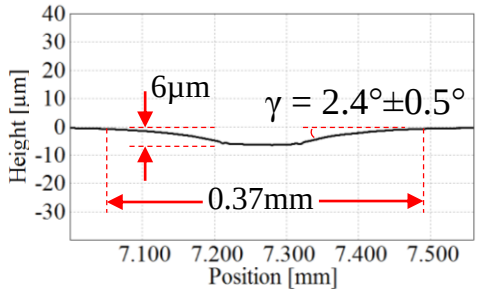
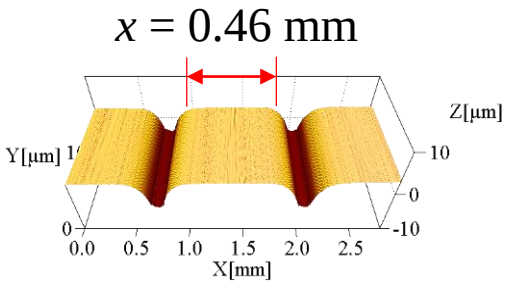
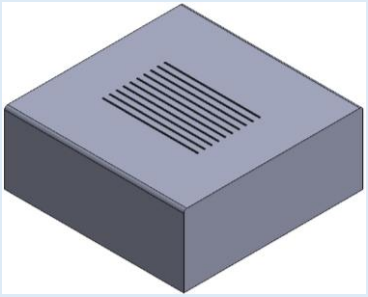
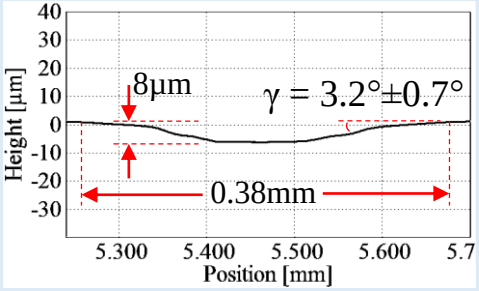
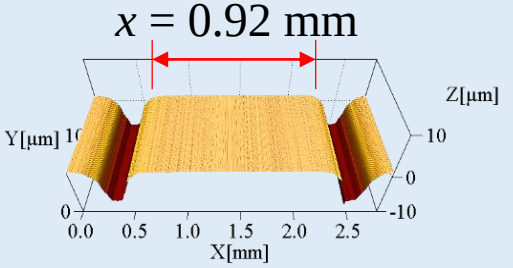
3, 1, 1/4 µm water based polycrystalline diamonds

Manufacture of Surface Textures



Post-polishing of tool surfaces to *Ra* 0.01 – 0.04µm

Manufacture of Surface Textures

Tool	*Ra* (µm)	Pocket angle γ	3D surface topography
	0.011		
	0.024		
	0.032		

Remarks:

- *x* represents distance between pockets.
- γ represents lubricant pocket angle.

Test Conditions & Materials

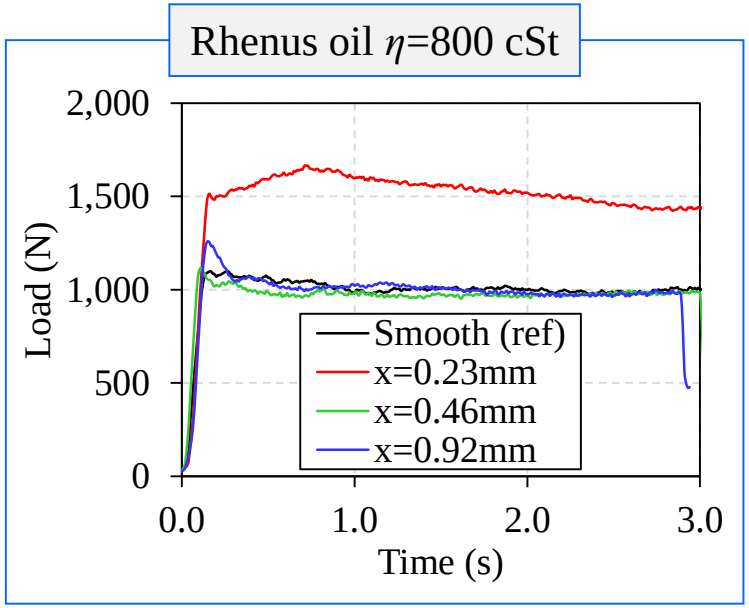
Test conditions:
- Test Speed *v*:
  - 65 & 240 mm/s
- Reduction:
  - 15 %

