Impact of the measurement conditions and the pre-machining on the residual stress state of deep rolled specimens

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Nataliya Lyubenova (**Presenting author**)[1], Dirk Bähre[1], Lukas Krupp[2], Titouan Cronier[2], Julie Fouquet[2], Jay Patel[2], Joachim Ernst Hoffmann[2]

[1] – Institute of Production Engineering, Saarland University, Saarbrücken, Germany

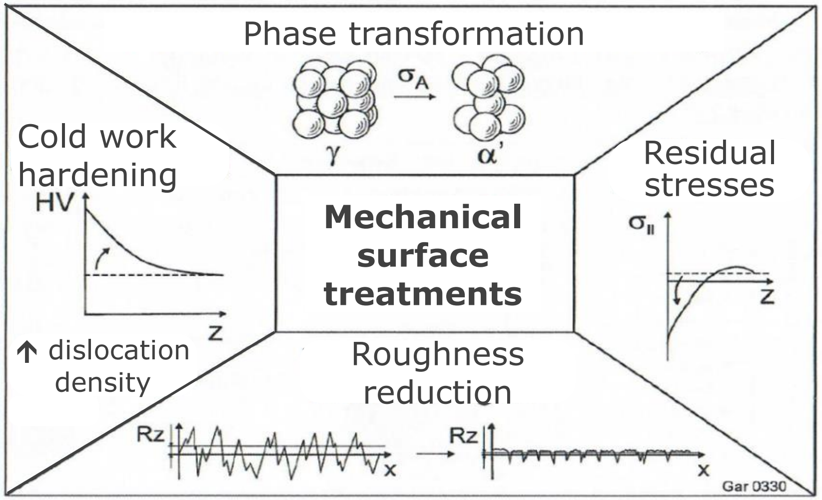
[2] – Department of materials science and materials testing, University of Applied Sciences, Kaiserslautern, Germany

Overview

1. Introduction
2. Material data and specimens' preparation
3. Experimental set up
4. Influence of the measurement device – RS surface distribution
5. Influence of the pre-machining – RS surface distribution
6. Influence of the pre-machining – RS depth distribution
7. Summary and conclusions

1. Introduction

- **Mechanical surface treatments** – specially developed for enhancement the fatigue strength and/or weight reduction.
- **Changes in the (sub)surface layer**:
  - Roughness reduction (in some cases)
  - Cold working
  - Phase transformation (in some cases)
  - <u>**Residual stresses**</u>

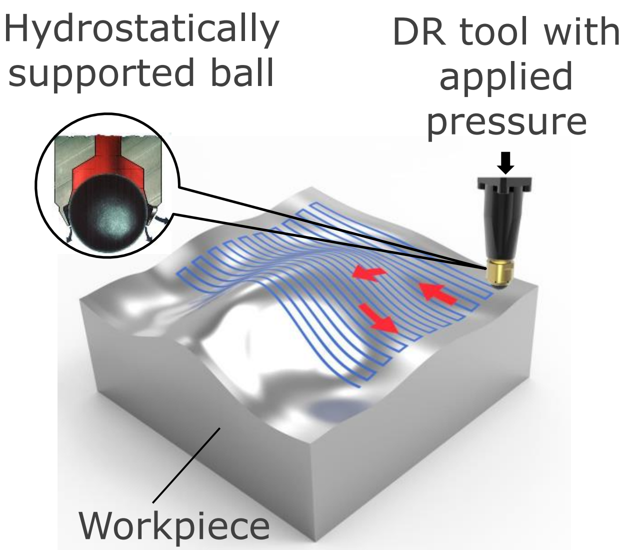


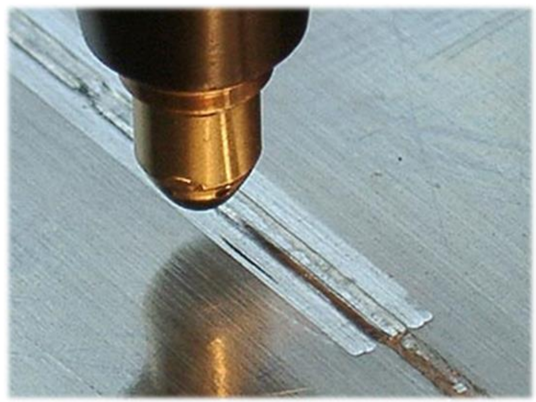
[M. Garbrecht, Mechanisches Randschichthärten in der Fertigung, Dissertation Universität Bremen, 2006]

1. Introduction

Deep Rolling (DR) - mechanical surface treatment which:

- induces compressive residual stresses,
- reduces of surface roughness
- creates a thick cold worked layer

