Advanced NDT to Monitor Friction Stir Welding

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Outline:

- Introduction
- Process parameters
- Monitoring of process forces
- Early detection of irregularities
- Superposition of powered ultrasound
- Benefits & Conclusion
- Acknowledgements

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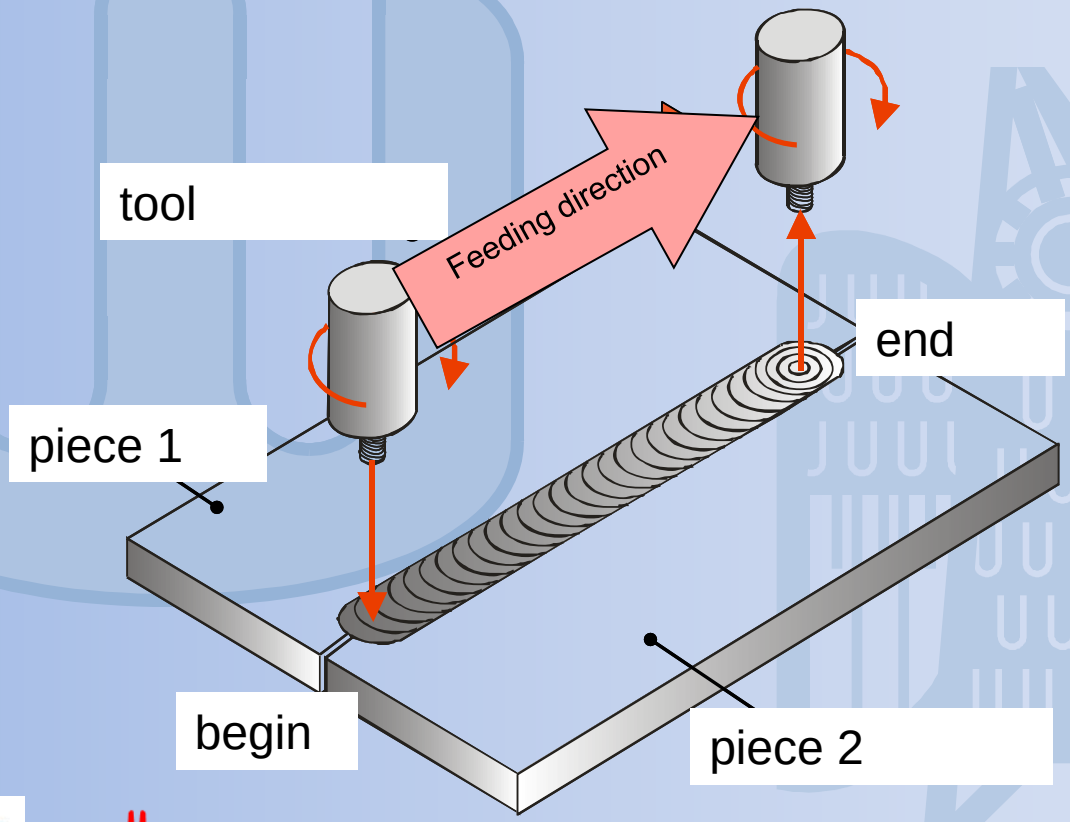
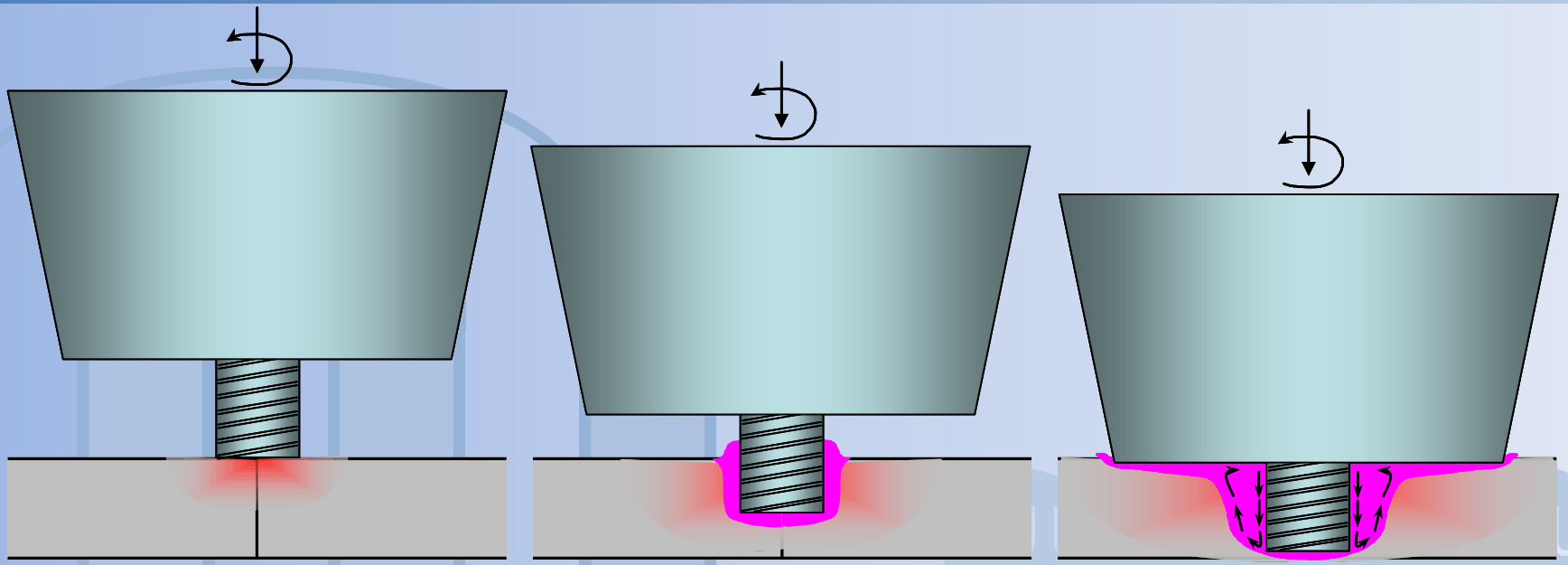
Friction Stir Welding