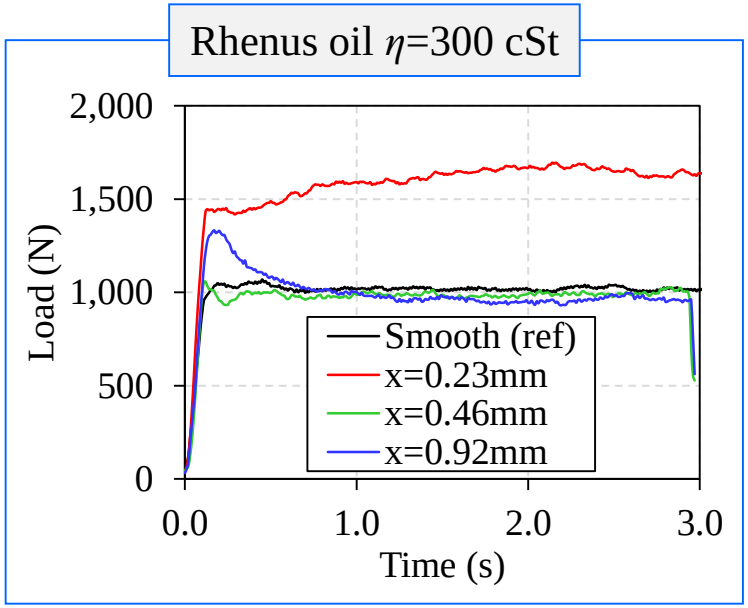
Components	Material Properties
Upper die & Die inserts (AISI D2)	• AISI D2 • Hardened and tempered to 60 HRC • Roughness *Ra* 0.01-0.04 µm
Workpiece	• Aluminium 99.5 • Roughness *Ra* 0.21 µm • Properties: Plains strain compression test ▪ Voce, $\sigma o = 55 + (149-55)(1-\exp(-1.52\varepsilon))$ MPa

Oil type	Product name	Kinematic Viscosity @40°C
Mineral oil containing additives	Rhenus LA 722086	800 cSt
Mineral oil containing additives	Rhenus LA 722083	300 cSt
Plain mineral oil	CR5	660 cSt
Plain mineral oil	CR5 – Sun (50 wt. % each)	60 cSt