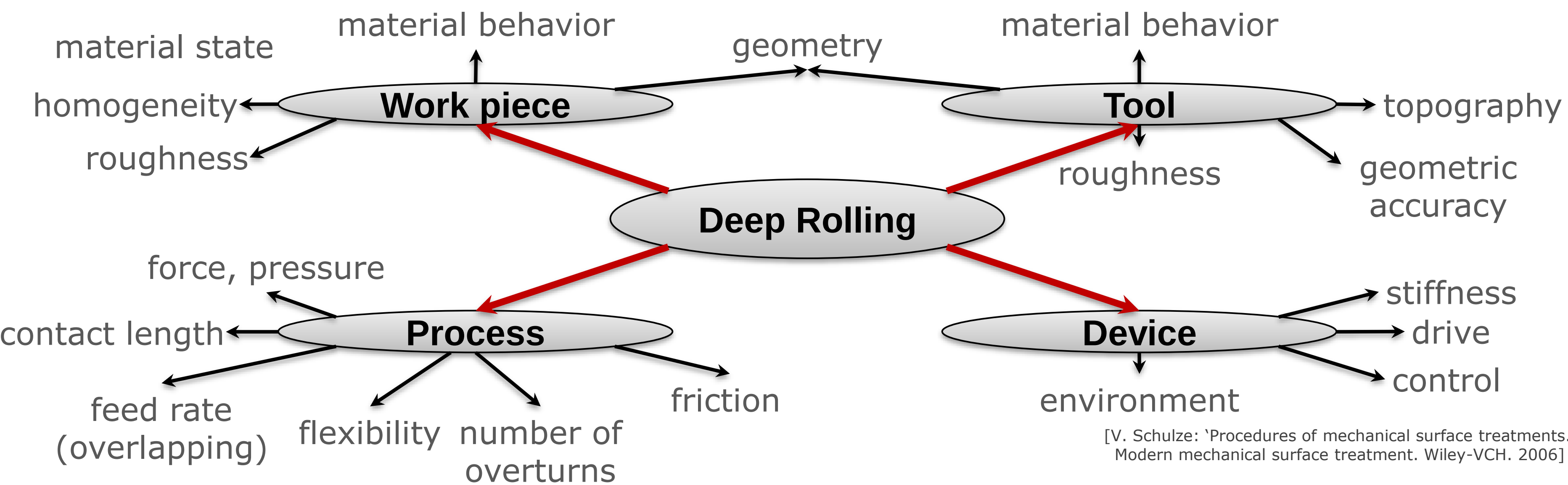




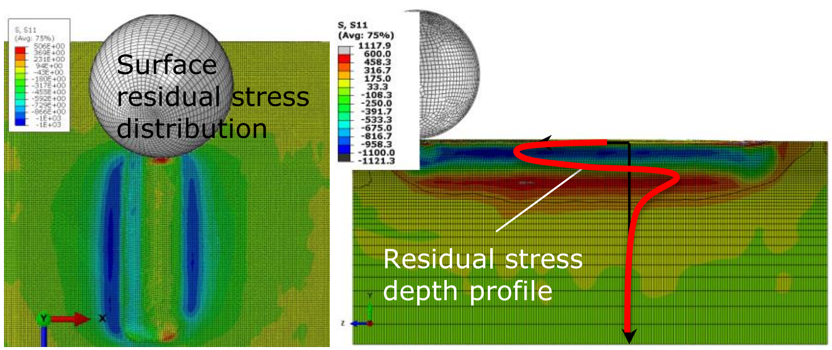
[http://www.ecoroll.de/anwendungen/sonstiges/schweissnaehte.html]

[http://www.glattwalzen.de/2003/festwalzen/verfahren/]

1. Introduction - DR input parameter classification



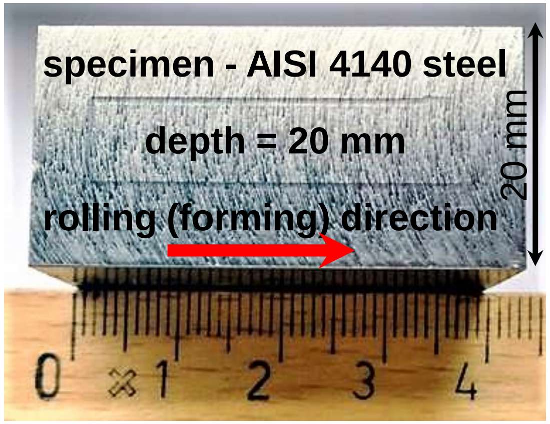
[V. Schulze: 'Procedures of mechanical surface treatments.' Modern mechanical surface treatment. Wiley-VCH. 2006]



[https://www.aaa-werbung.de/wp-content/uploads/2016/02/fragezeichen.jpg; https://dhrm.utah.gov/employment/verification-of-employment; http://www.apriso.com/blog/wp-content/uploads/2014/02/false_positive_manufacturing.jpg]

2. Material data and specimens' preparation

Material – 42CrMoS4 (AISI 4140); heat treatment:
- austenitized (hardened) at 860 ° C for 60 minutes
- quenched in polymer
- tempered at 560 ° C for 120 minutes
- cooled down to room temperature in air



Milling procedure

Spindle speed – n	600 rpm
Cutting speed – v_f	100 mm/min
Removed layer	4 x 1 mm + 2 x 0.5 mm
Cooling lubricant	emulsion

