Considerations for sound parameter studies in electron beam welding of thick walled components

Institute for Materials Science and Welding

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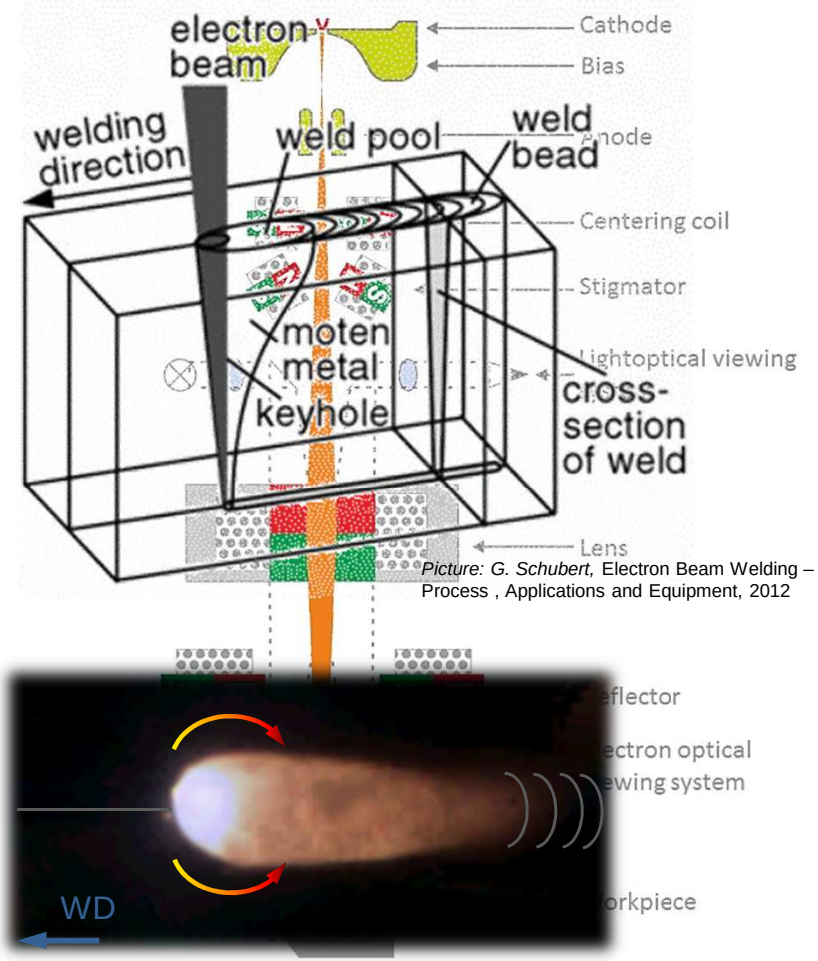
Content

- Introduction
  - EBW
  - Blind welding study
  - Defects
- Methods
  - Welding block
  - Analysis methods
- Results
- Conclusion

Electron Beam Welding

- Beam welding procedure
  - Kinetic energy of e^-
  - Keyhole effect

- High energy density **>10^5 W/cm²**
  - Thick walled welding
  - Single layer
  - Vacuum

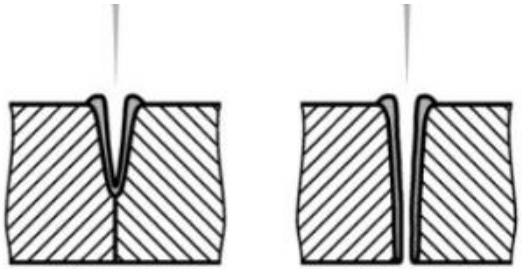


Picture: G. Schubert, Electron Beam Welding – Process , Applications and Equipment, 2012

Picture: Pro Beam 2012

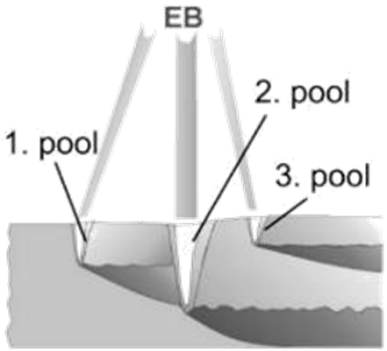
Electron Beam Welding

- Parameters
  - Acceleration voltage U
  - Beam current I
  - Welding speed v
  - Focal point fp
  - Beam oscillation



- Welding depth
- Seam Shape

- Facilitate process
- Freedom of defects

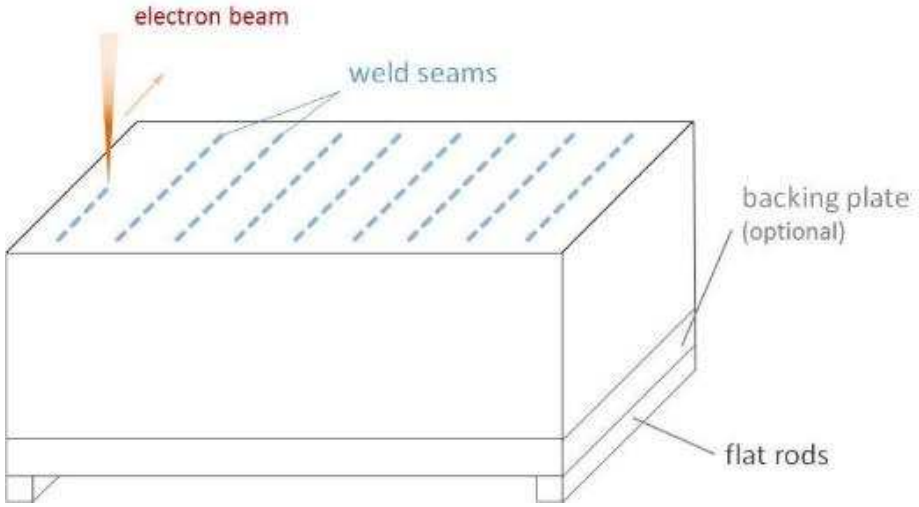


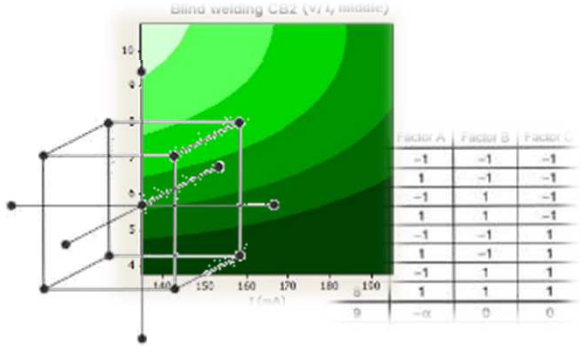
Pictures: P. Fu, et. Al., "International Electron Beam Welding Conference", 2012
Pro Beam, 2012, U. Dilthey, Schweißtechnischer Fertigungsverfahren 1, 3. Auflage. Aachen: Springer, 2006

