Investigation of the directional characteristics of the emitted airborne sound by Friction Stir Welding for online process monitoring

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Introduction

- FSW (Friction Stir Welding) is a solid-state technology mainly used for joining of aluminum alloys

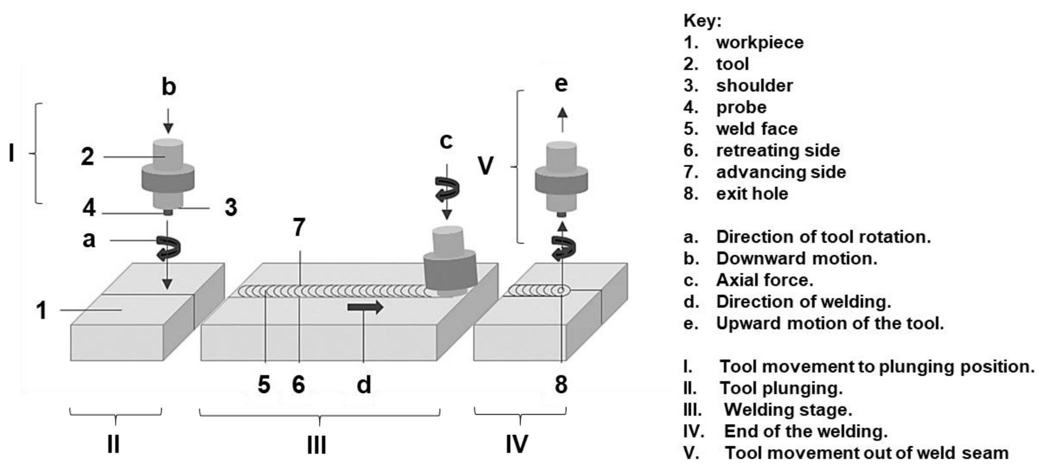

Figure 1 : FSW operation principle and process stages

Aim: detect weld seam irregularities during the welding process by using signals from the joining process or the welding setup (e.g. mechanical loads, forces, torque, spindle motor current Temperature, vibrations as well as audio signals)

New approach: analyzing airborne sound in the audible range for FSW process monitoring

Pre-study

1) evaluation of the correct mounting position of a suitable microphone
2) investigation, whether airborne sound signal can depict varying FSW process stages
3) usage of audio signals for detection of weld seam irregularities

Experimental Design

- robotized force-controlled FSW setup from Grenzebach Maschinenbau GmbH using a KUKA KR500 heavy duty robot (axial force of up to 10 kN, maximum rotational speed of up to 14000 1/min)