- 1991 developed by TWI



Process in Detail



Tools

Classic TWI 5651

Tri-flute™

Trivex™

Stir pins according to TWI

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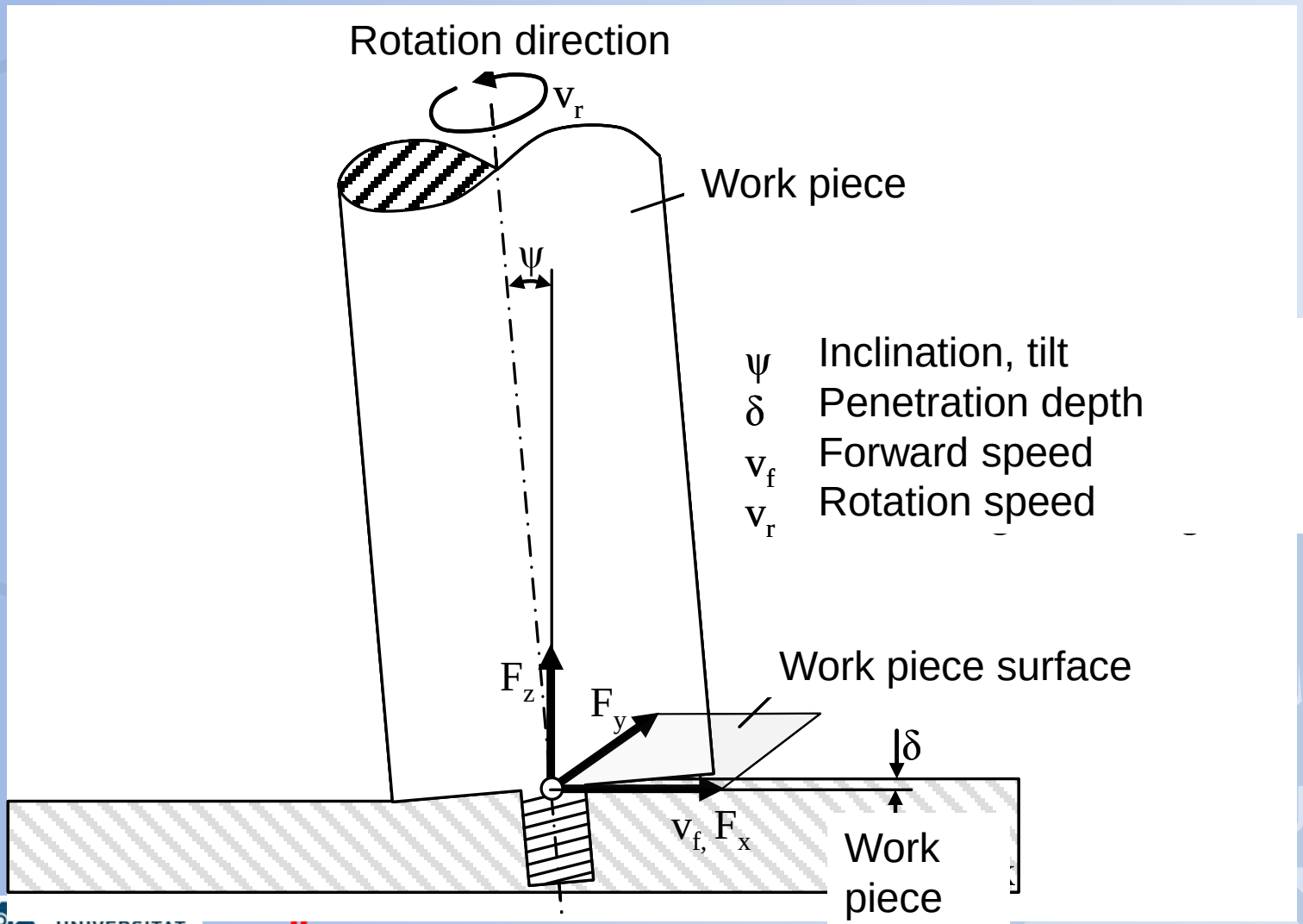
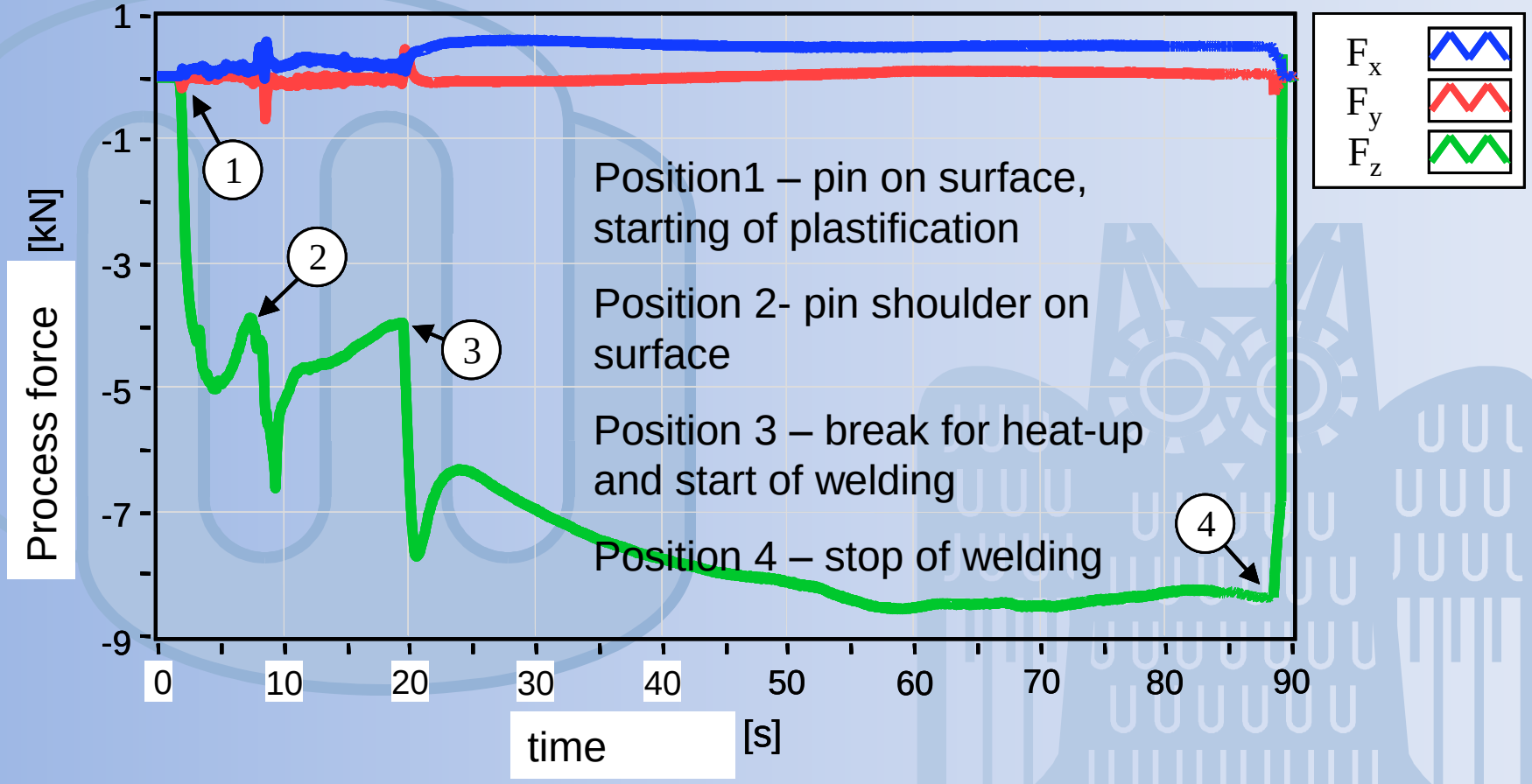
Process Parameters



ψ Inclination, tilt
δ Penetration depth
v_f Forward speed
v_r Rotation speed

Process forces



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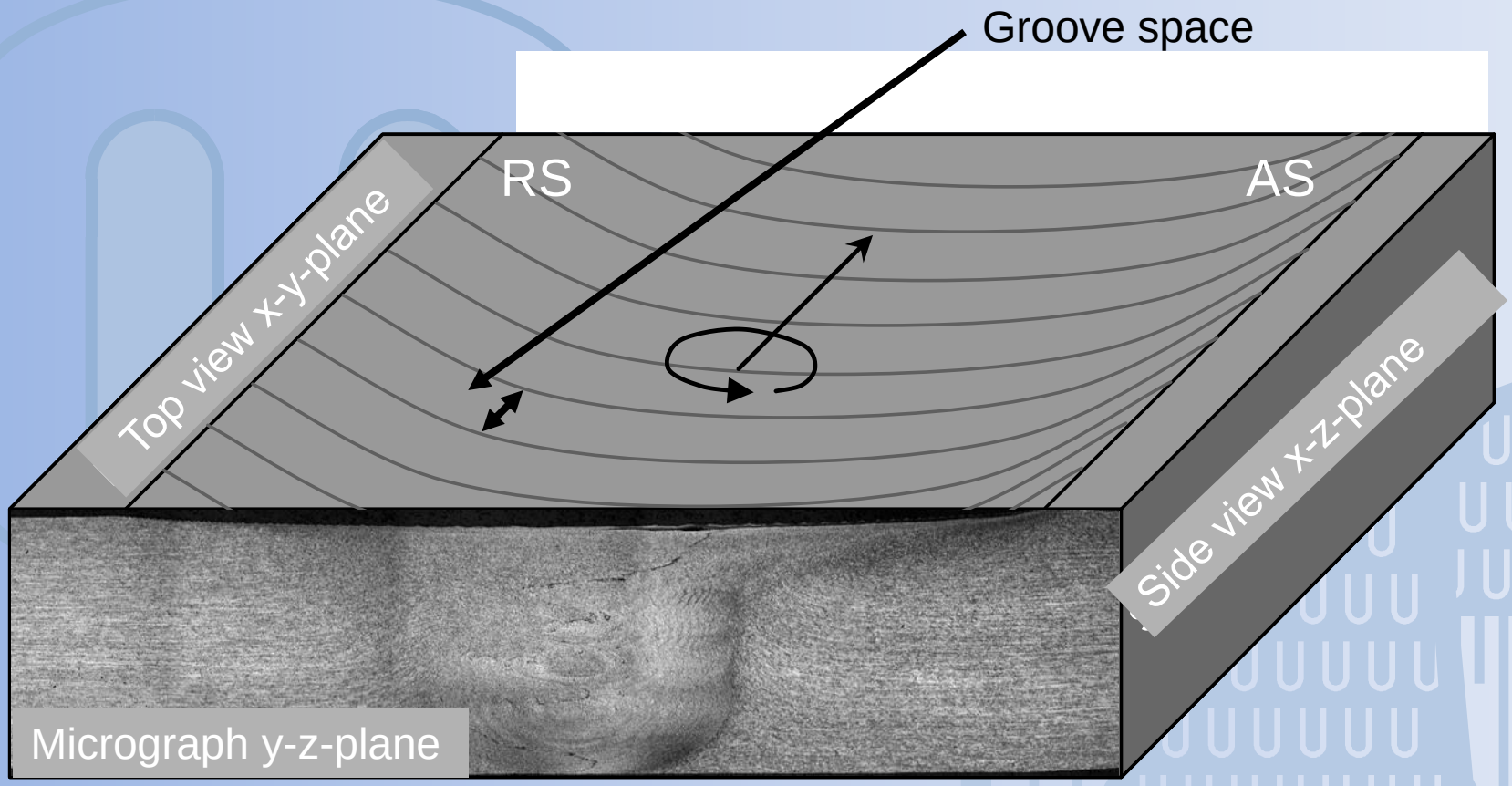
Material movement by rotation and translation



