Fundamental Investigation of the Applicability of Acoustic Emission and Vibration Analysis in Ultrasonic Metal Welding Processes

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Introduction

Ultrasonic Metal welding (USMW) is particularly suitable for connecting electro-technical components and joining dissimilar metals. Despite industrial spread, unexplainable process fluctuations may occur in USMW.

The aim of this research is the fundamental investigation of the applicability of acoustic emission analysis for process analysis in USMW: to derive measurable monitoring criteria for the application, to make the process more manageable, and in the future to open up new possibilities for online process control.

Description of the process

USMW works by pressing two workpieces against each other and vibrating them against each other at ultrasonic frequencies. In our case, the workpieces are metal sheets. First, the horn moves down and applies pressure vertically against two sheets of metal resting in top of each other. The lower sheet is resting on the anvil, and the upper sheet is placed on the lower sheet. The pressure applied is usually not enough to cause plastic deformation of the material. Then, the horn starts to vibrate in the horizontal direction at 20 kHz, creating the weld. Finally, once the welding process is finished, the horn moves up again [1]. This is shown in figure 1.

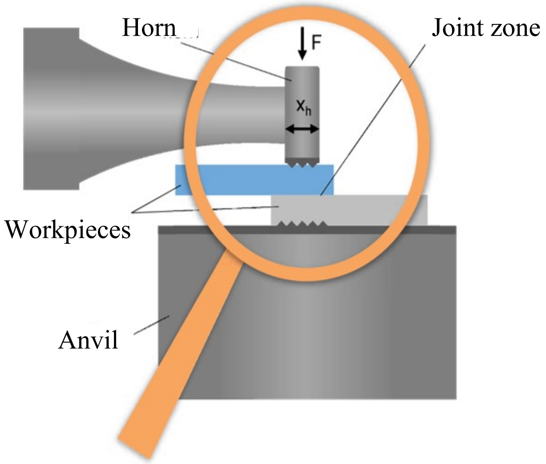

Figure 1: USMW works by pressing two workpieces against each other vertically and vibrating them against each other horizontally at 20 kHz.

In the literature, the interaction between the two plates during the welding process is often decomposed into stages based on the different physical phenomena that occur at that time and the behaviour of the workpieces. It is generally agreed that the welding is a plastic deformation process happening in solid state and that a cleaning phase occurs in the beginning of the process, during which the oxidized surface layers of the metal sheets are removed, and after which the actual welding takes place [1][2][3][4].

Figure 2 shows a simplified summary of the possible process phases. First, the physical contact phase occurs. During this phase, some elastic and plastic deformation of the surface peaks occurs, and the speed of the upper workpiece increases to match that of the horn [2]. Then, in the second stage, the oxidised surfaces of the sheets are removed. The repetitive friction induces an increase of the temperature, leading to a decrease in the yield strength of the workpieces. In the third stage, due to the decrease in yield strength, plastic deformation can occur, and microwelds start to form between the surface peaks of the specimen. The vibratory speed of the lower workpiece starts to increase. The fourth stage is characterized by an increase in the number of microwelds. The upper and lower workpieces vibrate at almost the same speed. The fifth stage is called overwelding. In this stage, due to fatigue failure, microwelds start to fracture [1][2][3][4].

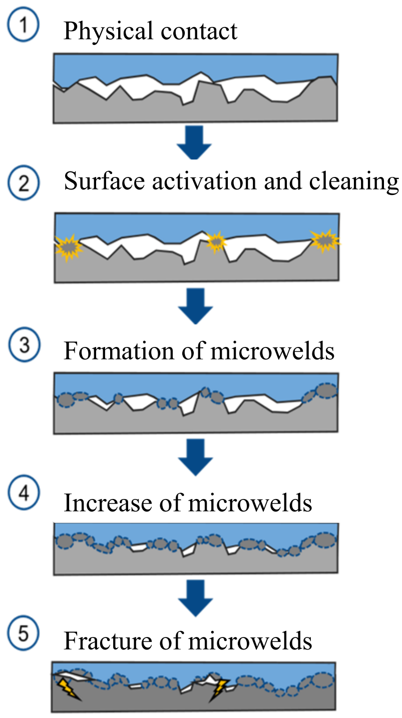

Figure 2: Suggested phases of the USMW process

Experimental apparatus

In each stage, the bond between the workpieces is different. This should lead to changes in the vibrations of the anvil and horn throughout the process, as well as the airborne sound. By measuring the vibrations of the horn and anvil and the airborne sound during the welding process, we hope to identify the different phases of USMW.

To do that, multiple welds were done and compared to the airborne sound and horn vibrations of the "free run" case.

The free run case consists of the horn vibrating freely above the anvil without any physical contact. Two Polytec CLV-2534 Compact Laser Vibrometers were used to measure the vibration velocities of the horn and anvil along the direction of welding. To measure the airborne sound, a ¼' GRAS microphone was placed at 50 cm distance and directed towards the joining area. Figure 3 and 4 show the experimental setup. The experiments were done on CW008A copper sheets of dimensions 0.8x45x125 mm^3. The sampling rate was 225 kHz. The welding area was 8x8 mm^2.