Blind welding study

- Plenty of Parameters
  - Big testing effort
  - Time & Material costs

- Design of Experiments
  - Statistical tool
  - Enhance testing

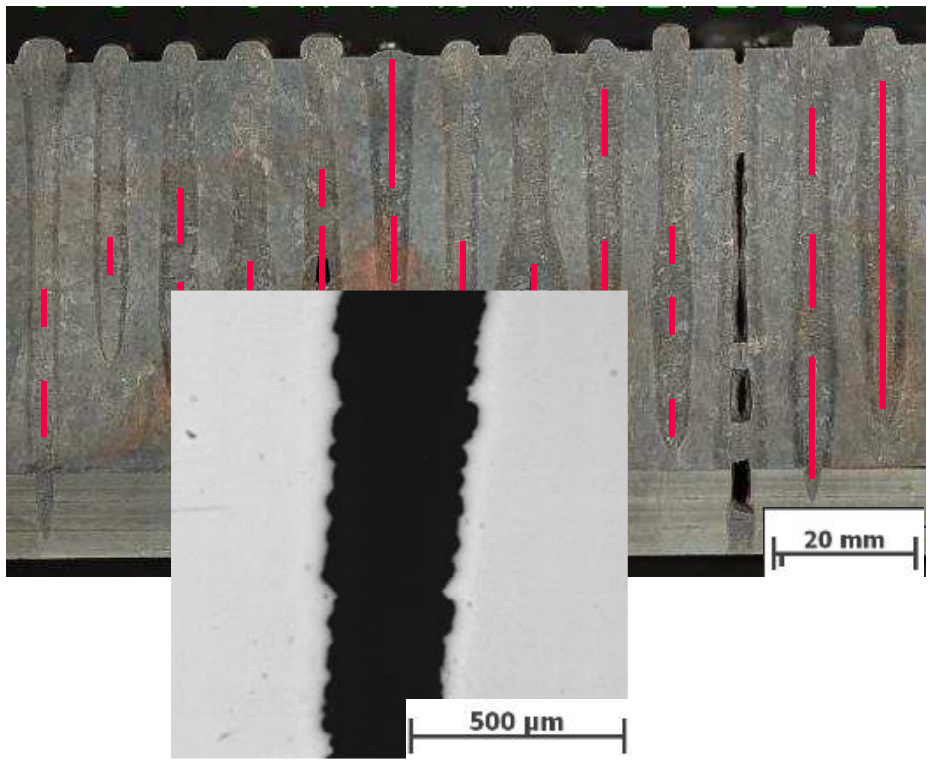


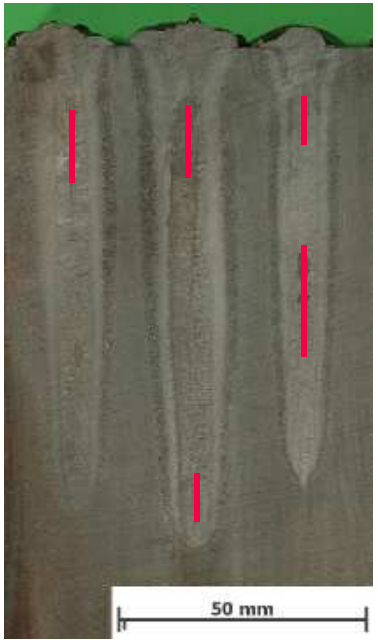


Welding defects in blind welding studies

- Excessive defects
- Different experiments
  - Materials
  - Welding depths

- Cracks
  - Similar appearance
  - Similar location

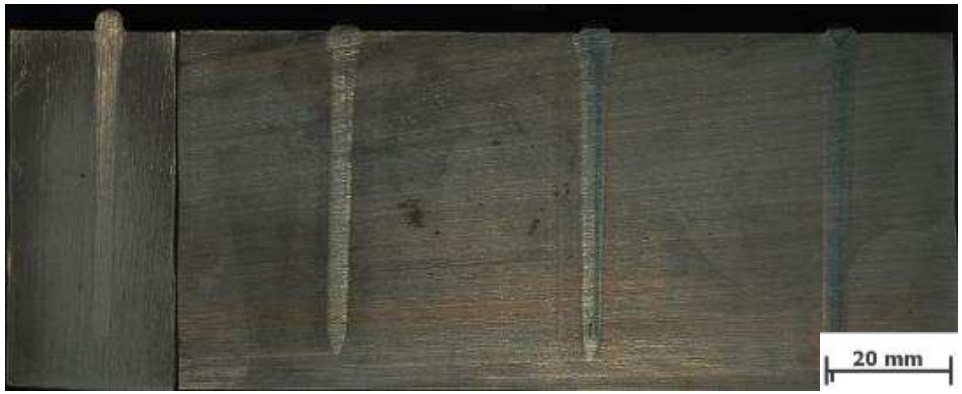


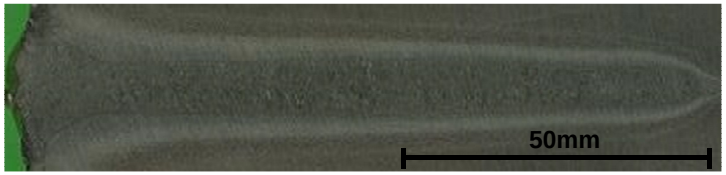


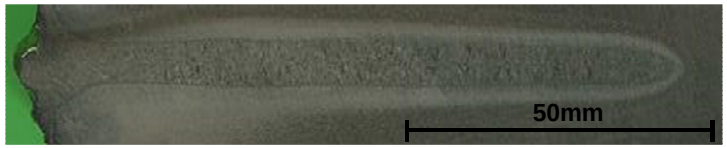
Welding defects in blind welding studies

- Welds were repeated
  - Equal welding parameter
  - Different testing setup
    - More spacing
    - Single welds