AS-advancing side RS-retreating side

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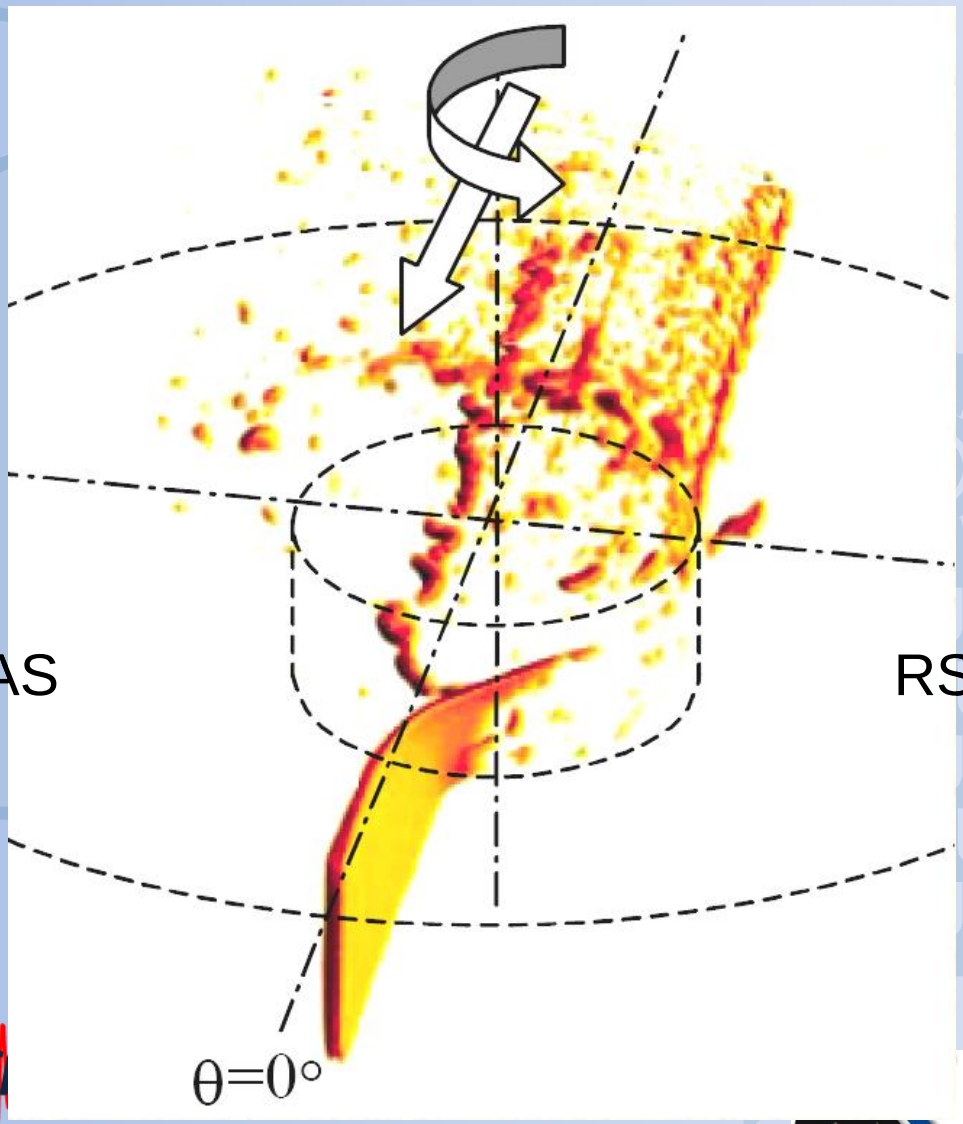
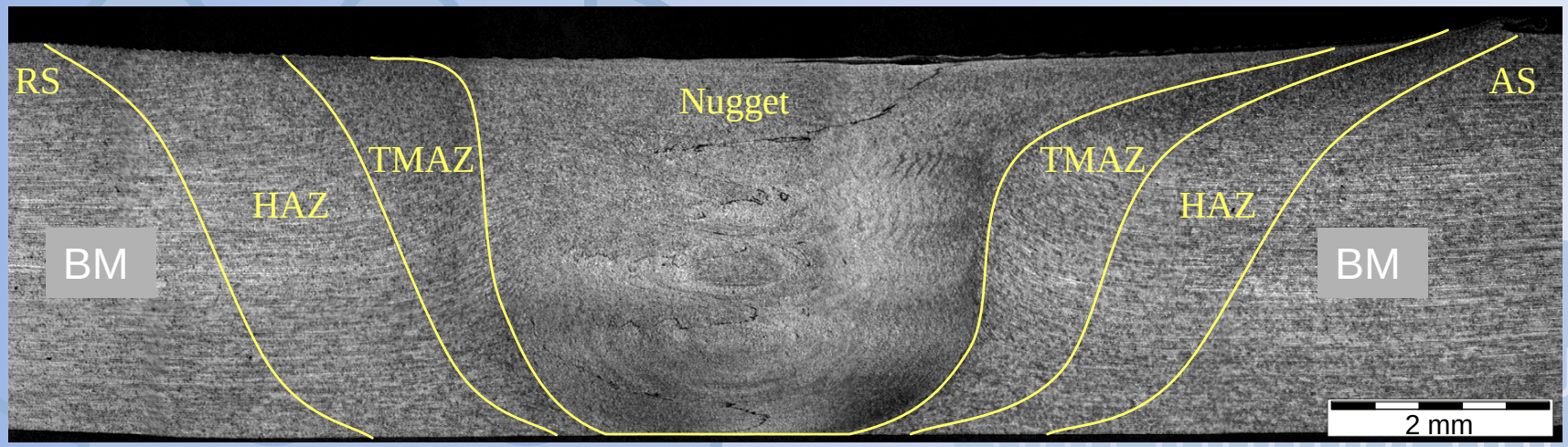
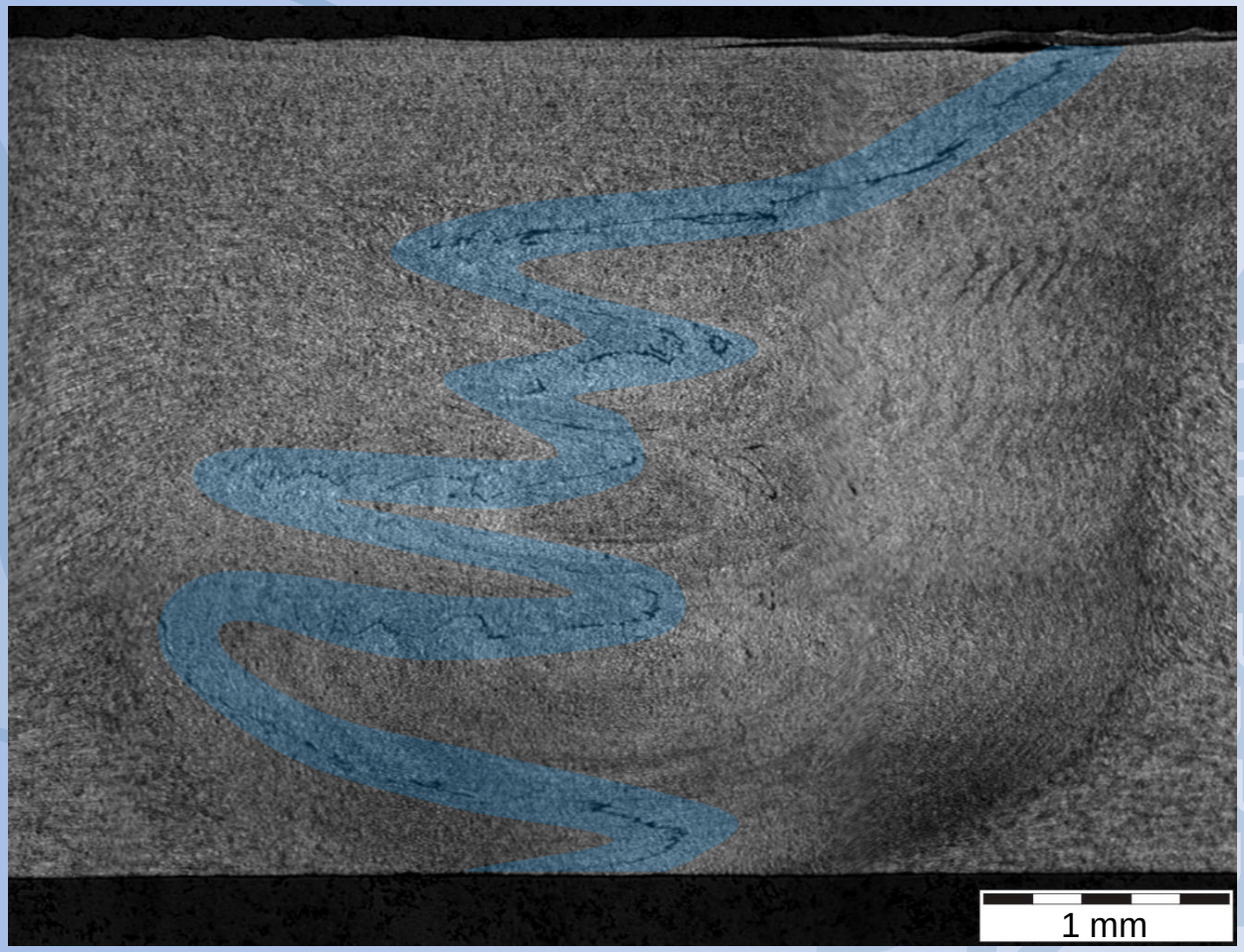
Material movement visualized by 3D-CT according Dickerson 2003