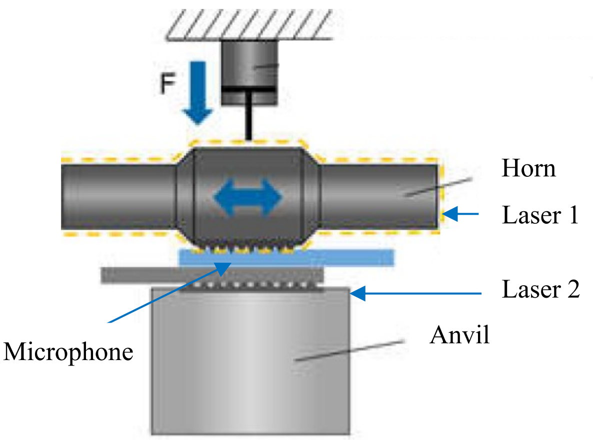

Figure 3: The experimental setup: two laser vibrometers and a microphone recorded the vibrations of the horn and anvil and the airborne sound.

Preliminary results

Figures 4 and 5 show that the airborne sound and the energy of the vibrations of the anvil and horn during welding and during a free run is centered on the welding frequency of 20 kHz and its harmonics. While the energy during the free run is almost entirely at the 1st harmonic, it is more evenly distributed along the harmonics during welding. There are also different tonal components in the airborne sound.

Figures 6 and 7 show the variation of the airborne pressure of the different harmonics in time.

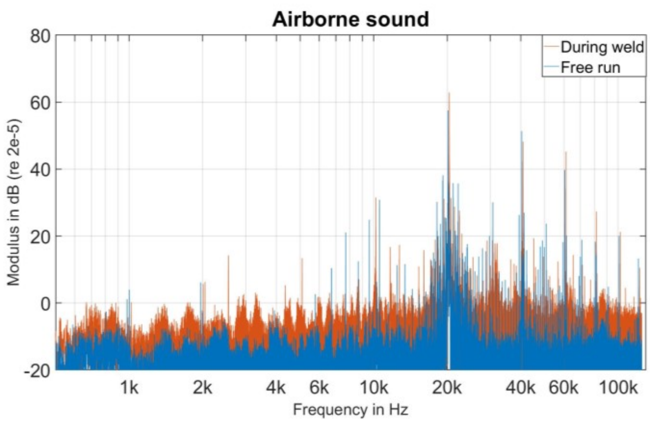

Figure 4: Airborne sound frequency plot of free run and during welding

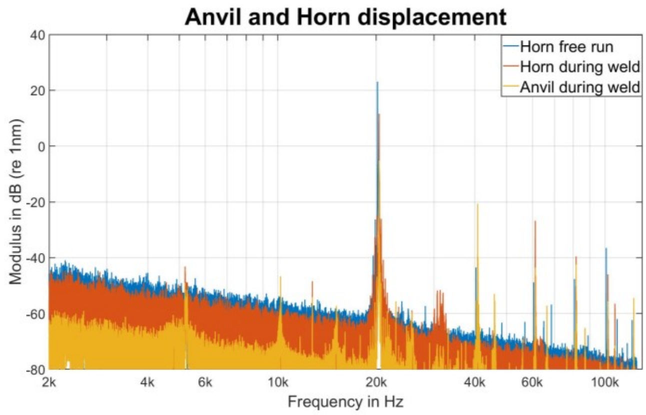

Figure 5: Frequency plot of displacement of anvil and horn during welding and free run

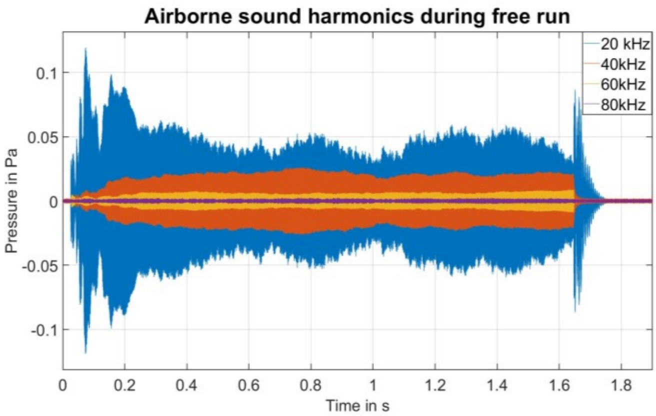

Figure 6: Amplitude of airborne sound during free run for the first four harmonics

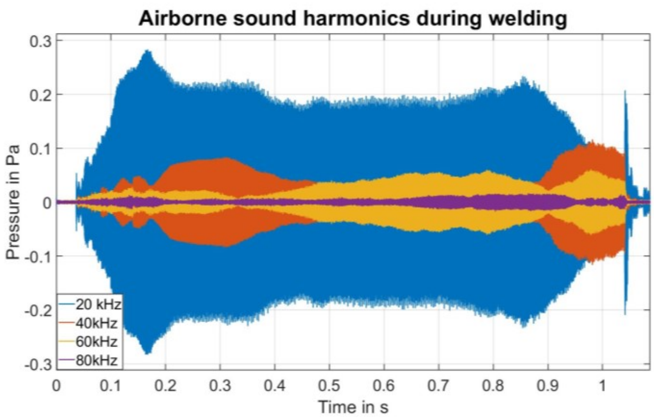

Figure 7: Amplitude of airborne sound during welding for the first four harmonics

Discussion

The energy of the vibrations and airborne sound is concentrated around the harmonics of the welding frequency, namely 20 kHz, 40 kHz, 60 kHz and 80 kHz. Looking more closely into the evolution of the energy in those harmonics, it would seems that stages of increase and decrease of the energy happen in time. It may be possible to use those changes to identify the different stages of welding.

Conclusion

For this paper, we have tried to find whether vibration measurements and pressure measurements could be used to characterize an USMW process into different stages. The preliminary results show that it might be possible. More work is required to process the data before coming to a conclusion.

Literature

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