D. Acoustic Monitoring of Inertia Friction Welded Austenitic Stainless Steels: Initial Studies

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Introduction

Austenitic stainless steels (γ-SSs) are widely used in chemical processing and petroleum refining applications due to their corrosion resistance in many environments. Inertia friction welding (IFW) is a solid-state joining process that can be used for welding a wide variety of components and does generally work well for stainless steel alloys. Most production environments rely upon a post-process, bookend inspection approach to monitoring quality in IFW. This process provides a reliable and quantitative assessment of the test weld but imparts very little information about the lot as a whole or any specific weld in particular. Furthermore, monitoring the machine parameters through machine diagnostics (i.e., fault detection) can indicate when maintenance is required but may not unambiguously identify weld fault conditions of potential interest. Ultimately, no reliable method for detecting quality in-situ during IFW exists in a production environment, and despite the relatively high reliability of IFW, the possibility of defects for the most critical applications is of concern.

In Ref. 1, Wang, et al. demonstrated the feasibility of using a contact-based, acoustic emission (AE) sensor as an in-process quality metric for IFW of ferrous metals. In particular, the authors were able to correlate the on-cooling AE counts to joint strength for plain-carbon and low-alloy steels as well as an austenitic stainless steel for bar-to-bar and tube-to-tube welds. Hartman, et al. (Ref. 2) investigated the use of a non-contact, audio-based, acoustic sensor for monitoring bond integrity during IFW of copper to stainless. By analyzing the resonant frequency component of the audio signal, the authors were able to classify weld quality into three categories (acceptable, conditional, and unacceptable) according to the percent of metallurgical integrity of the bonded interface.

The goal of this work was to investigate the feasibility of acoustic monitoring for inertia friction welding of three austenitic stainless steels. Process results and a discussion of microstructural evolution for the same sets of welds are outlined in a companion presentation.

Technical Approach

Three stainless steels were chosen for this study: 310, 304 and 255. The 310 and 304 alloys are considered to be austenitic stainless steels, while the 255 alloy is a duplex (~50% austenite and 50% ferrite) alloy. Five inertia friction welds were produced on 1” OD tube samples (1/8” wall thickness) of each alloy using an MTI model 90B machine. All welds used the same initial energy of approximately 15.3 kJ. Welds were made at three levels of forge pressure and three combinations of I (moment of inertia) and RPM to give the same initial energy.

A non-contact, audio-based, free-field microphone (Brüel & Kjær type 4939) was mounted several inches away from the weld zone and recorded the acoustic energy (in the form of sound pressure) that emanates from the friction welding process. The audio data was sampled at 50kHz to account for potential signal content above a human's nominal audible sound sensitivity. High-speed video was also collected synchronously with the audio data in an attempt to correlate the audio data with the physical mechanisms of the IFW process.

Results and Discussion

The three alloys exhibited distinct acoustic signatures versus time. Examples of representative signatures are shown in Figures 1 to 3. The 255 alloy signatures showed an initial small acoustic burst at the start of the weld only. For the 304 alloy, acoustic bursts were found at the start and finish of the welds with a quiet period in between. Acoustic signals continued throughout the 310 welds with higher amplitude spikes at the start and finish. For all of the alloys, the amplitude and duration of the bursts and quiet periods varied with changes in welding parameters. For example, the amplitude and duration of the bursts increased with increasing pressure. The majority of the frequency content is beyond the audible region in the 20 - 25 kHz range.

IFWs are characterized by a three-stage torque curve with a rapid rise in torque to the first torque peak and a drop to the flatter steady-state region followed by a gradual transition to a second torque peak. The initial bursts in the 255 and 304 welds have a very close temporal correlation with the first stage of the torque curve. The quiet time for the 304 welds corresponds closely with the steady-state second stage of the torque curve. The second burst for the 304 welds occurs during the rise in torque of the third stage before the second torque peak. However, the second burst ends before the second torque peak is reached.

The three alloys studied here are similar in composition and microstructure. They differ mainly in the volume fractions of austenite and ferrite phases. The differences in acoustic signatures for welds made on the different alloys using identical welding conditions likely stem from differences in the acoustic, thermo-physical and thermo-mechanical properties between the alloys. The origins of the different acoustic signals are currently not clearly identified but may be associated with work-hardening and dislocation generation. They appear to scale with the volume fraction of austenite with the fully austenitic 310 alloy showing continuous acoustic signals and the duplex 255 alloy showing only an initial burst. Future work will be devoted to developing this method to discern the phase balance of the weld region after welding.