Results

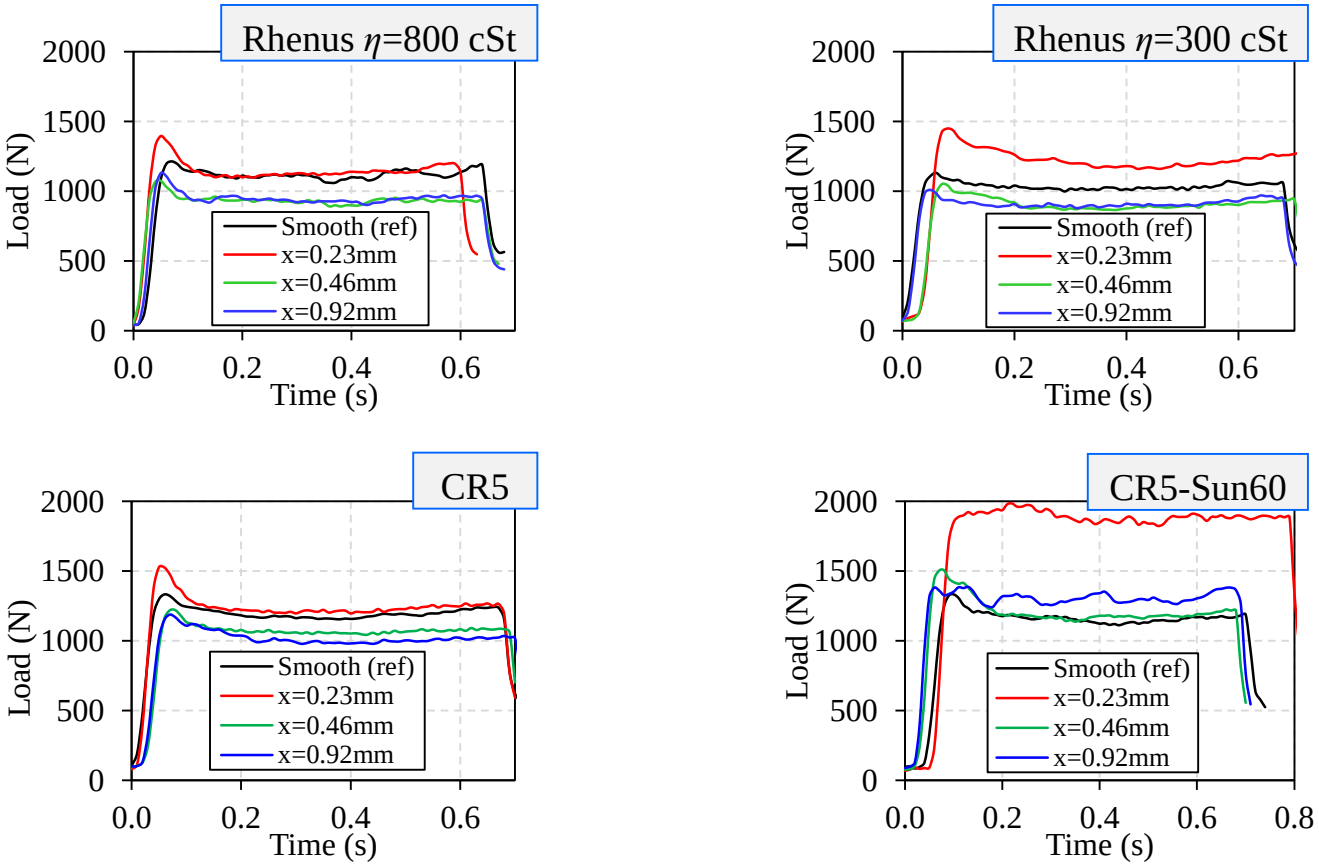
- Forming load at low speed v=65 mm/s





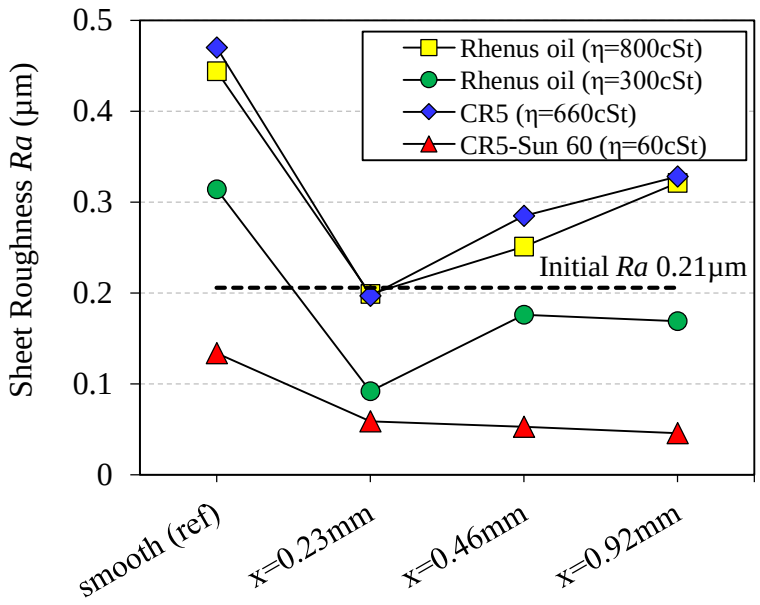
Results

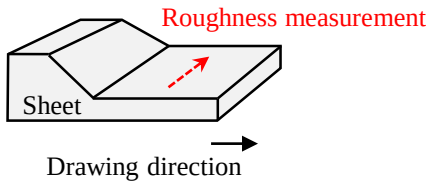
- Forming load at high speed v=240 mm/s



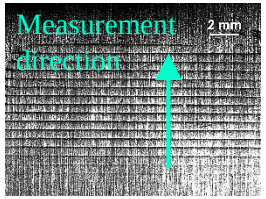
Results

Sheet roughness

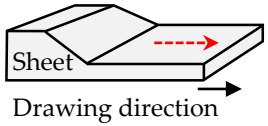




Results



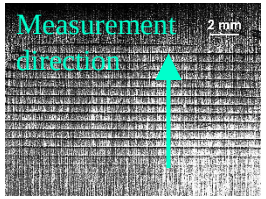
Measurement direction



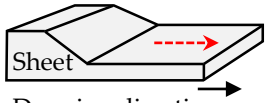
	Rhenus (η=800cSt)	Rhenus (η=300cSt)	CR5 (η=660cSt)	CR5-Sun 60 (η=60cSt)
Smooth (reference)	Rough surface *Ra* 0.38µm	Fairly rough surface *Ra* 0.22µm	Fairly rough surface *Ra* 0.20µm	Scratch depth 1µm; Smooth surface *Ra* 0.025µm
x=0.23mm	Pocket indents	Pocket indents	Pocket indents	Pocket indents
x=0.46mm	Pocket indents; Rough plateau	Pocket indents; Fairly smooth plateau	Pocket indents; Fairly rough plateau	Pocket indents; Smooth plateau
x=0. 92mm	Pocket indents; Rough plateau *Ra* 0.12µm	Pocket indents; *Ra* 0.02µm; Fairly smooth plateau	Pocket indents; *Ra* 0.08µm; Fairly rough plateau	Pocket indents; Smooth plateau *Ra* 0.002µm