- Defects did **not** occur







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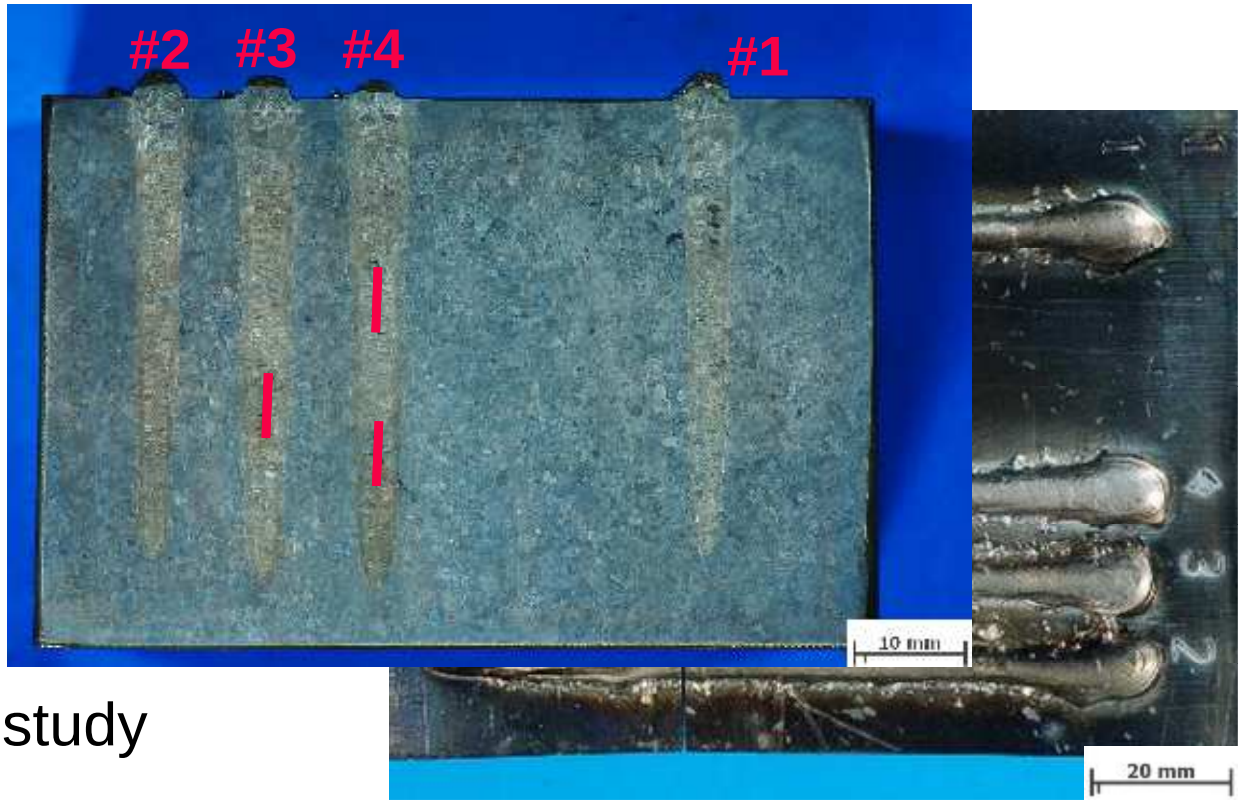
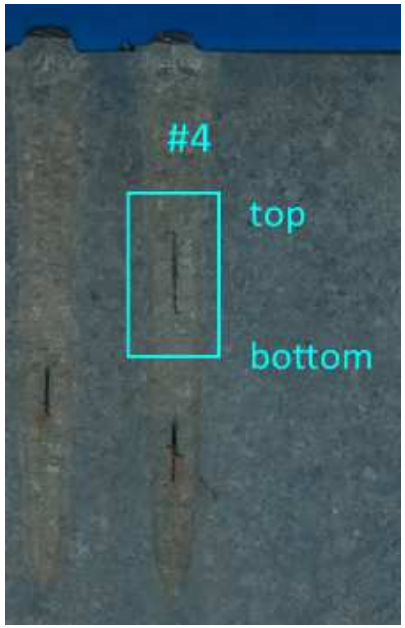
Experimental setup

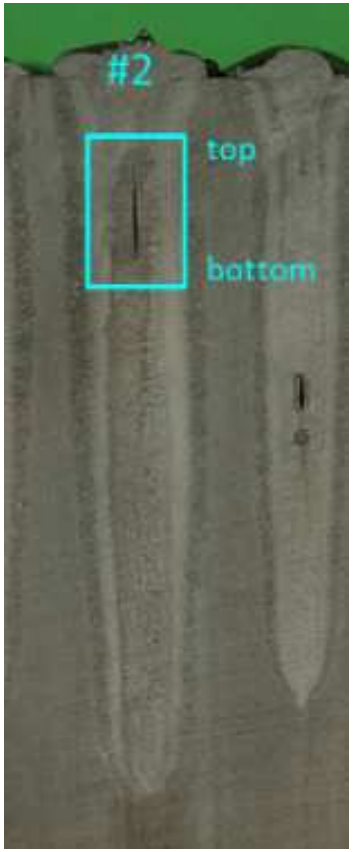
- Experimental-block
  - 4 Welds
  - Equal parameters
- 1 “reference” weld
  - Parameters correct?
- 3 “blocked” welds
  - Simulate blind welding study



Investigation methods

- Crack opening
  - cracks were cut out
  - frozen in liquid nitrogen
  - broken apart
- Macroscopic Investigation
- SEM investigation





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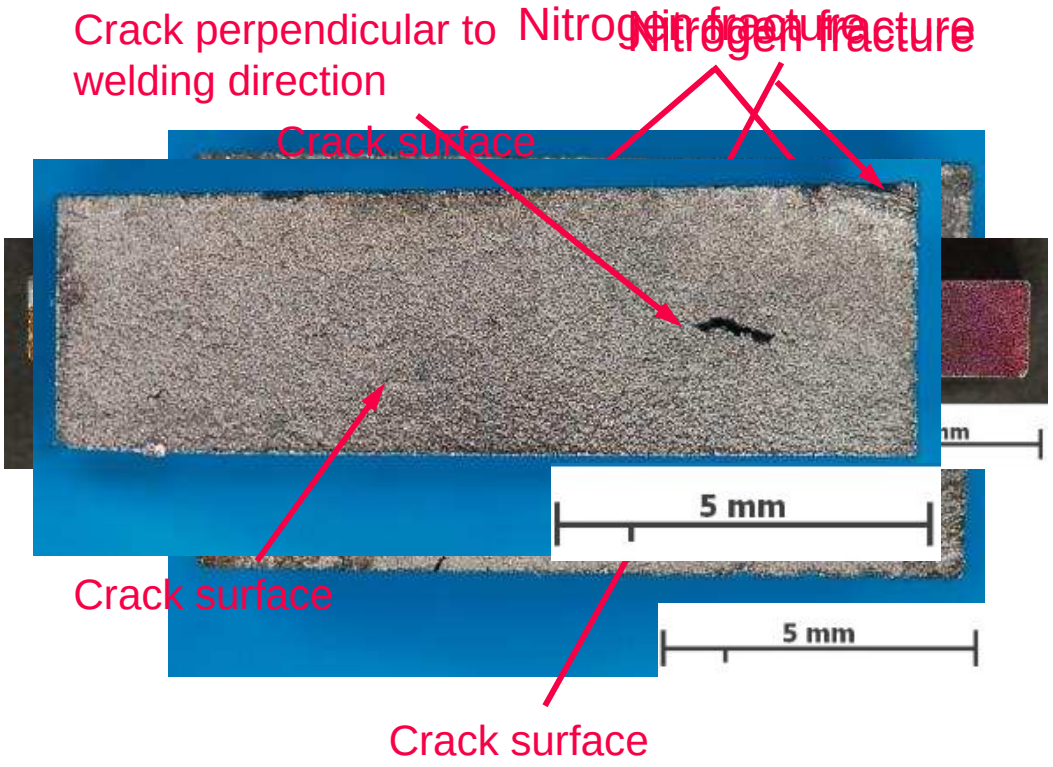
Macroscopic Investigation