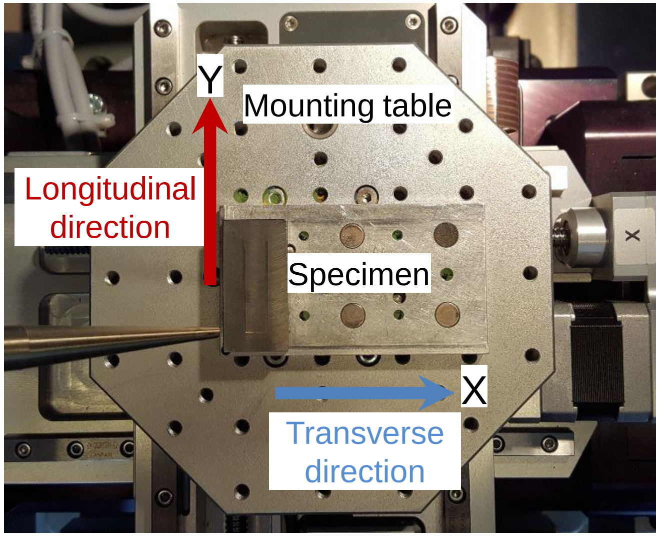
Polishing procedure

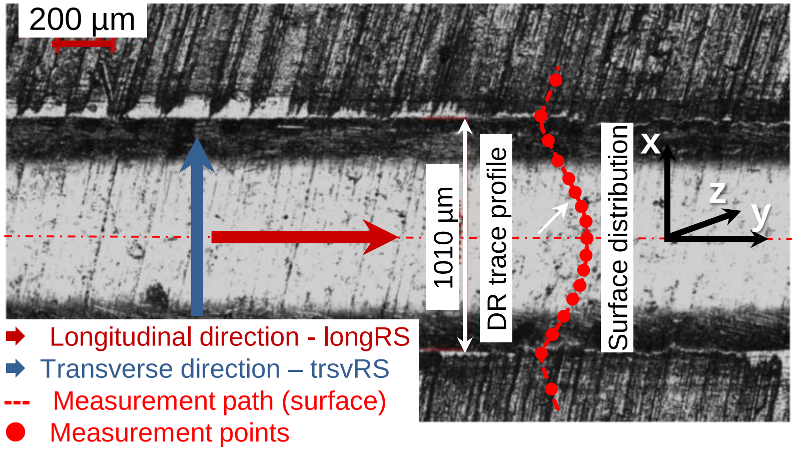
Applied force	25 N
Velocity	150 rpm
Coarse grinding	at least 100 μm removed
Fine grinding	SiC paper: 120; 320; 600 and 1200
Polishing	Polishing cloth Struers Delta + diamond suspension 3 μm; Polishing cloth Struers Zeta + diamond suspension 1 μm;

DR procedure

Specimen No (milled + DR)	Specimen No (milled + polished + DR)	Process parameters		
		DR pressure	Overturn (o.t.)	Overlapping (o.l.)
M12	P11	20 MPa	1	0 %
M15	P8	40 MPa	1	0 %
M18	-	40 MPa	5	0 %
M19	P4	40 MPa	7	0 %
M22	P2	40 MPa	1	75 %

3. Experimental set up





Hardware data		
Diffractometer	PANalytical Empyrean, θ-θ configuration	Seifert, XRD 3000 PTS, Goniometer TS-4, ψ-type 2014
Detector	PIXcel3D	Meteor 1D, 2011
Radiation	Cr-K_{α}	Cr-K_{α}
K_{β}-Filter	Vanadium	Vanadium
Primary slit	Polycapillary glass mini-lens	Polycapillary glass mini-lens, 2016
Primary beam diameter (focused)	0.05 mm - manufacturer's data	0.05 mm - manufacturer's data; 0.1 mm - own measurement
Measurement parameters		
Measured lattice plane	{211}	{211}
Diffraction angle $2\theta_0$	156.5 °	156.084 ° (acc. [1])
Measurement range 2θ	151.7 ° to 161.3 °	147° to 159.5 ° or 141° to 161°
Measurement time parameter	390 sec	120 sec
Number of ψ tiltings	7 equidistant, 0 - 50 °, with $\sin^2\psi$	27 equidistant, ± 50 °, with $\sin^2\psi$
Measurement directions φ	Longitudinal (0 °), transversal (90 °)	Longitudinal (0 °), transversal (90 °)
Oscillation	None	Around φ axis ± 5 °
Evaluation parameters		
Evaluation method	$\sin^2\psi$	$\sin^2\psi$
Elasticity constant ½ $s_2^{\{211\}}$	6.10 x10^{-6} mm²/N	5.81 x10^{-6} mm²/N (acc. [1])
Young's modulus $E^{\{211\}}$	210000 MPa	220000 MPa (acc. [1])
Poisson's ratio $v^{\{211\}}$	0.28	0.28
Peak positioning	Center of gravity 20 %	Center of gravity 70 %