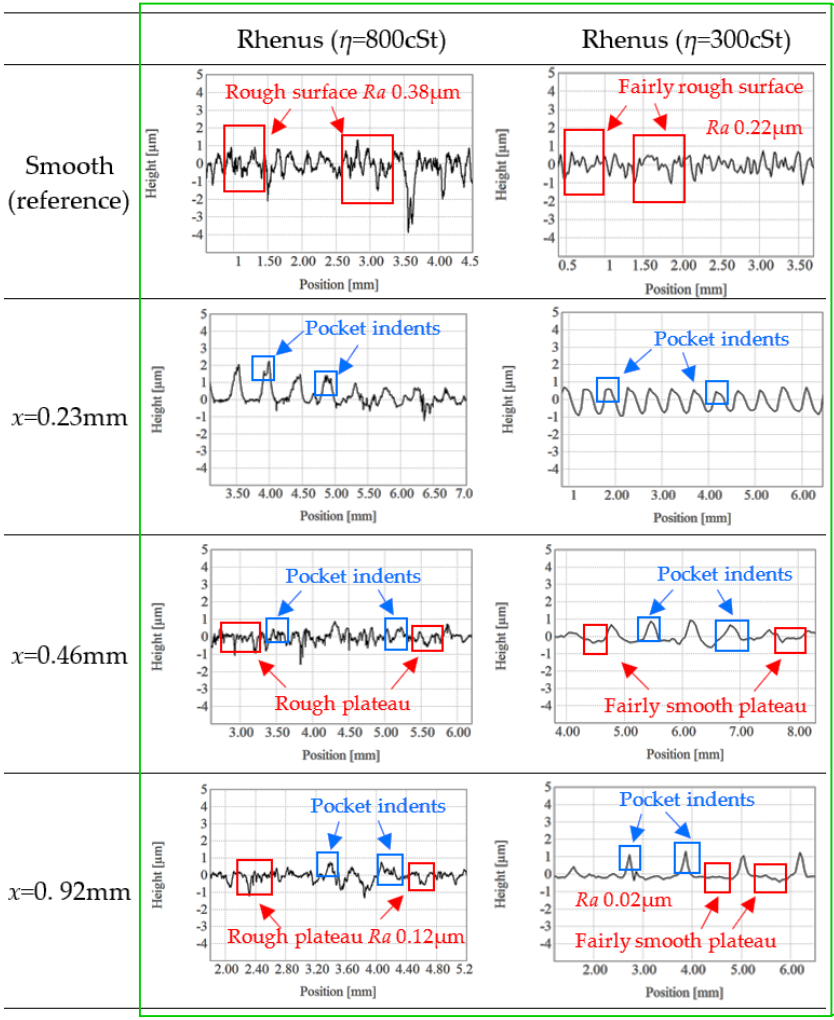
Results

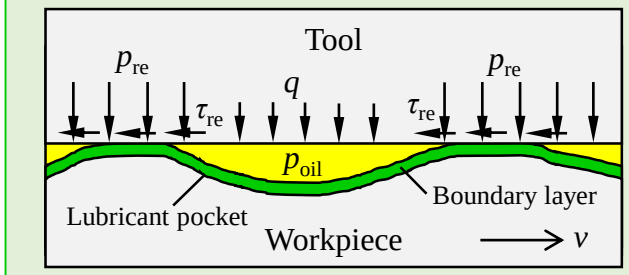
Micro-plasto hydrodynamic lubrication



Measurement direction



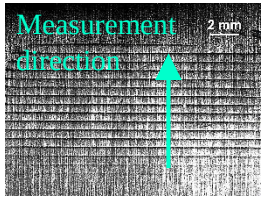




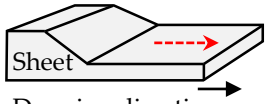
Mineral oil contained additives