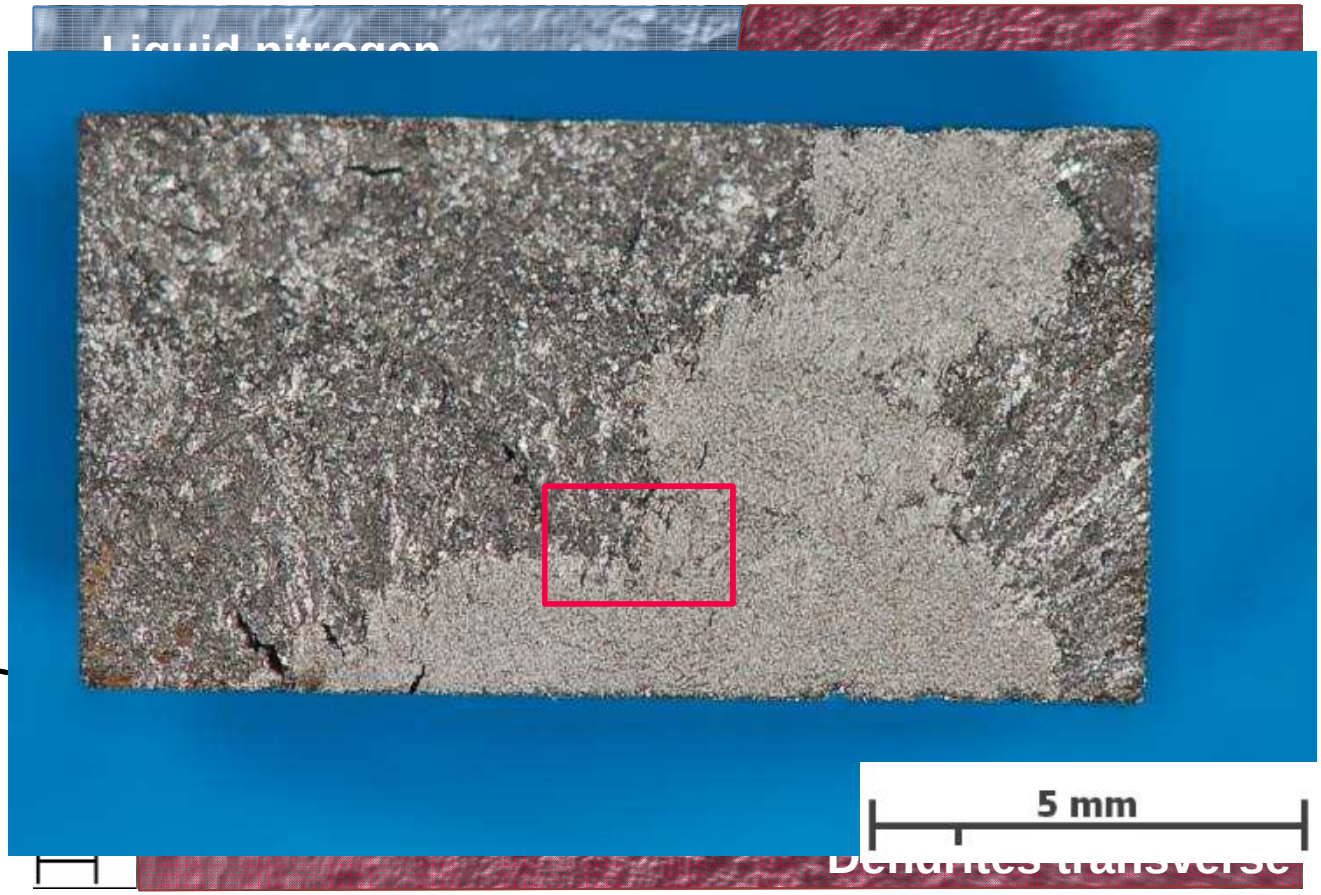
- All surfaces examined
- Crack surface and surface of the liquid nitrogen fracture is distinguishable
- Annealing colours in one crack
  - Crack occured direktly after welding
- Cracks perpendicular to crack surface



SEM Investigation

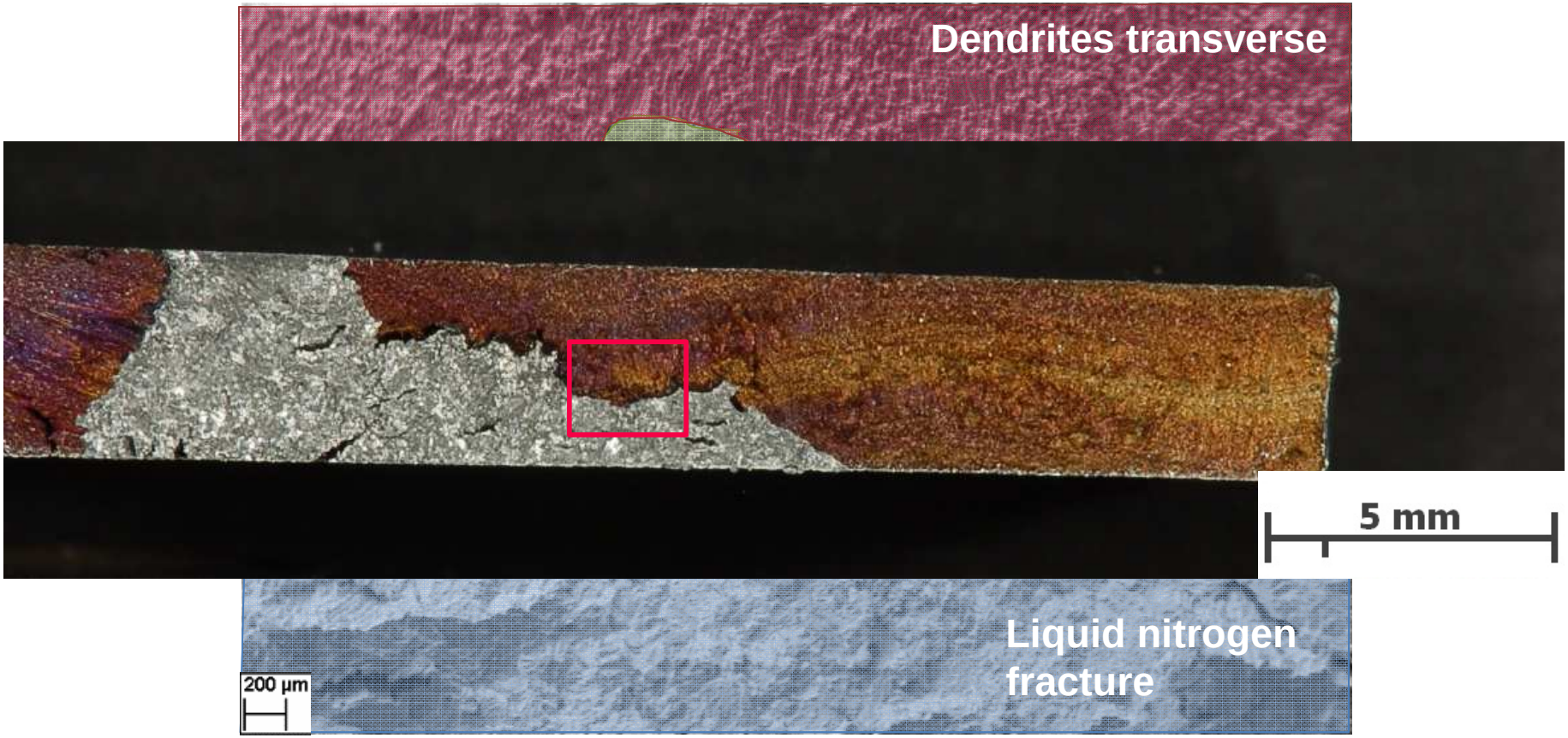
- Crack surfaces were examined comprehensively
- 3 different surface structures were recorded
  - **Dendrites transverse** to growing direction
  - **Dendrites longitudinal**
  - Residual crack surface of the **liquid nitrogen fracture**
- Results correspond for all examined materials and specimen