AlMg3Mn-AlMg3Mn FSW with nugget, TMAZ, HAZ and BM at RS and AS



Joint Line Remnant JLR, Oxid-Hydroxid Particles



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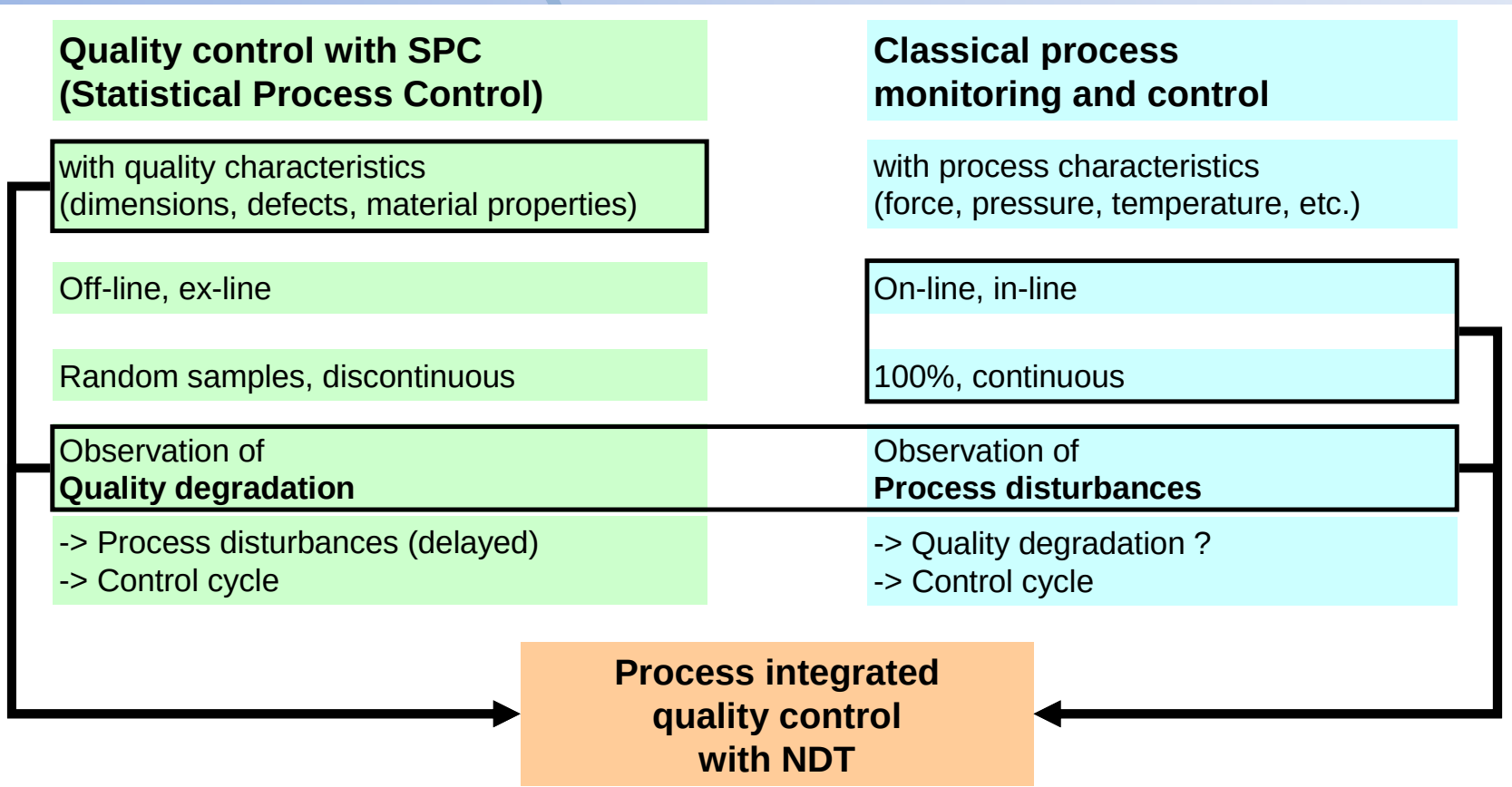
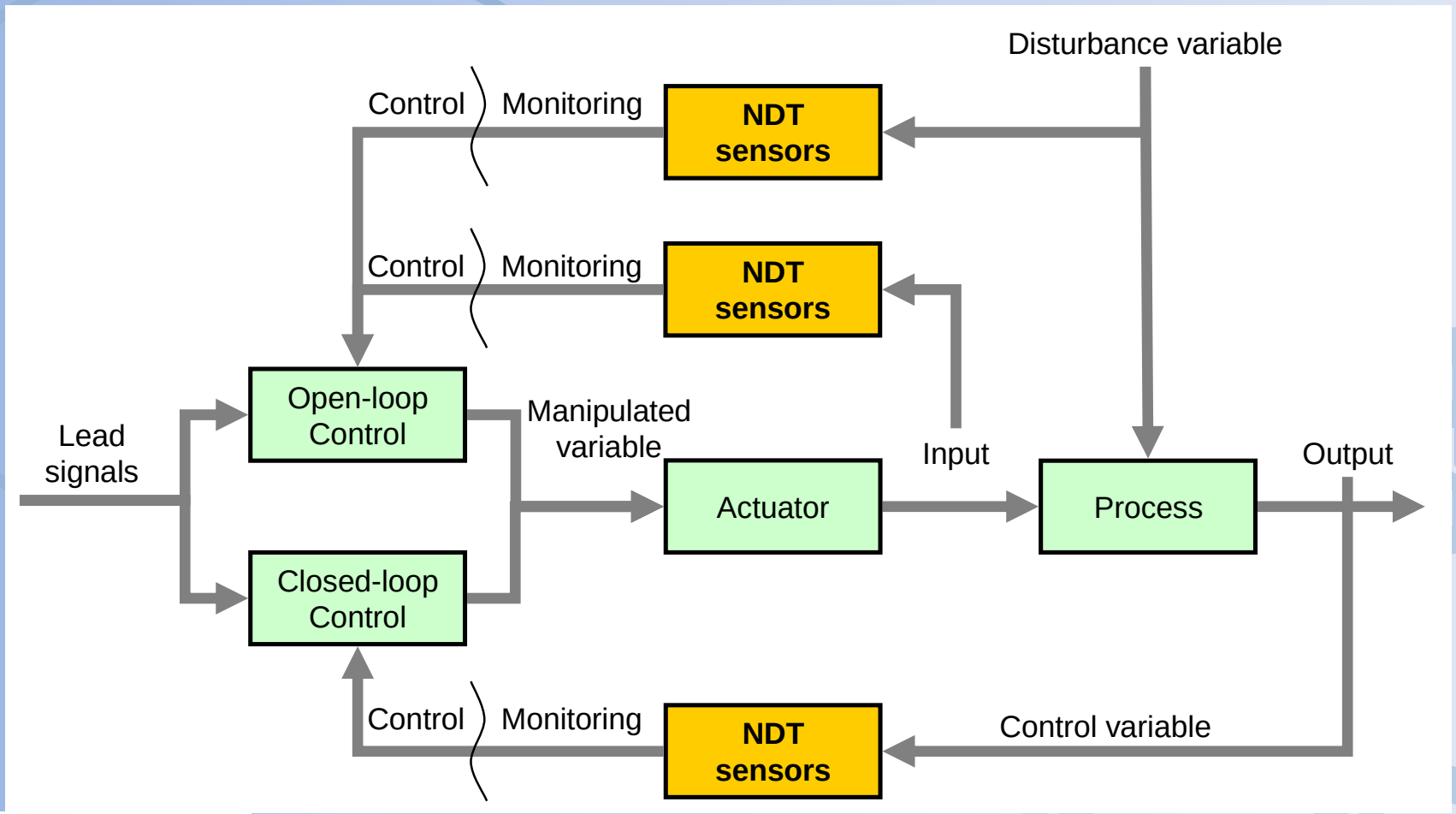
Process monitoring and control