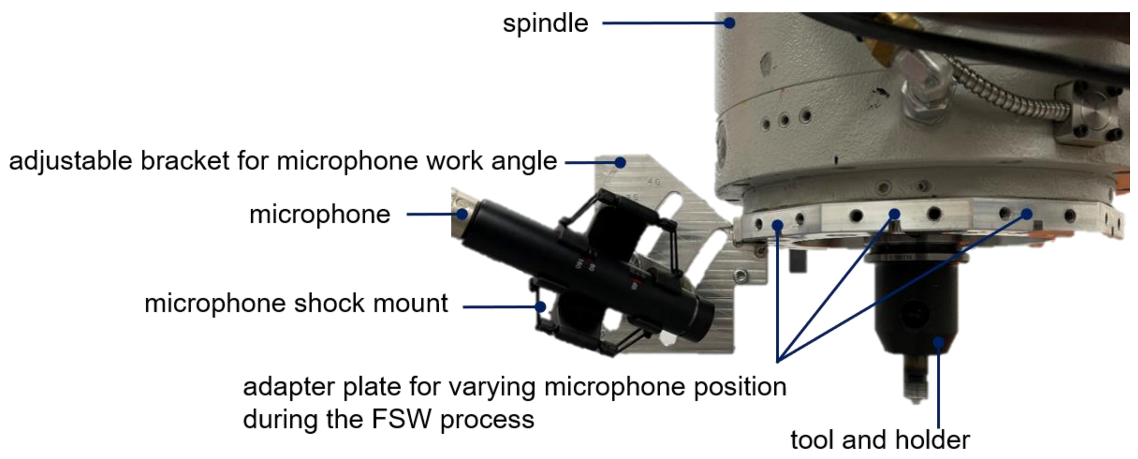

Figure 2: Measurement setup for the recording of the emitted airborne sound

- spindle of the robot is equipped with a condenser microphone (frequency range from 20 to 20.000 Hz similar to the human hearing range)
- attempt with microphone sE 8 (cardioid characteristics, (see Figure 2)
- microphone is mounted to the robot via elastic microphone shock mounts to protect it from vibrations and thus avoid distortion of the signals (see Figure 2)
- microphone and mount are attached to the spindle via adapter plate, which provides ten different micro-phone positions (in 36° steps) (see Figure 3a)
- distance between the microphone and the tool center point remained constant at 150 mm

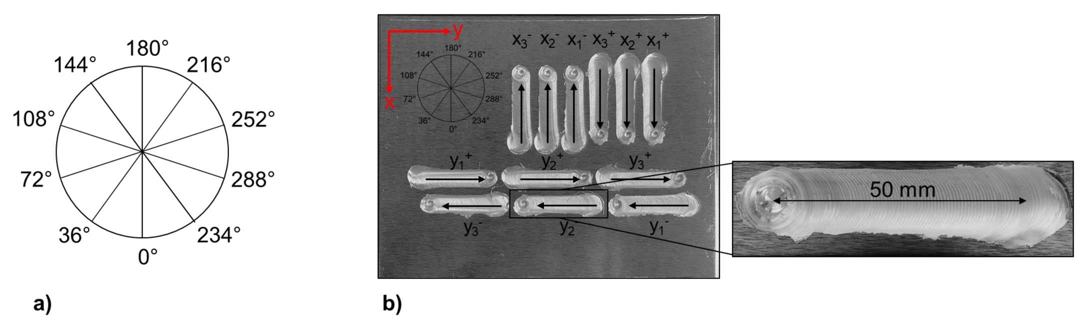

Figure 3: a) varying rotation angles compared to the welding direction and b) FSW weld seams joined in ± *x* and ± *y* direction with an enlarged section of a weld seam

Experiment implementation

- positioning of the microphone could be crucial for picking up audio signal
- directional characteristics of the process are assessed at various points in order to obtain those positions at which the strongest sound signal is emitted
- 50 mm long weld seams were recorded acoustically (three for each direction in +*x*, – x, +*y*, and –*y* see Figure 3b)