SEM Investigation



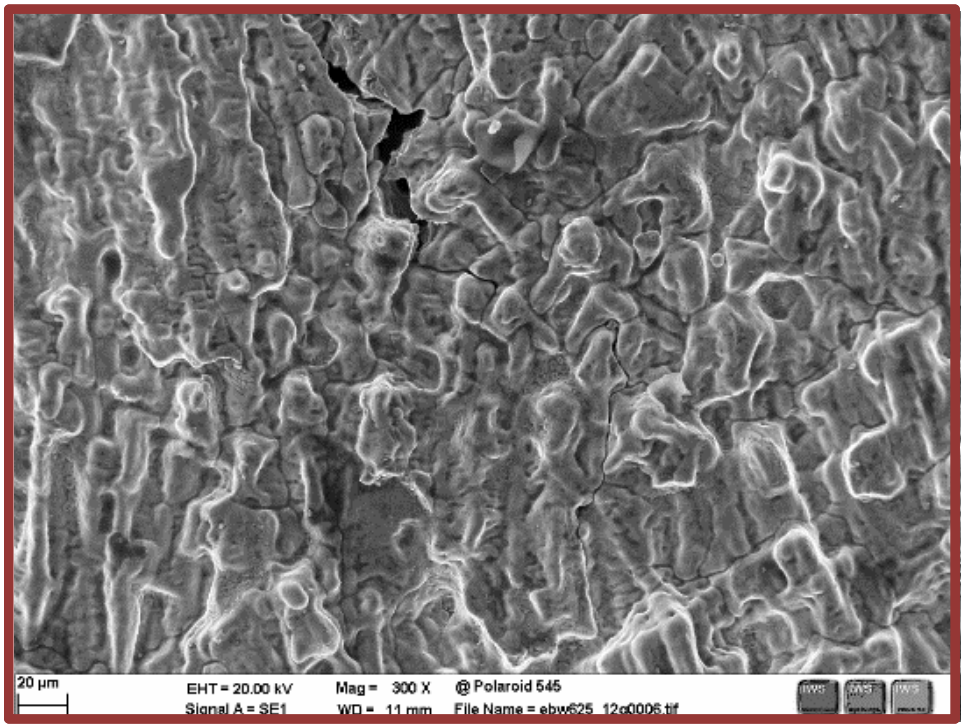
Dendrites longitudinal

SEM Investigation

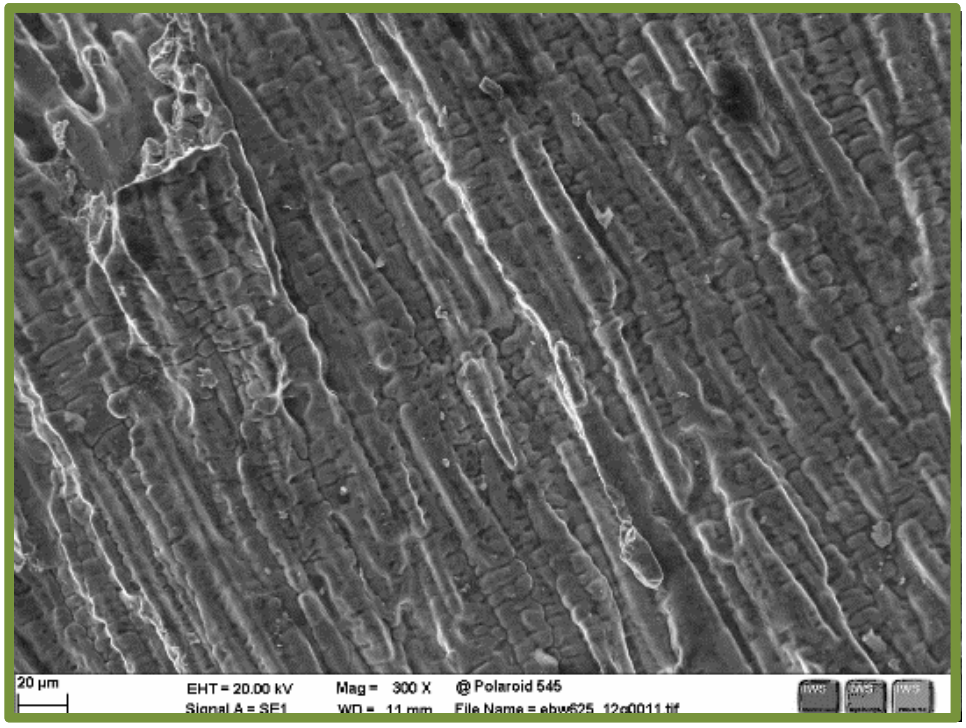


SEM Investigation

Dendrites transverse

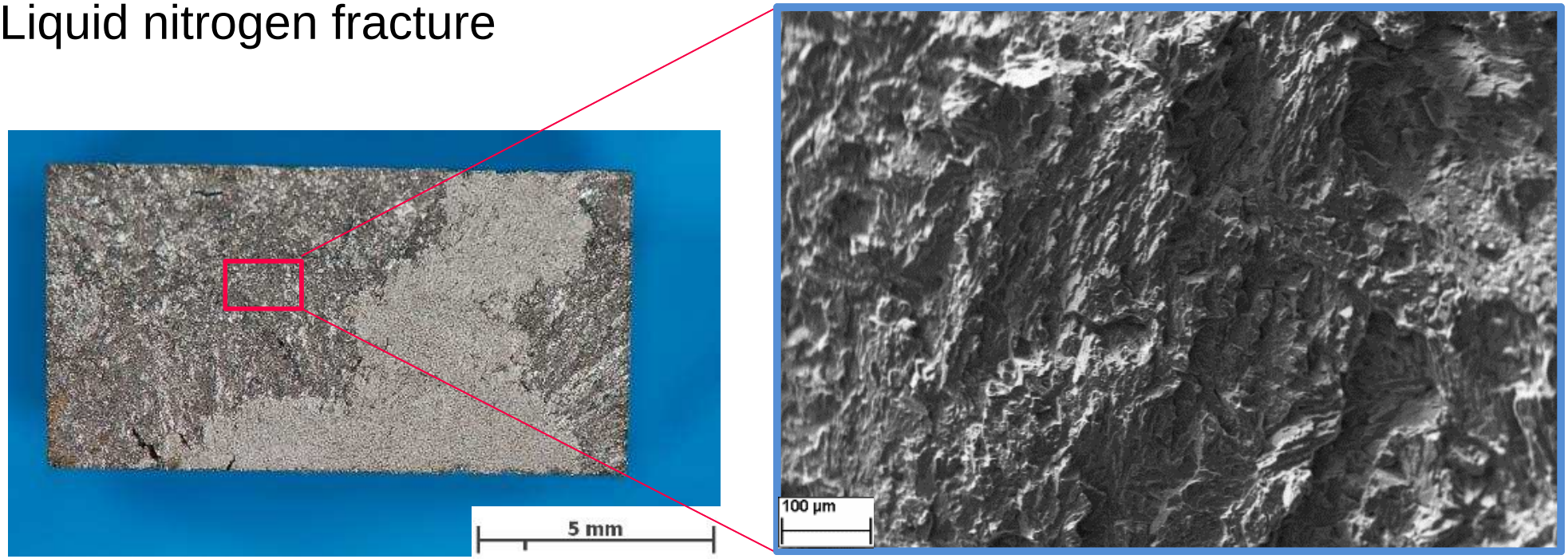


Dendrites longitudinal



SEM Investigation

Liquid nitrogen fracture



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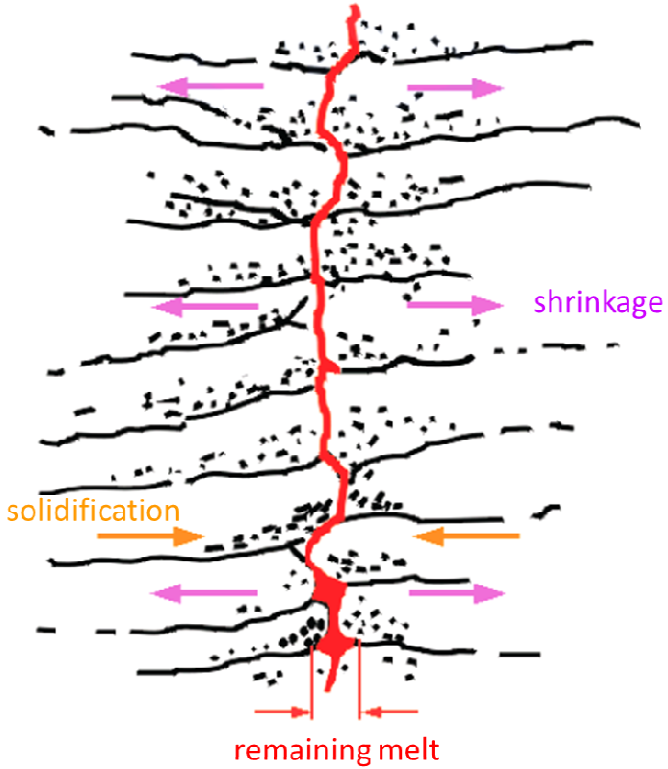
Cracking mechanism

- Cracks are seam cantered
- Cracks show a dendritic surface
- Annealing colours
  - **Solidification cracks ***



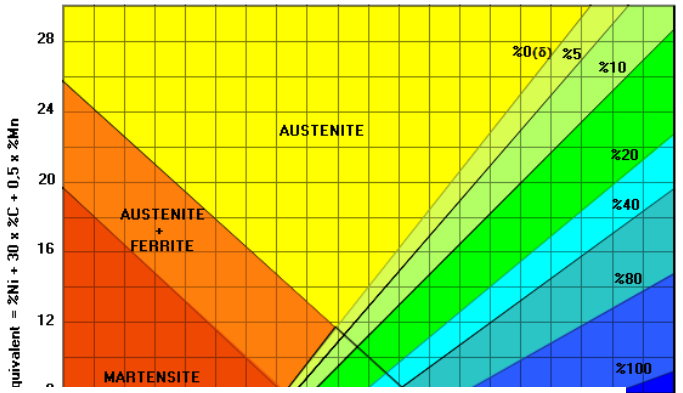
Picture: Gesellschaft für Schweißtechnik, “Theoretische Ausbildung, Lehrplan und Lernziele SFI / IWE,” in *Internationaler Schweißfachingenieurlehrgang*, GSI, Ed. Düsseldorf: DVS-Verlag GmbH, 2009.

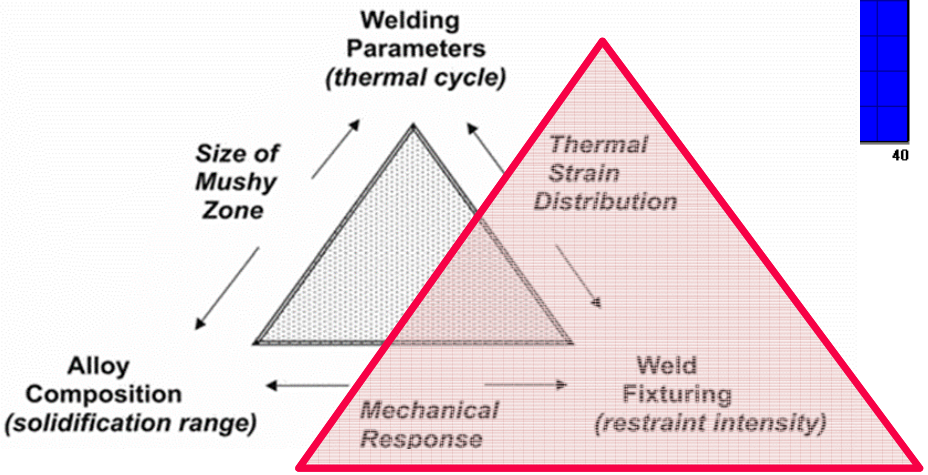
* **J. Wang and F. Lu**, “INVESTIGATION ON HOT CRACKING PROPAGATION IN FIBER LASER WELDING ON6013 ALUMINUM ALLOY,” in *IIW C-IV Annual Assembly*, pp. 1–15.
TWI, “Defects - solidification cracking,” 1999. [Online]. Available: http://www.twi-global.com/technicalknowledge/job-knowledge/defects-solidification-cracking-044/. [Accessed: 10-Mar-2014].
J. F. Wallace, “Effects of sulphur and phosphorus on weld metal solidification cracking,” *Met. Constr. Br. Weld. J.*, vol. 2, no. 8, pp. 333–338, 1970.