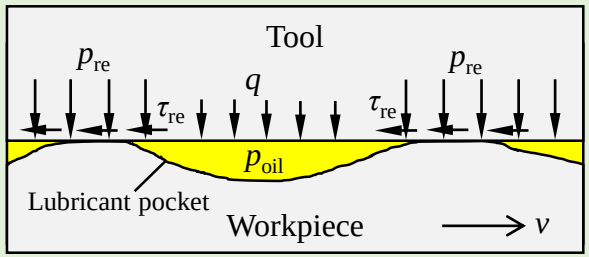
Results

Micro-plasto hydrodynamic lubrication

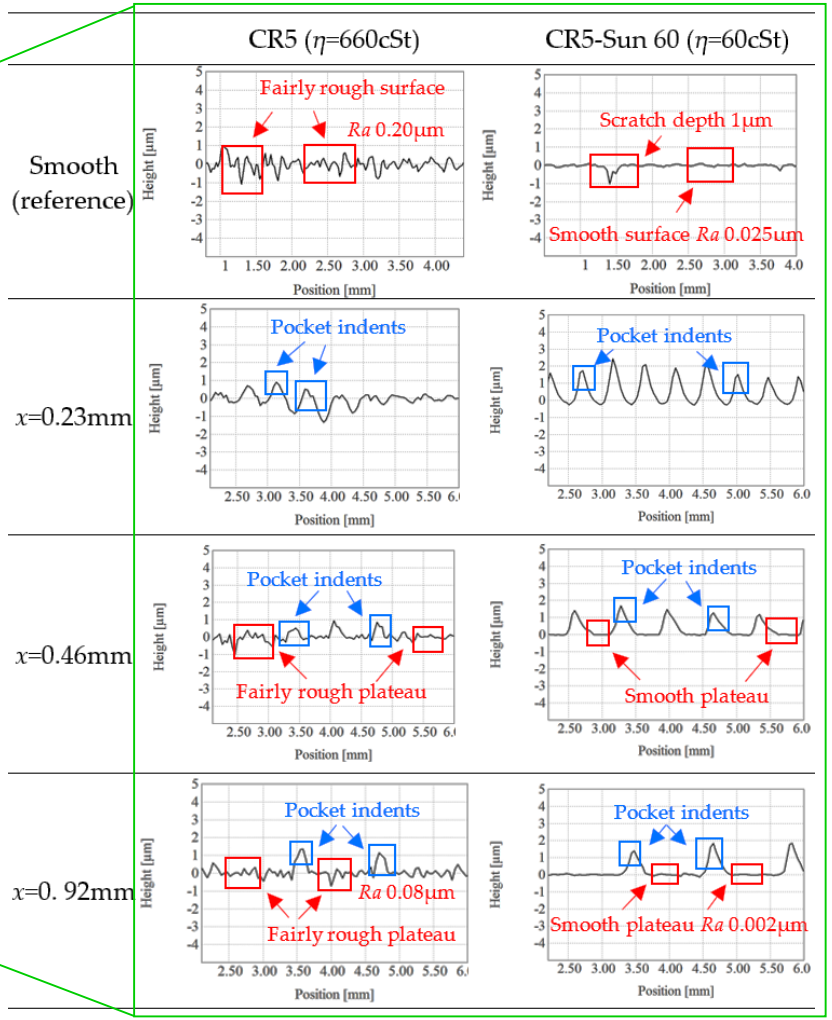


Measurement direction

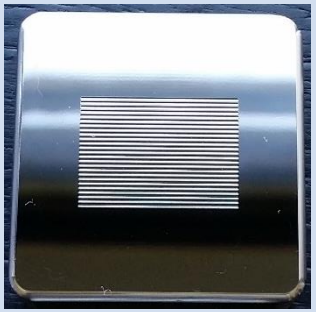
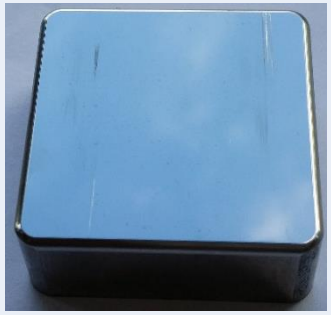
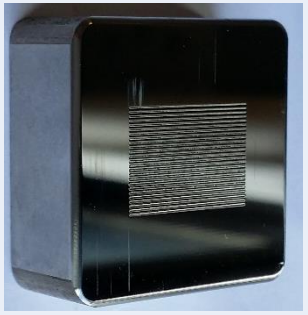