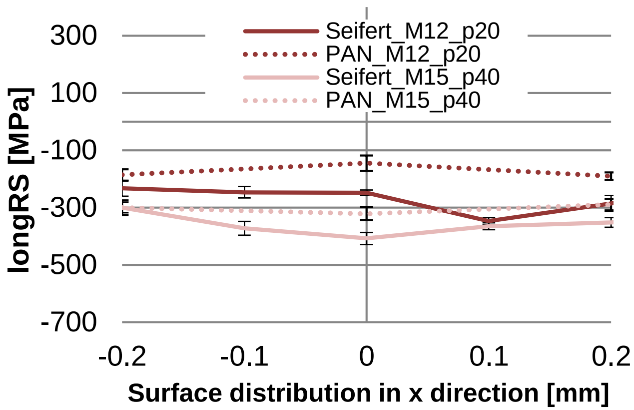
[1] [Eigenmann, Macherauch, Rontgenographische Untersuchung von Spannungszustanden in Werkstoffen, Teil III, Mat.-wiss. u. Werkstofftech. 26, 148-160 (1995)]

4. Influence of the measurement device – RS surface distribution

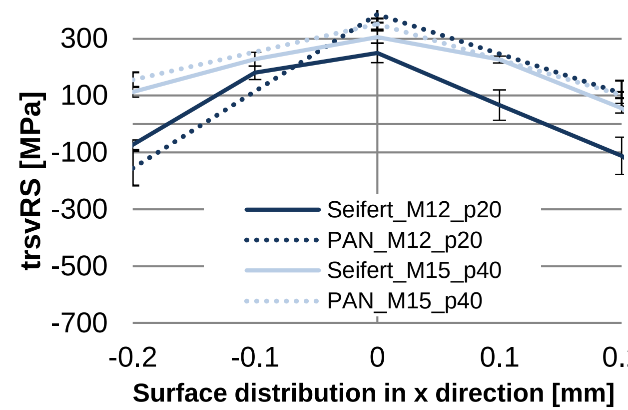
Legend

- Seifert – Diffraktometer Seifert, XRD 3000 PTS
- PAN – Diffraktometer PANalytical Empyrean
- M12_p20 – Milled + DR; DR pressure = 20 MPa
- M15_p40 – Milled + DR; DR pressure = 40 MPa
- M19_7 o.t. – Milled + DR; 7 overturns
- M22_75% – Milled + DR; 75 % overlappings (o.l.)
- longRS – residual stress along the DR trace
- trsvRS – residual stress transverse to the DR trace

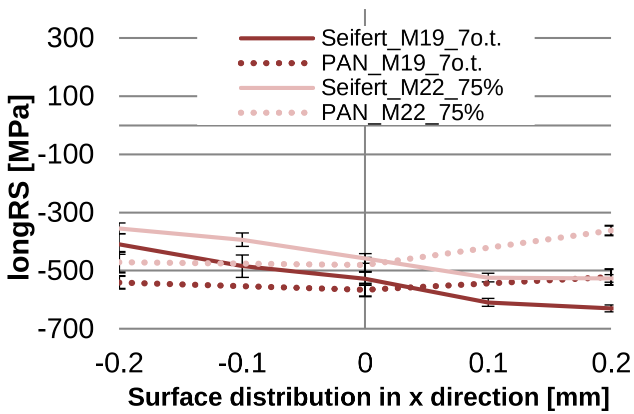
a) **Different diffractometers, pressure variation**



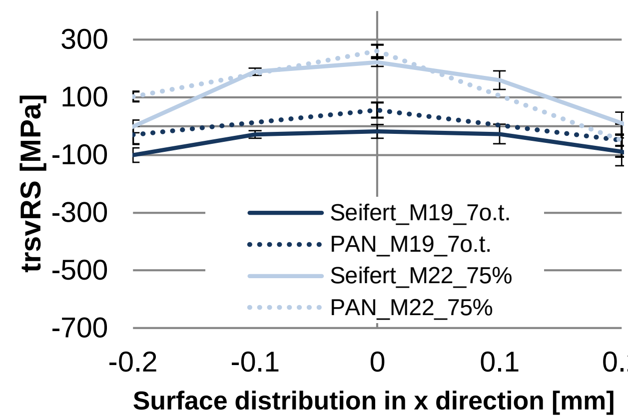
b) **Different diffractometers, pressure variation**