Process monitoring and control



Welding parameters

Wrought Al-alloy AA5454 (300x125 mm^2) with a thickness of 3.5 mm were friction stir welded.

Milling machine from the type Deckel Maho DMU80T, DMG Germany.

Tool shoulder possesses a 14 mm diameter and a M3.5 pin and was tilted by 2° during the process.

The ratio of the welding parameters, feed rate and rotational speed per revolution, FPR, ranges from 50 µm/R to 200µm/R.

The machine is equipped with a force measurement system which allows recording the welding forces in x-, y-, and z-direction emerging during the welding process.

For microscopic investigations the cuts of the welded sheets were etched in hydrofluoric acid for 10 s.

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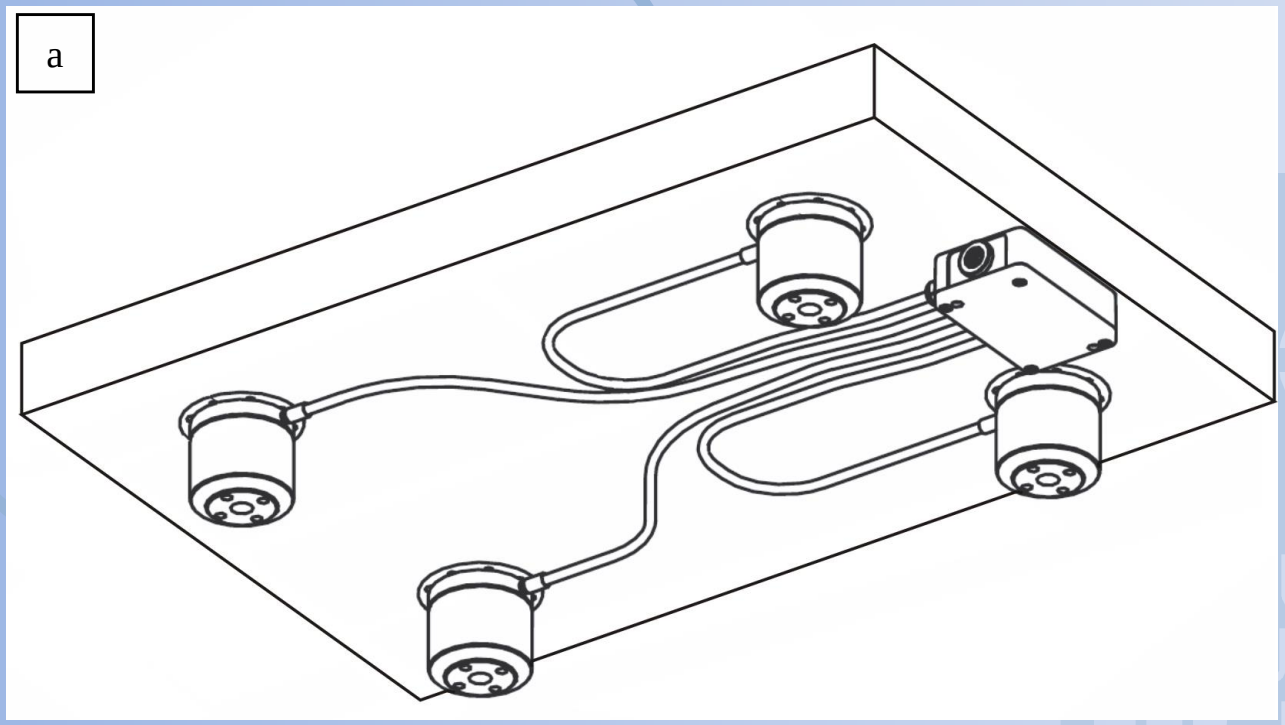
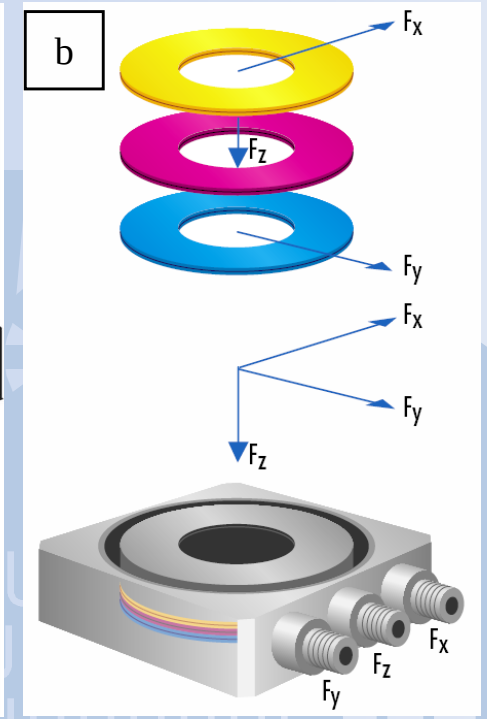
Force measurement by piezoelectric sensors according to Kistler





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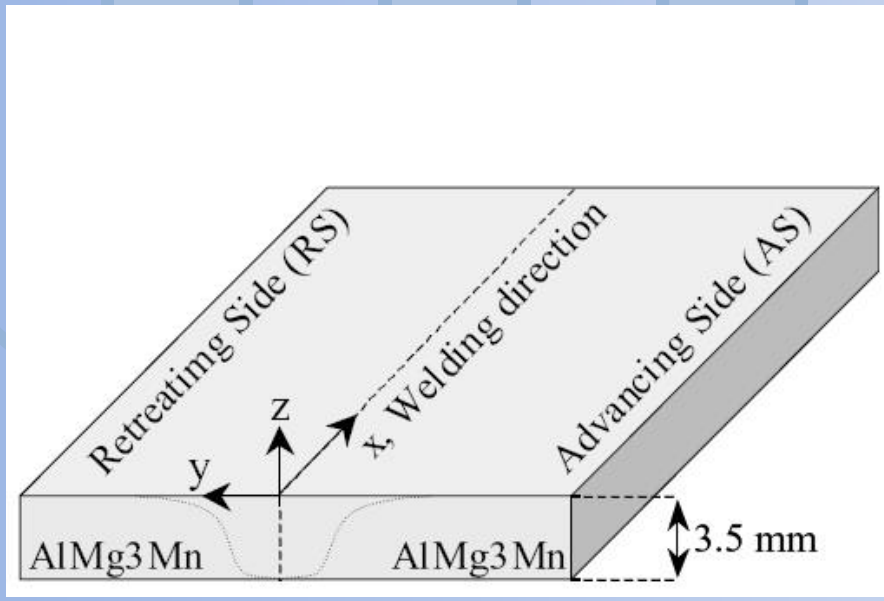
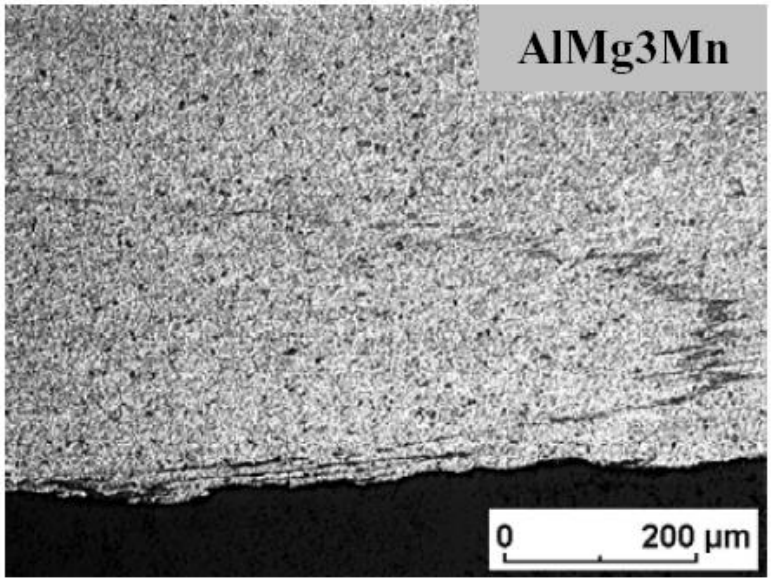
ZigZag indications