D. J. Grieve, “Welding Defects,” 2003. [Online]. Available: http://www.tech.plym.ac.uk/sme/strc201/wdefects.htm. [Accessed: 10-Mar-2014].
P. Schaumann and M. Collmann, “Influence of Weld Defects on the Fatigue Resistance of Thick Steel Plates,” *Procedia Eng.*, vol. 66, pp. 62–72, 2013.

Cracking mechanism

- Materials which are **not** prone to solidification cracks
- **No** cracks in single performed welds

➢ Residual stresses *





* **C. Liu, J. Zhang, B. Wu, and S. Gong,** "Numerical investigation on the variation of welding stresses after material removal from a thick titanium alloy plate joined by electron beam welding," *Mater. Des.*, vol. 34, pp. 609–617, Feb. 2012.
P**. Lacki, K. Adamus, and P. Wieczorek**, "Theoretical and experimental analysis of thermo-mechanical phenomena during electron beam welding process," *Comput. Mater. Sci.*, pp. 1–10, Feb. 2014.
P. Venkata Ramana, G. Madhusudhan Reddy, T. Mohandas, and a. V. S. S. K. S. Gupta, "Microstructure and residual stress distribution of similar and dissimilar electron beam welds – Maraging steel to medium alloy medium carbon steel," *Mater. Des.*, vol. 31, no. 2, pp. 749–760, Feb. 2010