a) **Different diffractometers, o.t. and o.l. variation**



b) **Different diffractometers, o.t. and o.l. variation**

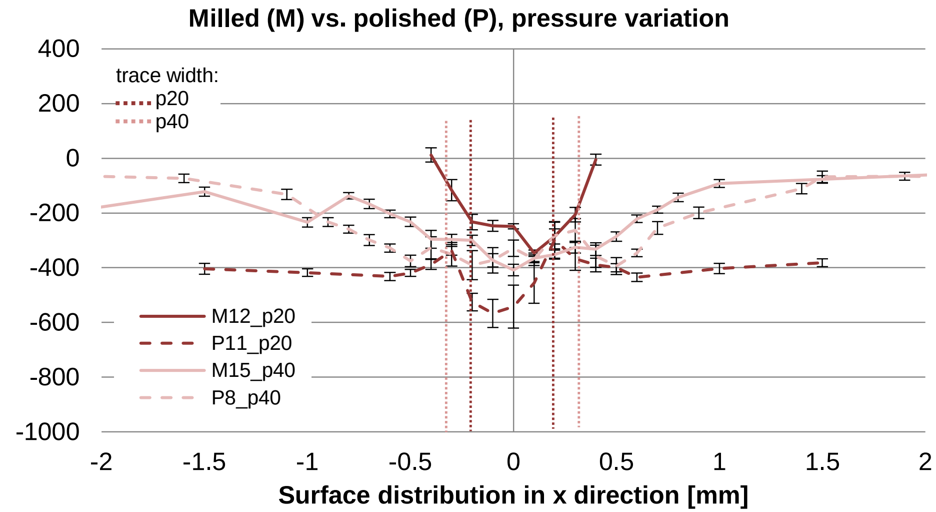


5. Influence of the pre-machining – RS surface distribution

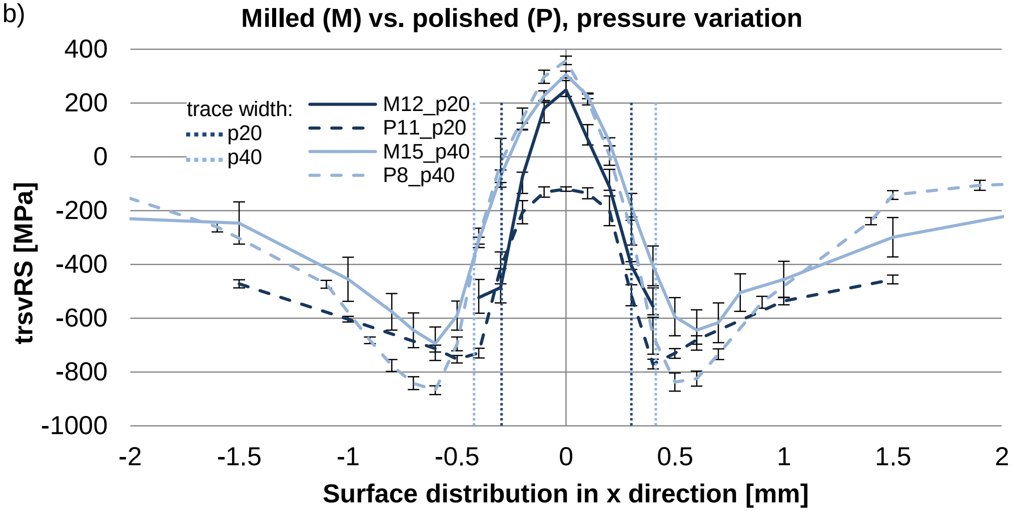
Legend
M12_p20 – Milled + DR; DR pressure = 20 MPa
P11_p20 – Milled + polished + DR; DR pressure = 20 MPa
M15_p40 – Milled + DR; DR pressure = 40 MPa
P8_p40 – Milled + polished + DR; DR pressure = 40 MPa
longRS – residual stress along the DR trace
trsvRS – residual transverse to the DR trace

- ✓ The stress distribution in both directions for all specimens exceed the width of the DR trace
- ✓ The pre-machining influences the stress state mostly by following DR with low pressure
- ✓ The polishing procedure facilitate the generation of compressive residual stresses

a)



b)