Conclusions

The three alloys exhibit distinct acoustic signatures versus time that varied slightly with changes in welding parameters. The bursts appear to correlate temporally with features of the torque curve. The differences in acoustic signatures for welds made on the different alloys using identical welding conditions likely stem from differences in the acoustic, thermo-physical and thermo-mechanical properties between the alloys. This technique may prove useful for determining the phase balance of the weld region after welding and predicting weld quality in-situ.

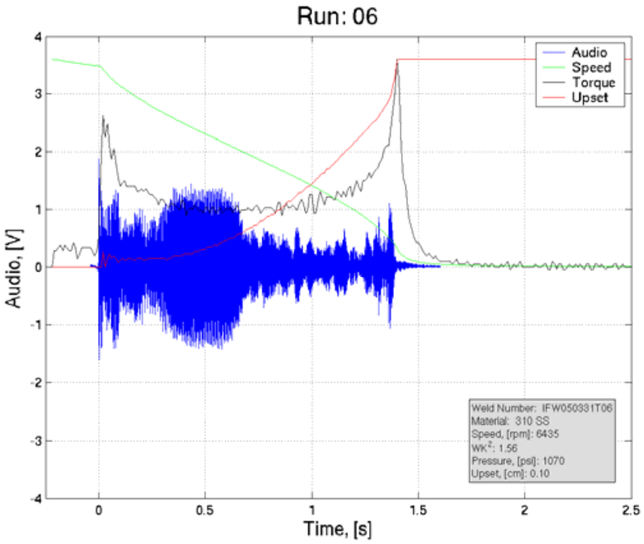

Figure 1 – Acoustic signature for the 310 alloy.

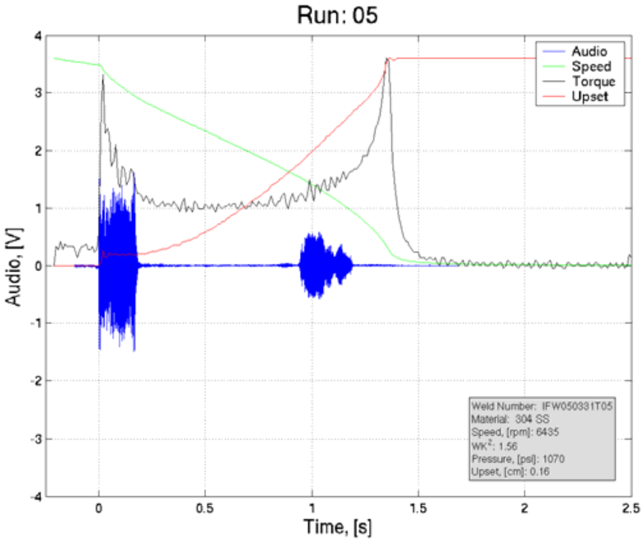

Figure 2 – Acoustic signature for the 304 alloy.

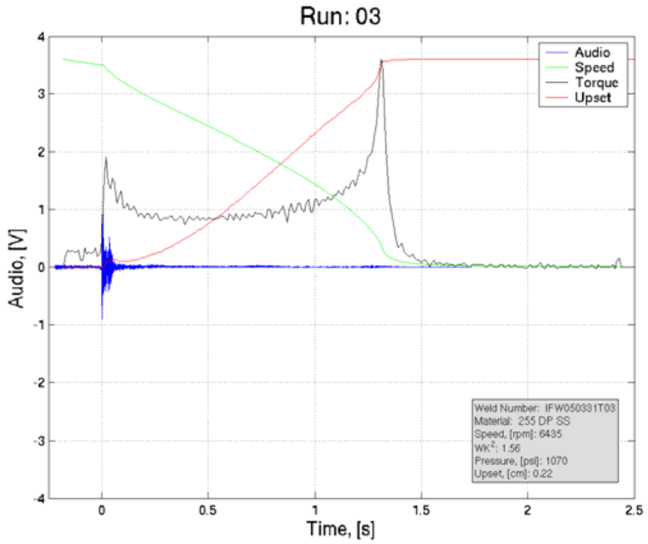

Figure 3 – Acoustic signature for the 255 alloy.

References

1. K.K. Wang, G. Reif, S. Oh: In-process quality detection of friction welds using acoustic emission techniques. Welding Journal, vol. 61, no. 9, pp. 312s-316s. 1982.
2. D.A. Hartman, M.J. Cola, V.R. Dave, N.G. Dozhier and R.W. Carpenter: Nondestructive, in-process inspection of inertia friction *welding*: an investigation into a new sensing technique. 6th International Conference: Trends in *Welding* Research; Pine Mountain, GA; USA; 15-19 Apr. 2002. pp. 948-954. 2003.