Plain mineral oil



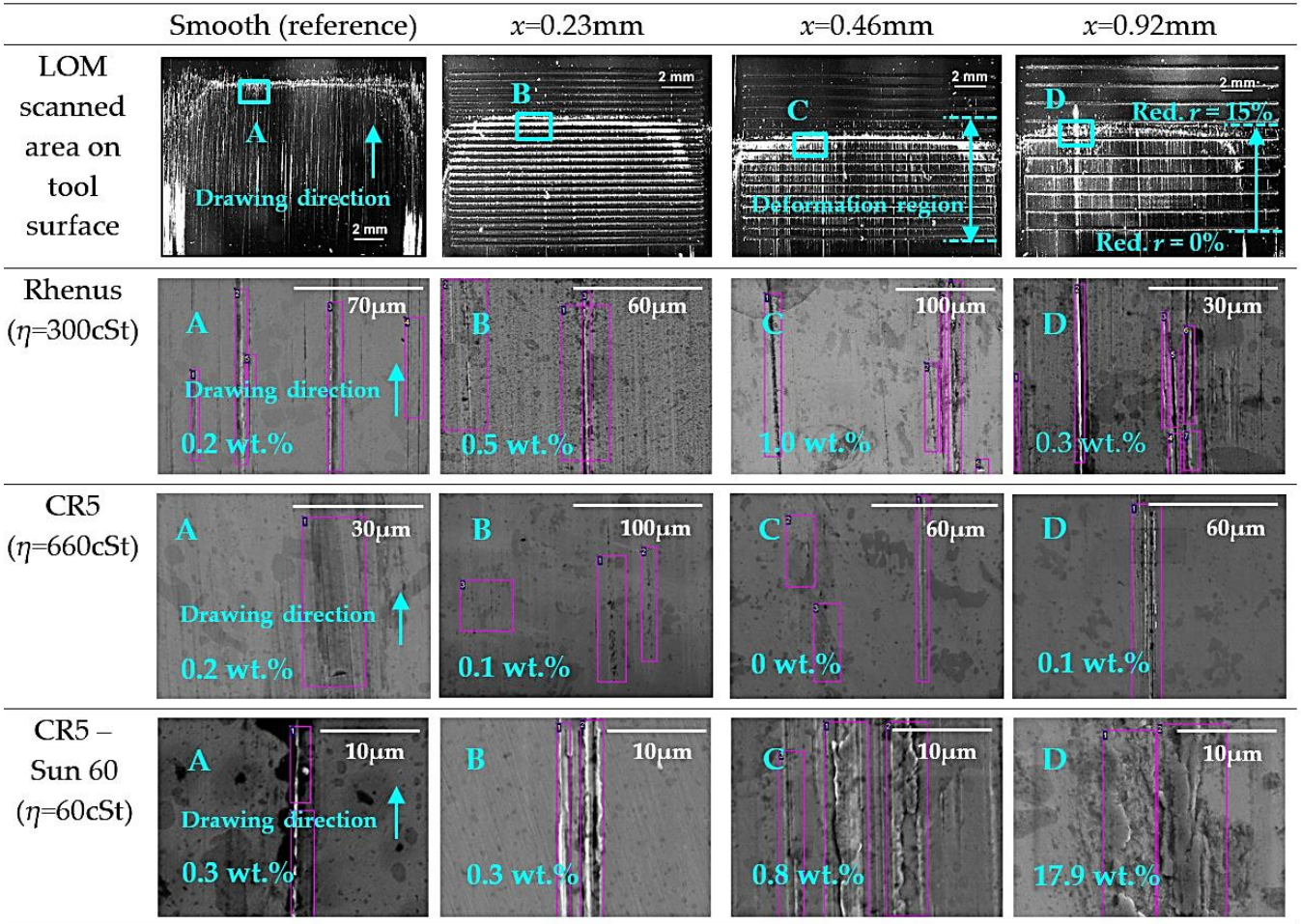
Results

Die insert	Smooth	*x*=0.23mm	*x*=0.46mm	*x*=0.92mm
Before				
After				

✓ No aluminium pick up on all tool surfaces.
✓ Shiny, mirror-like surface condition before and after tests.

Results

Pick-up occurred at the larger reduction region *r* of 15%



Conclusion

Textured tool surface topographies:

1. A technique to improve resistivity towards galling.
2. Pocket geometry:
   - ✓ Shallow pockets with small pocket angles, and oriented perpendicular to the sliding direction.
3. Distance between the pockets:
   - ✓ The pocket distance is 2-4 times the pocket width.
4. Test condition:
   - ✓ The tool textures were advantageous at larger sliding speeds when using higher viscosity oils, which facilitates the escape of trapped lubricant by micro-plasto-hydrodynamic lubrication.