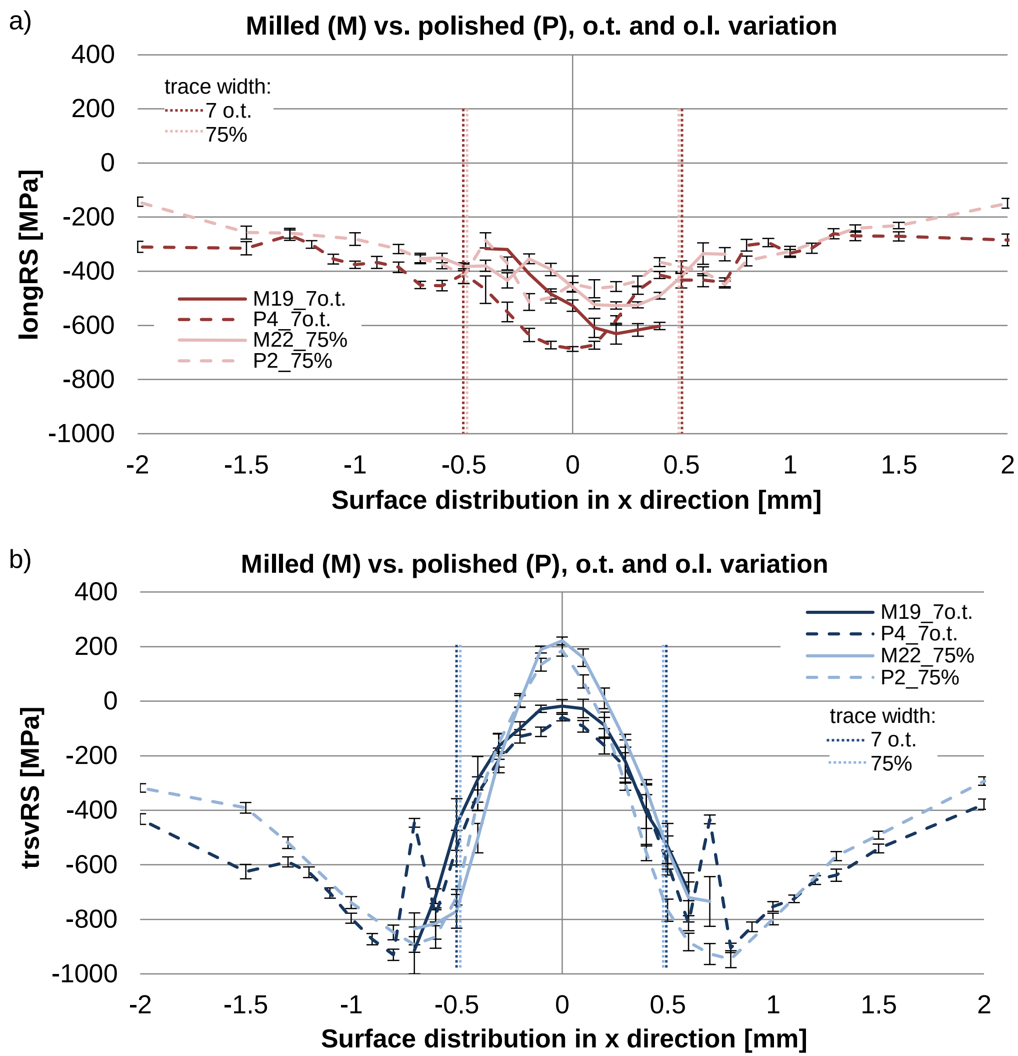


5. Influence of the pre-machining – RS surface distribution

Legend

M19_7 o.t. – Milled + DR; 7 overturns
P4_7 o.t. – Milled + polished + DR; 7 overturns
M22_75% – Milled + DR; overlapping 75 % (o.l.)
P4_75% – Milled + polished + DR; overlapping 75 % (o.l.)
longRS – residual stress along the DR trace
trsvRS – residual stress transverse to the DR trace

- ✓ No significant difference in the stress state by variable pre-machining
- ✓ DR with 7 overturns leads to higher compressive RS
- ✓ DR with 7 overturns reduces the surface tensile RS
- ✓ Lateral shifting of the RS by M19_7o.t. → probably positioning inaccuracy



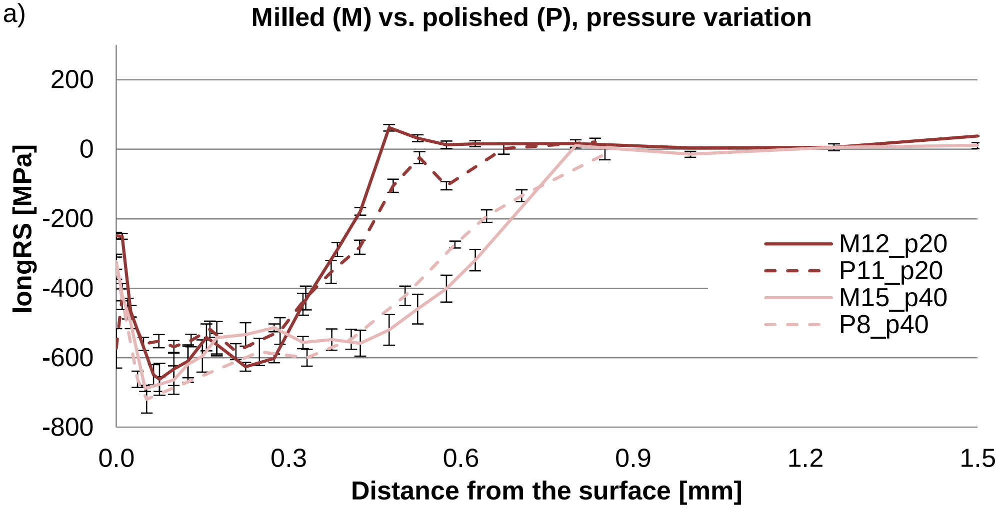
6. Influence of the pre-machining – RS depth distribution

Legend

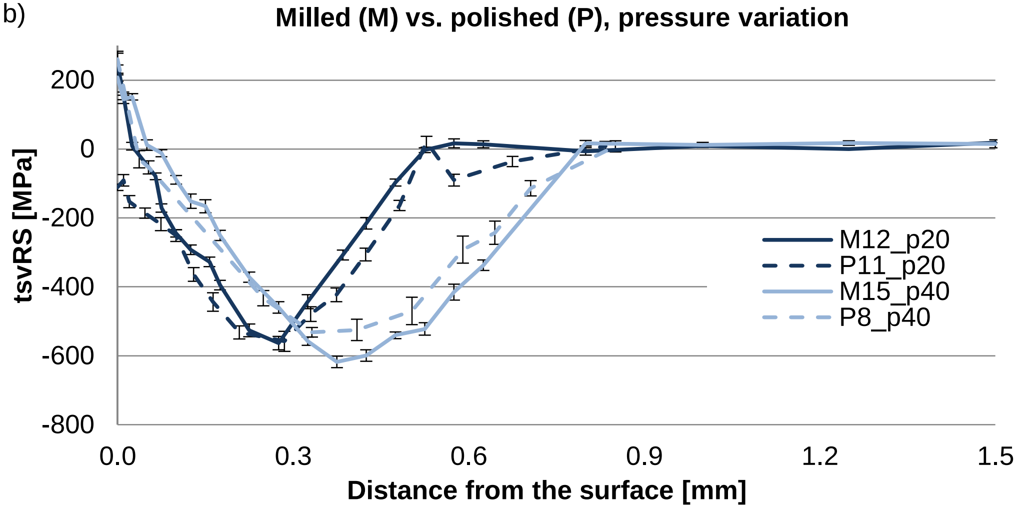
M12_p20 – Milled + DR; DR pressure = 20 MPa
P11_p20 – Milled + polished + DR; DR pressure = 20 MPa
M15_p40 – Milled + DR; DR pressure = 40 MPa
P8_p40 – Milled + polished + DR; DR pressure = 40 MPa
longRS – residual stress along the DR trace
trsvRS – residual stress transverse to the DR trace