Temperature Measurement

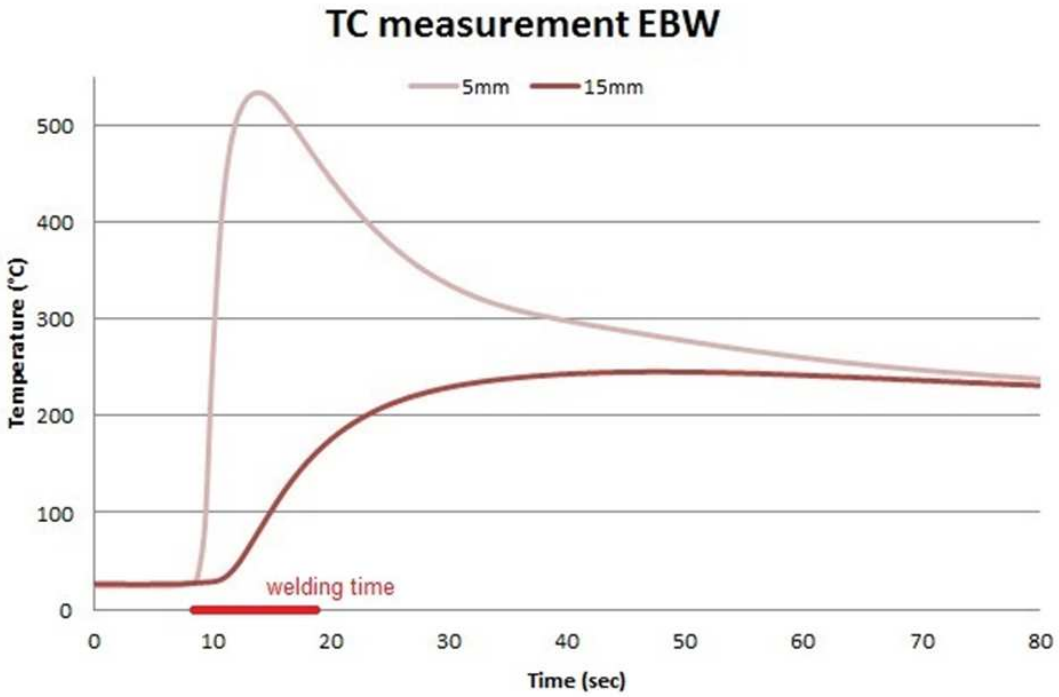
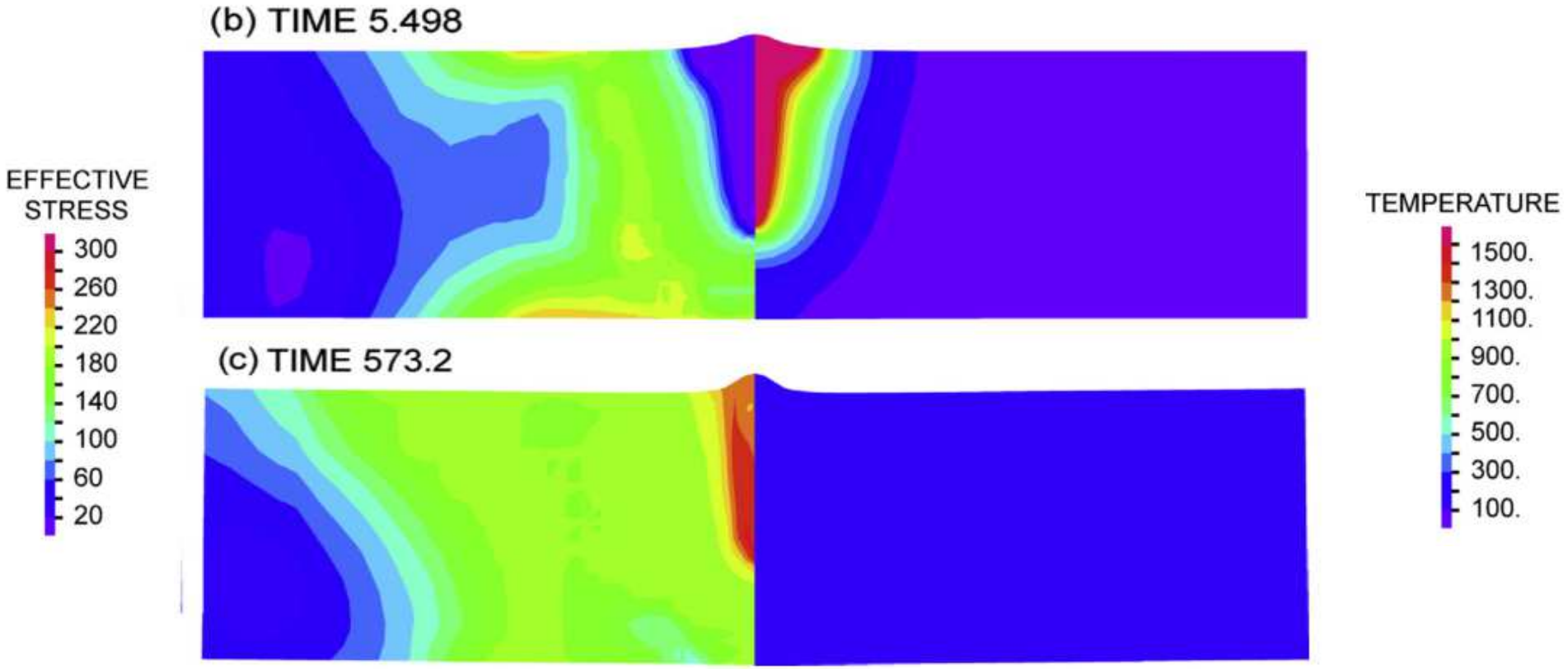


Figure 24: Thermocouple measurements for a 55mm deep EB seam (current 180mA, speed 10mm/s); seam width 3mm; TC on top surface

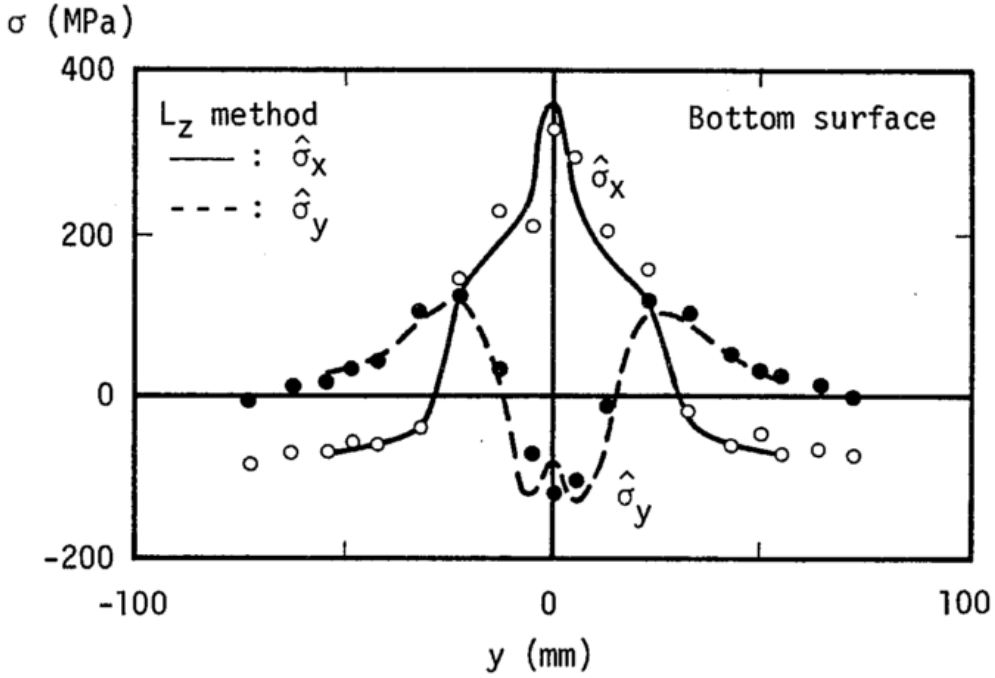
Residual stress vs. temperature distribution (12mm weld, St)