Results and discussion

1) Analysis of the directionality of the FSW process by using polar plots

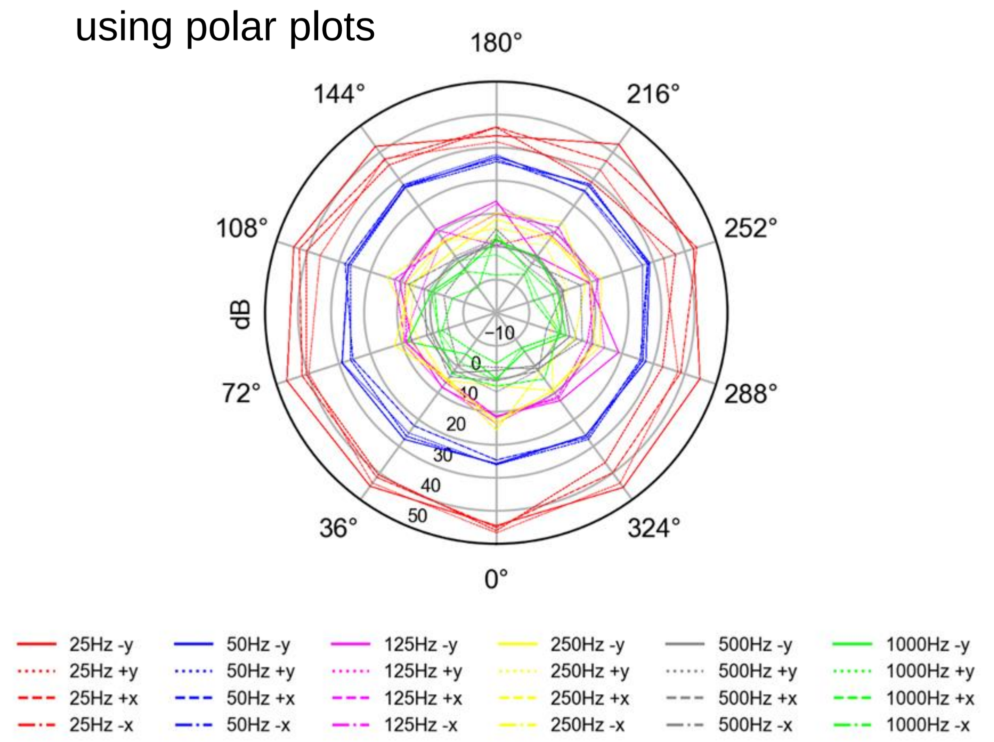

Figure 4: Comparative polar plot of selected frequencies as function of all directions

- relevant frequency levels are equally attenuated in all directions
- no significant differences between the process directions [+*x*, – x, +*y*, and –*y* recognized]
- directionality of the FSW process has no direct preferred direction

2) Comparison of process forces and audio signal

- changes in the force signal are predominantly also visible in the audio signal (see Figure 5a-c)

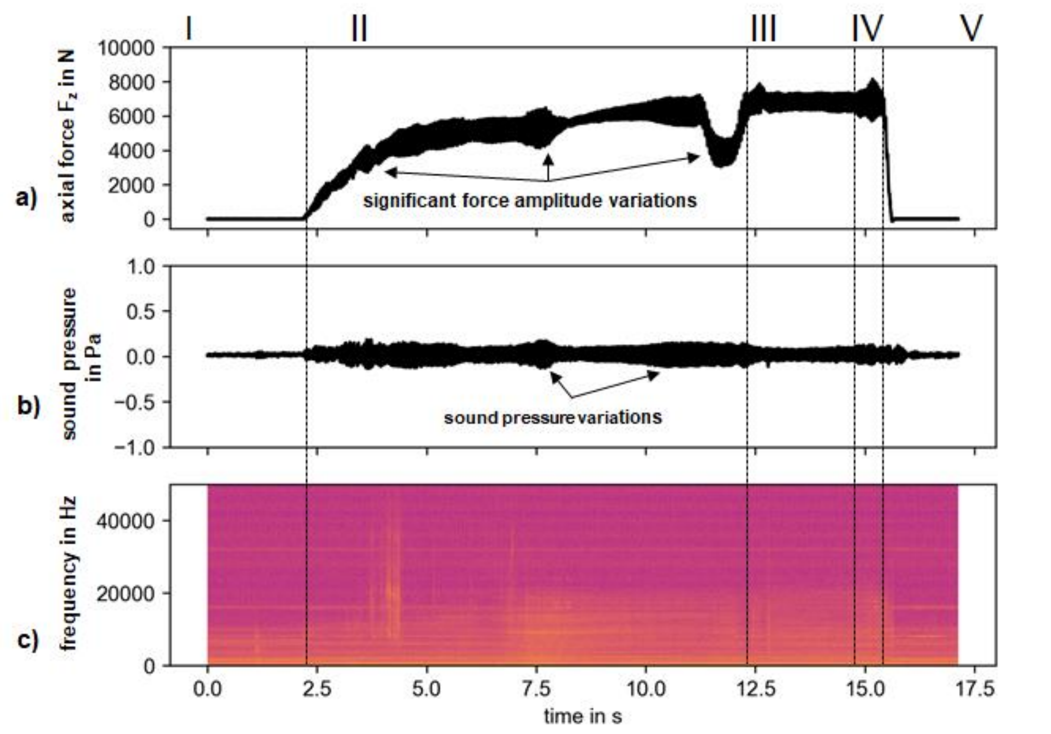

Figure 5: a) Axial force F_z, b) sound pressure, and c) spectrogram of the acoustic signal as a function of time and process stages I-V