- ✓ Removed layer not corrected
- ✓ The pre-machining has not a significant influence on the residual stresses in depth (in both directions and for variable DR pressure)
- ✓ longRS → maximum compression near the surface
- ✓ trsvRS → maximum compression at higher depth
- ✓ Higher DR pressure → deeper residual stresses

a)



b)

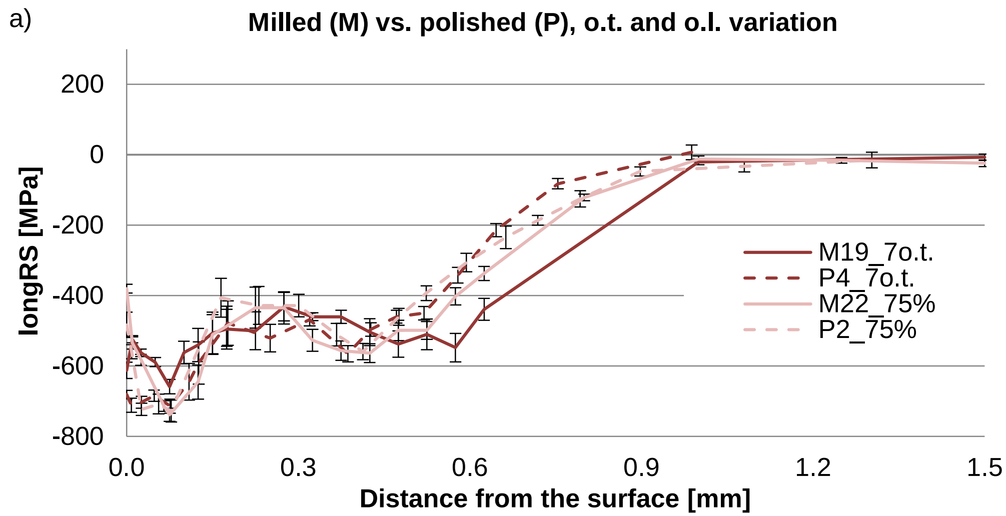


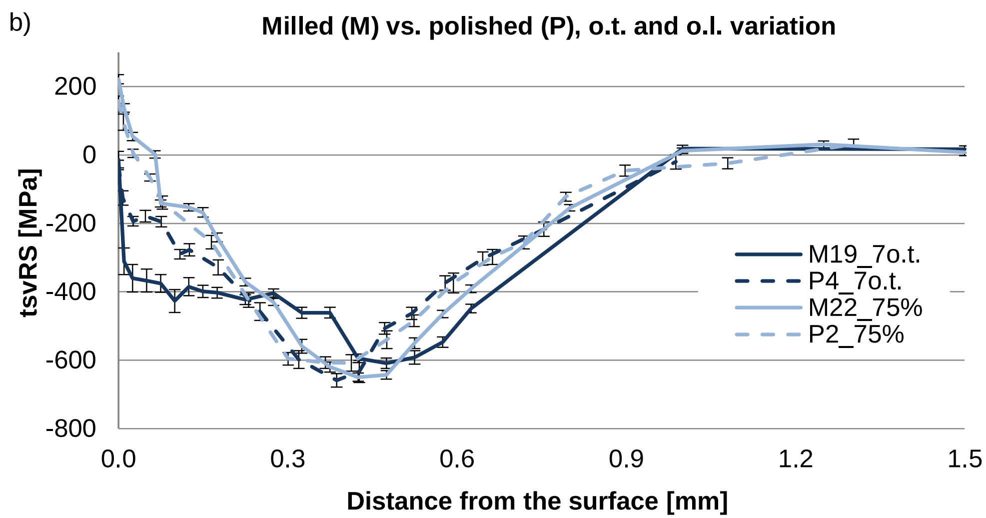
6. Influence of the pre-machining – RS depth distribution

Legend

M19_7 o.t. – Milled + DR; 7 overturns
P4_7 o.t. – Milled + polished + DR; 7 overturns
M22_75% – Milled + DR; overlapping 75 % (o.l.)
P4_75% – Milled + polished + DR; overlapping 75 % (o.l.)
longRS – residual stress along the DR trace
trsvRS – residual stress transverse to the DR trace