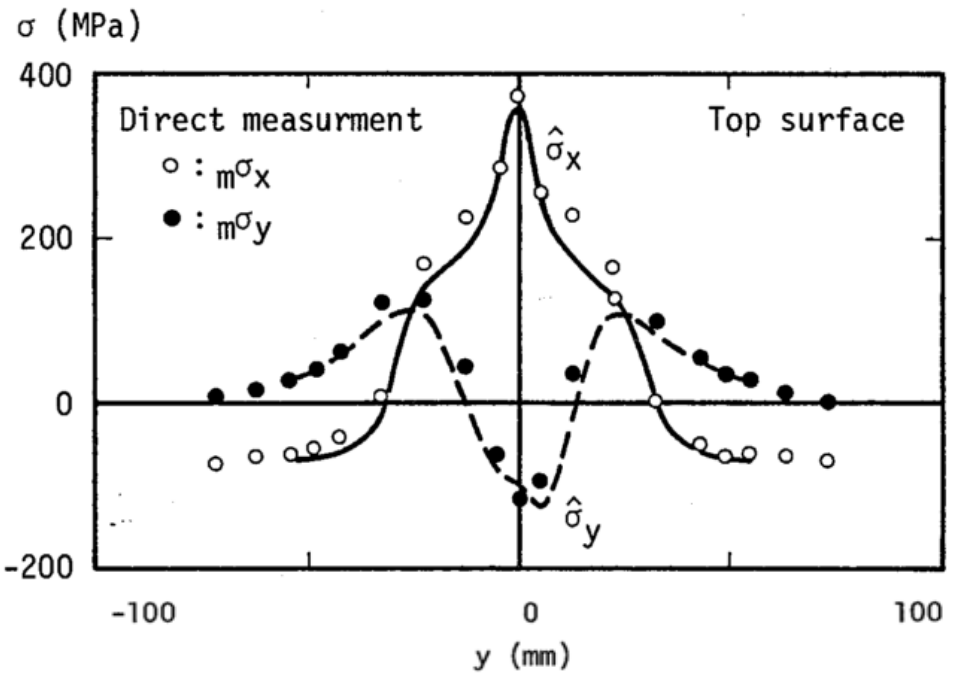
P. Lacki, K. Adamus, and P. Wieczorek, “Theoretical and experimental analysis of thermo-mechanical phenomena during electron beam welding process,” *Comput. Mater. Sci.*, pp. 1–10, Feb. 2014.



Welding residual stress measurements (49mm weld, St)

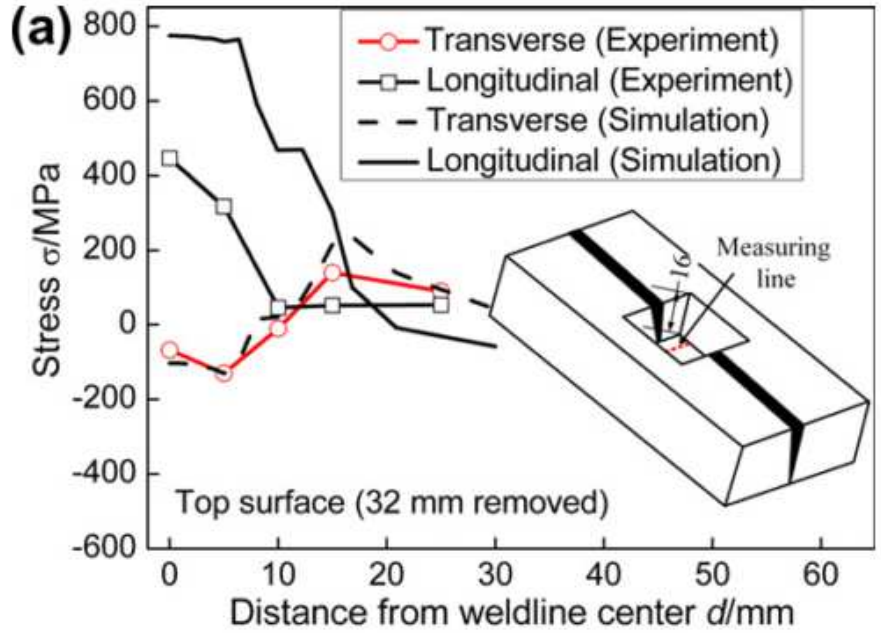
Y. Ueda, Y. C. Kim, and A. Umekuni, “Measurement of three-dimensional welding residual stresses due to electron beam welding.,” *Q. J. Japan Weld. Soc.*, vol. 4, no. 1, pp. 138–142, 1986.

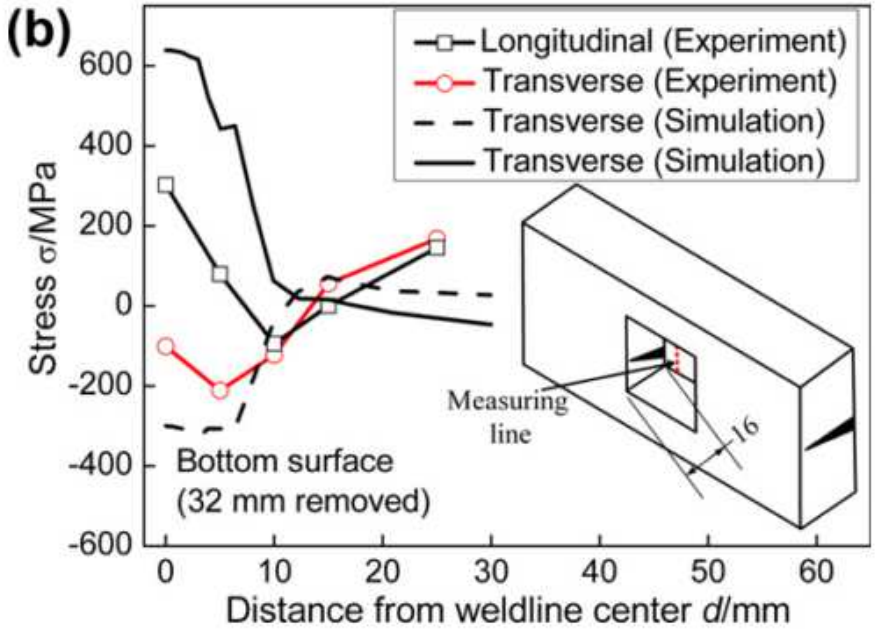




Welding residual stress measurements (50mm weld, Ti)

C. Liu, J. Zhang, B. Wu, and S. Gong, “Numerical investigation on the variation of welding stresses after material removal from a thick titanium alloy plate joined by electron beam welding,” Mater. Des., vol. 34, pp. 609–617, Feb. 2012.





Recommendations to avoid misleading results in EBW parameter studies of for a thick walled component

- Limit the number of welds in one block
  - Stress distribution in EBW is much wider than the visible heat affected zone
- Same initial situation for all welds important
  - Residual stresses
- Residual stress evaluation is recommended where stress zones of welds interact

Considerations for sound parameter studies in electron beam welding of thick walled components

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SEM Investigation

Crack perpendicular to welding direction