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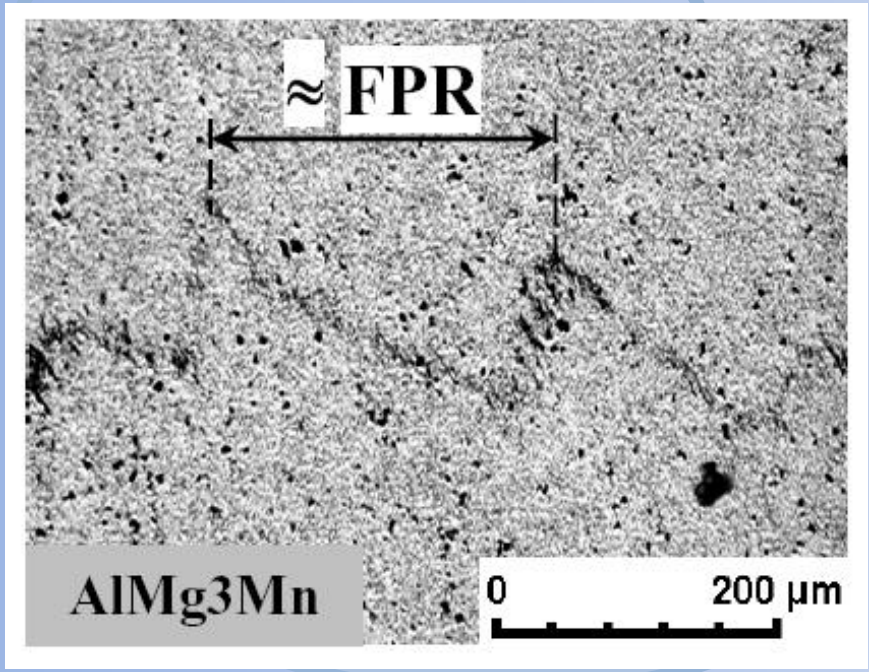
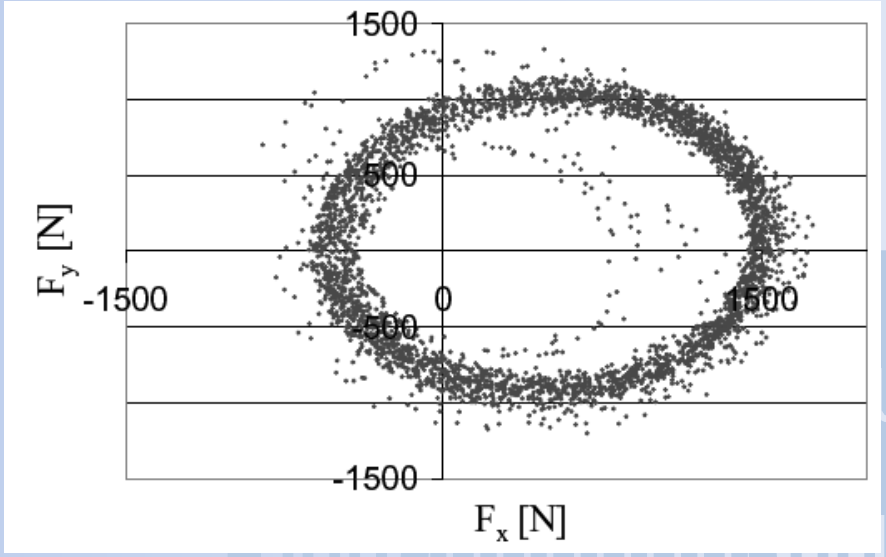
Periodic welding forces





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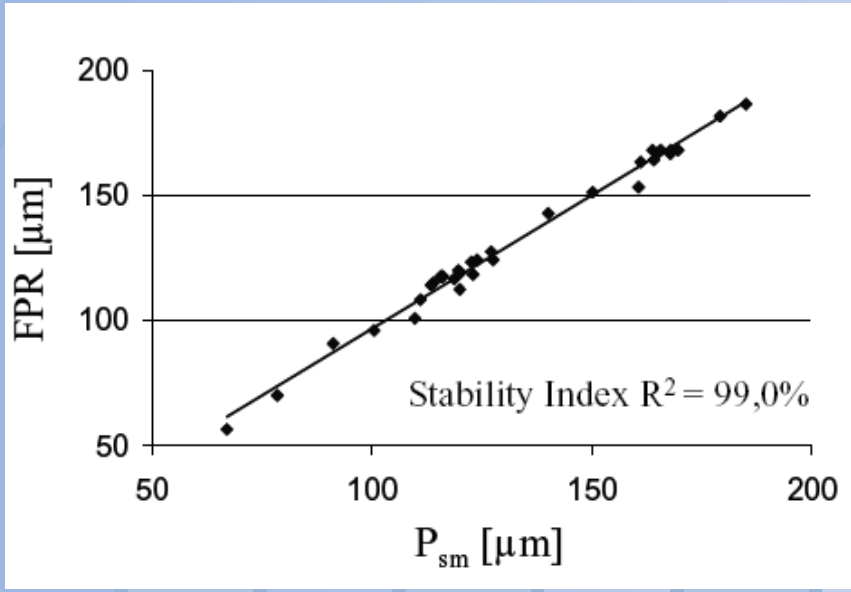
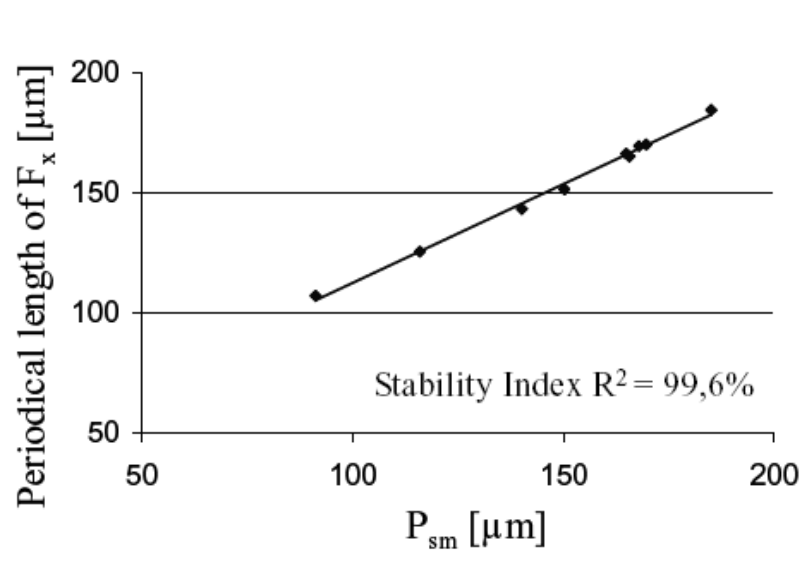
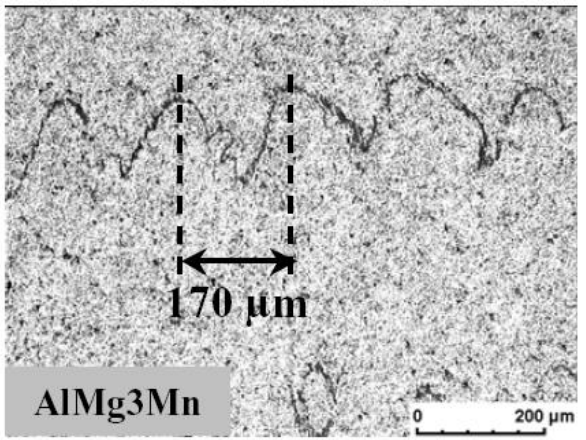
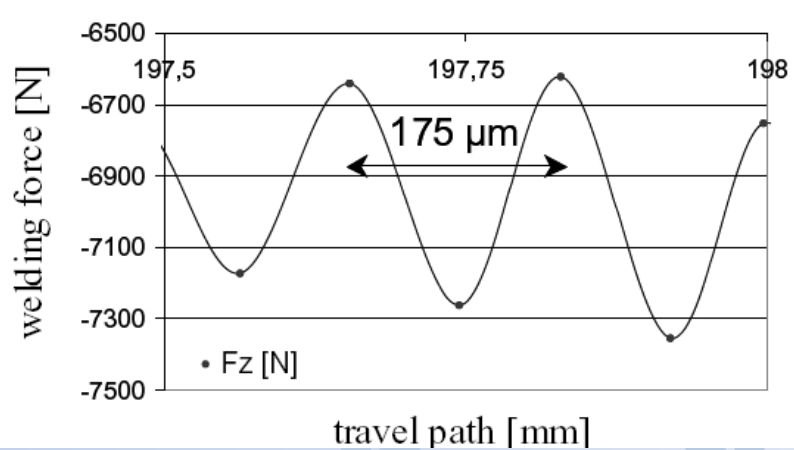
Feed per revolution and groove spacing P_{sm}