3) Analysis of weld seam irregularities by using audio signals

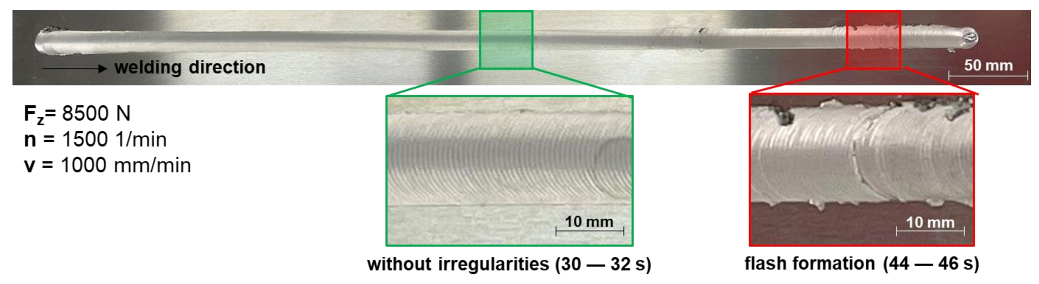

Figure 6: Varying surface quality at the center and end of the weld seam

- Weld seam irregularities-free and flash formation detectable

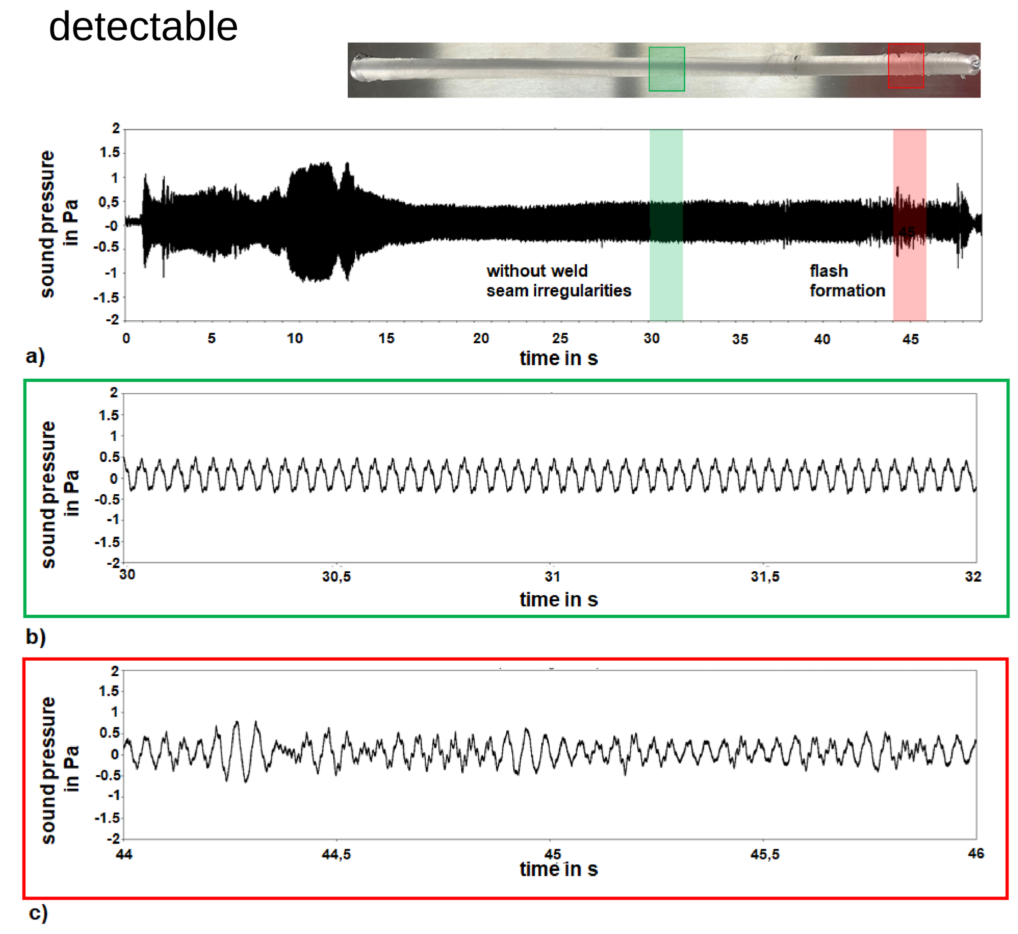

Figure 7: a) FSW weld seam and sound pressure b) without weld seam irregularities, and c) during flash formation

- areas without weld seam irregularities show an almost stable sound pressure signal
- area with flash formation exhibits unstable audio signal with sound pressure variations

Conclusion

- free mounting positions of the airborne sound microphone during the FSW process could be proven
- relevant FSW process stages are detectable in the airborne sound signal
- general applicability of airborne sound signals for detecting weld seam irregularities was investigated

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