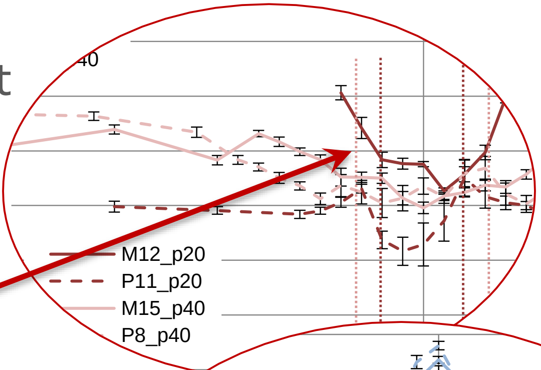
- ✓ DR with 75% overlapping (o.l.) → deeper residual stresses than w/o overlapping
- ✓ DR with 7 overturns (o.t.) do not increase the compressive residual stress maximum but reduce the near-surface tensile residual stress
- ✓ DR with 7 overturns (o.t.) do not increase the depth of the residual stresses in comparison with 75% overlapping (o.l.)

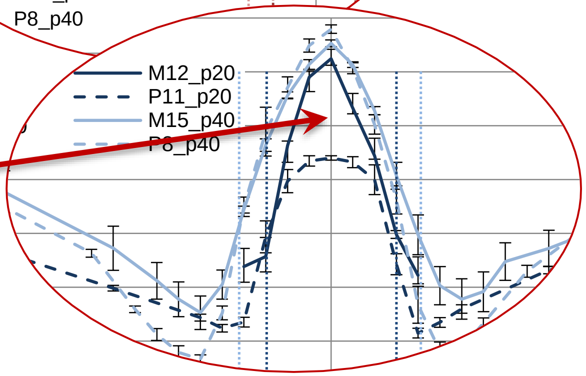




7. Summary and conclusions

- ✓ Residual stress analysis of deep rolled specimens, where the following influences were investigated:
  - Measurement conditions
  - Pre-machining
  - Process parameters
- ✓ Measurement conditions influence
  - The variable measurement parameters do not have a significant impact on the measured residual stresses
  - The specimen's positioning and alignment is crucial as it leads to shifting of the surface residual stress profile
- ✓ Pre-machining
  - Influences mostly the surface residual stress profile and in case of low pressure DR

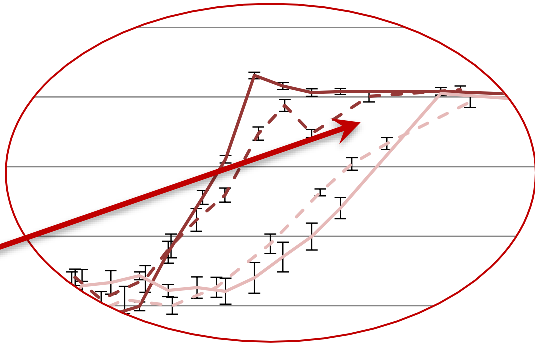




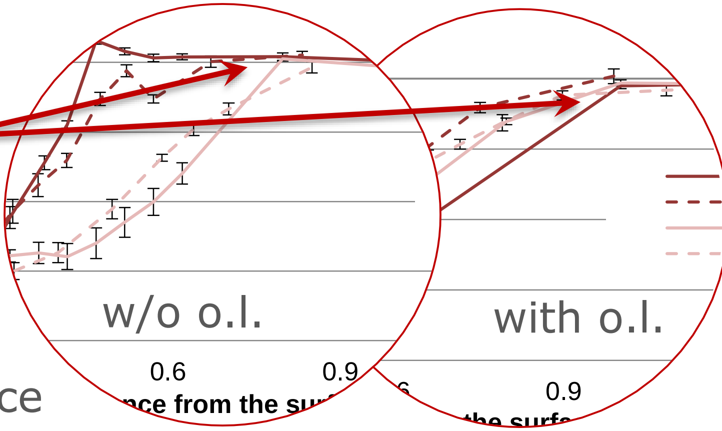
7. Summary and conclusions

✓ Process parameters

- DR pressure
  - RS surface distribution – higher DR pressure → wider RS affected area
  - RS depth distribution – higher DR pressure does not influence the compressive RS maximum but leads to deeper distributed RS



- Overlapping
  - RS maximum amount on the surface – similar with or w/o overlapping
  - RS depth distribution – with vs. w/o overlapping, the same compressive RS maximum but with overlapping → RS at higher depth.



- Number of overturns
  - RS depth distribution – lower near surface tensile RS and deeper compressive RS

Thank you for your attention!

Prof. Dr.-Ing. Joachim E. Hoffmann
Werkstoffkunde und Werkstoffprüfung
Morlauterer Str. 31
67657 Kaiserslautern
Tel. dienstl. : 0631/3724-2304
Fax. dienstl. : 0631/3724-2105
E-Mail: joachim.hoffmann@hs-kl.de

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X-Ray Diffraction Technology

Nataliya Lyubenova, M.Sc.
development engineer
Felsenweg 6,
D-91220 Schnaittach-Hormersdorf
mobil: +49 (0)160 / 9151 9063, Fax: +49 (0)9152 / 926693
e-mail: nataliya.lyubenova@XRD-eigenmann.de
http://www.XRD-eigenmann.de