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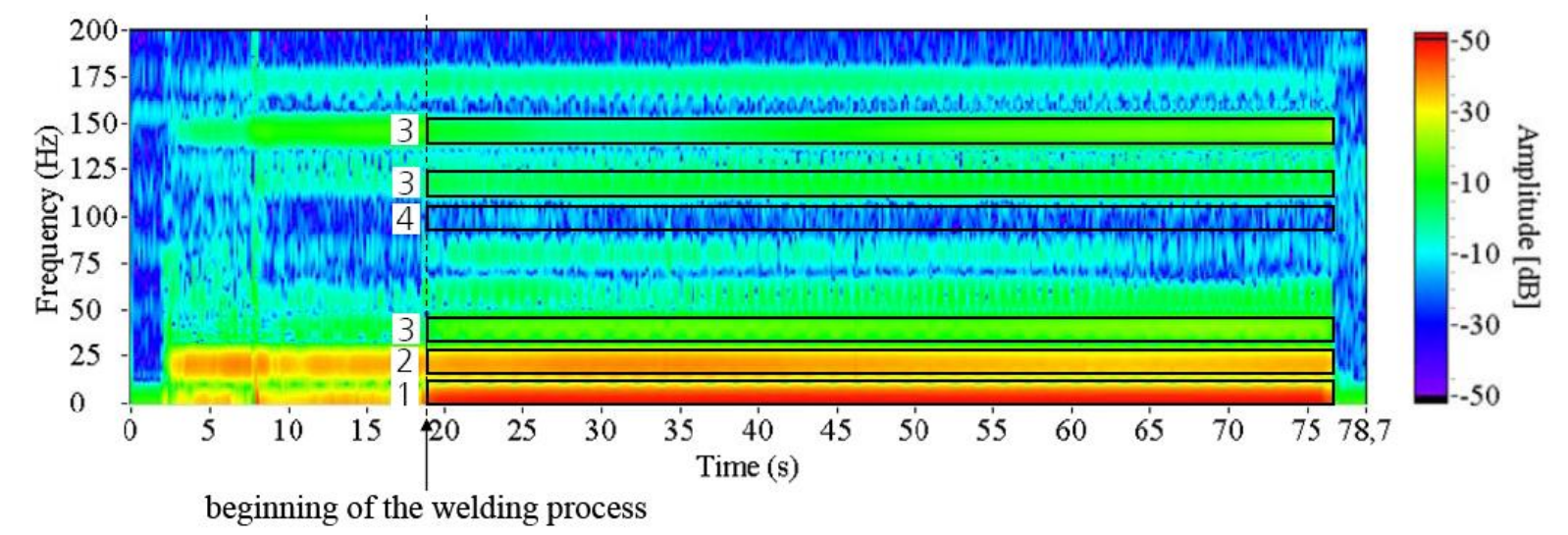
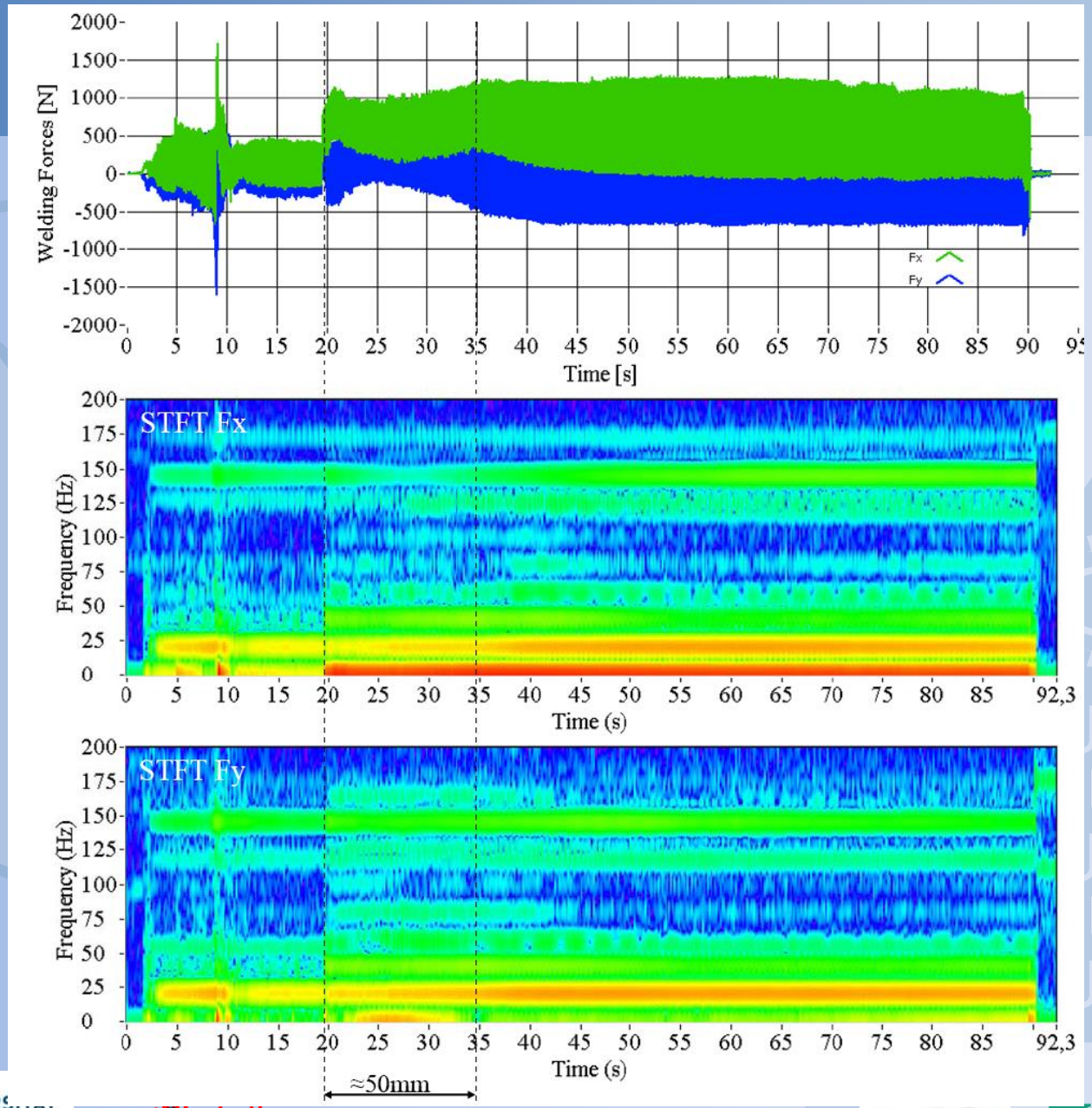
Pattern recognition in the spectrogram of a sound weld

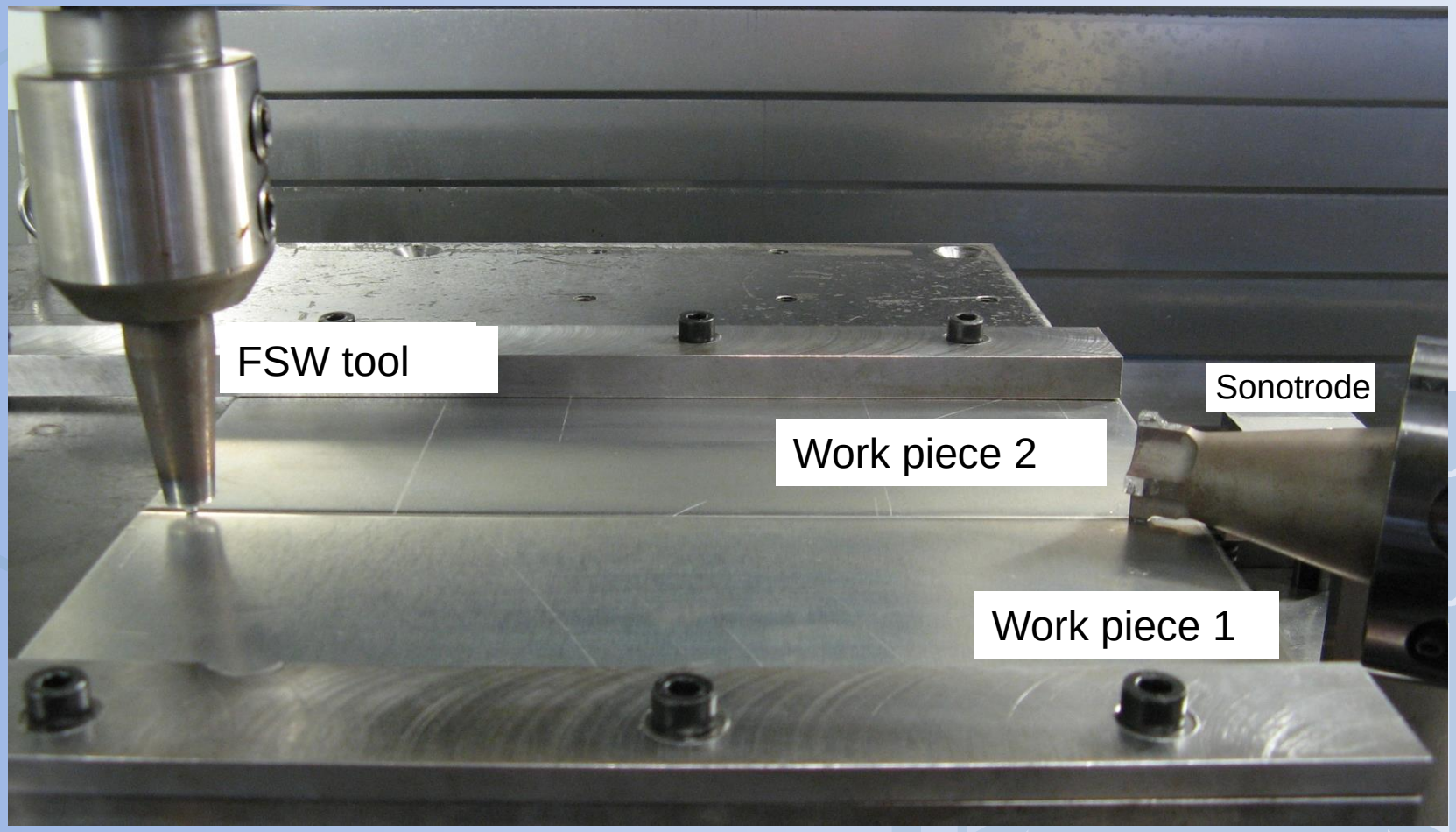


Continuously high amplitudes in the F x -frequency range lower than that of tool rotation (contrary to the STFT of F y).
Continuously high amplitudes in the frequency range of the tool rotation frequency.
Continuously high amplitudes in the frequency range of the harmonics.
Continuously low amplitudes at 100 Hz, independent of tool rotation frequency.



Development of a worm hole

Superposition of high powered (20 kHz, 25-40µm, 3kW) ultrasound, 500N



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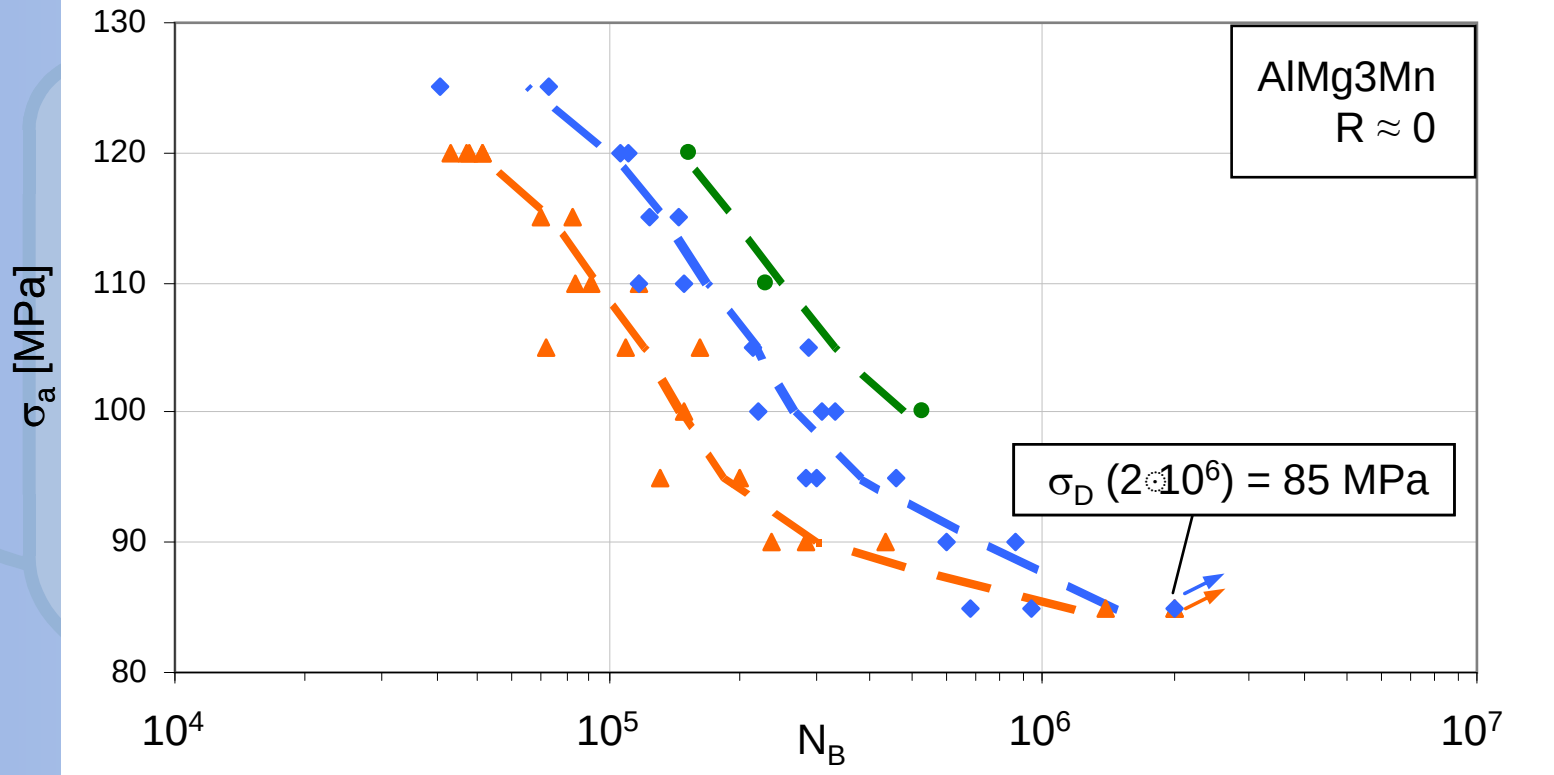
Benefit & conclusion – more than a factor 2 in lifetime



Red=with oxide particles, blue=oxide removed by grinding, green=powered ultrasound

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Conclusions

- The FSW-Process can be online monitored due to Force-Measurement and –Analysis
- The early development of welding irregularities can be detected
- The Process can be controlled
- The superposition of High-Powered Ultrasound is enhancing the welding quality in terms of fatigue life time with at least a factor two.

Acknowledgements

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- The fruitful and longtime cooperation with the Institute of Materials Science and Engineering, WKK, Technical University Kaiserslautern, Prof. Dietmar EIFLER and Prof. Guntram WAGNER