EFFECTS OF MICROSTRUCTURE AND BOND QUALITY ON THE ULTRASONIC EVALUATION OF DISSIMILAR METAL FRICTION WELDS

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INTRODUCTION

During the last several years we have been investigating ultrasonic techniques for evaluating the quality of solid state weld interfaces [1,2]. Promising results have been obtained on a variety of different solid state welds by extracting features from the ultrasonic waveforms and applying pattern recognition algorithms to separate acceptable from unacceptable welds. In general, the primary difficulty in evaluating solid state interfaces is separating the influence of microstructural variations (volumetric) from the effects of interface defects (planar). To better understand the influence of microstructure on our assessment of solid state welds, we have ultrasonically and destructively analyzed steel-to-aluminum friction welds of varying weld quality and microstructure. A matrix of samples was prepared to produce microstructural variations in the aluminum. Since the steel's microstructure was unaffected by our friction weld process, acoustic energy sent from the steel side was primarily influenced by the bondline. Thus, we could monitor the influence of the microstructure and bond quality from the aluminum side and the bondline alone from the steel side. First, ultrasonic data from the steel side of our friction welds were processed with feature extraction and pattern recognition techniques as in our previous studies to determine solid state bond quality. Then data from the aluminum side were processed the same way and the classification results were compared to the results obtained from the steel side. The discrepancies in the classification results were caused the microstructure variation in the aluminum.

SAMPLE PREPARATION

The friction welding process [3] was selected for this study because it joins dissimilar metals and the weld quality can be controlled by varying the energy of the process and/or by contaminating the interface. In this study we chose a 304L stainless steel to be joined to one of two aluminum alloys, 6063 or 1050 (99.5% pure aluminum). The steel was not heated enough by the

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friction welding to change its microstructure; whereas, the aluminum grain structure was locally changed near the bondline. Different aluminum alloys were studied to provide two levels of microstructural variation as well as manipulating the types of defects at the interface. Good welds in both cases were made with the optimal cleanliness and friction welding parameters. The poor welds were produced by deliberately overheating the joint during welding to grow the maximum possible amount of interfacial intermetallic. The amount of intermetallic was greater for the aluminum alloy specimens than for the pure aluminum welds. The final specimen shape was a right circular cylinder 2.54 cm in diameter and 2.54 cm long.

ULTRASONIC DATA ACQUISITION

Before performing data acquisition and signal processing on the friction weld samples, they were ultrasonically scanned to generate acoustic images of the steel-to-aluminum interfaces. These images formed by the reflected energy from the bondlines display gross defects in the welds, and specimens with such defects were disqualified from this study. Figure 1 is an example of the high resolution C-scan of a good and poor friction weld from both the steel side and the aluminum side. The subtle change in the reflected signal amplitude when interrogating from the aluminum side was caused in part by the variation in microstructure of the aluminum and does not necessarily indicate bond quality.

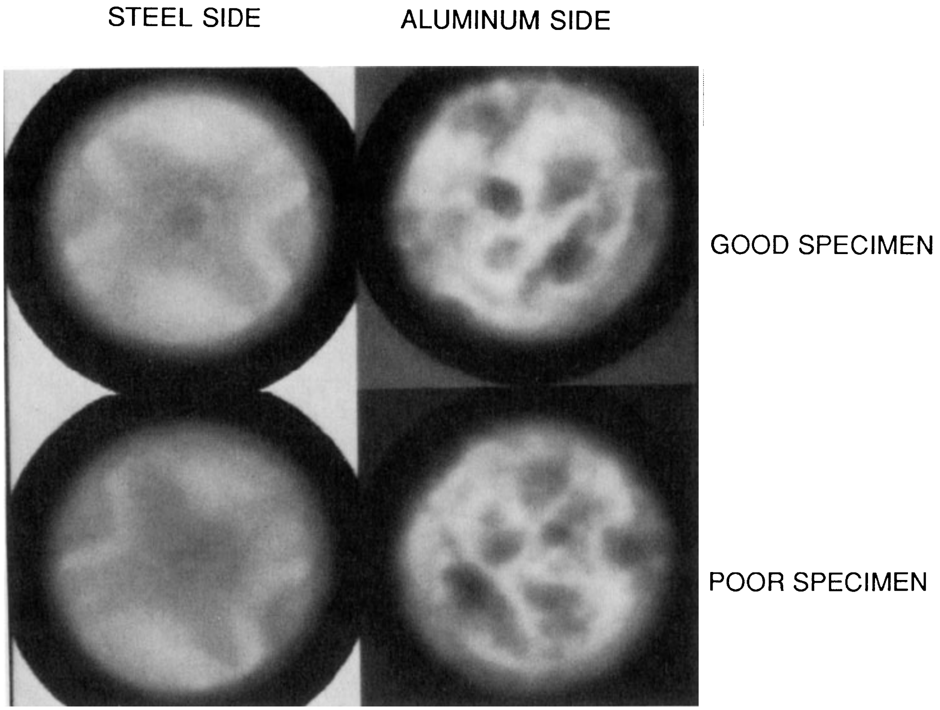

Figure 1 - High resolution C-scans of good and poor friction weld samples from both steel and aluminum sides. Patterns shown in images are caused by microstructural variations.

The next step was to acquire ultrasonic waveforms reflected from the friction weld interfaces from both the steel side and the aluminum side. A 15 MHz, broad band transducer with a usable frequency content of 5 to 25 MHz was selected for both the imaging of the bondline and the bond quality assessment. As illustrated in Figure 2, these waveforms were then processed to provide the video envelope, the frequency spectra, and the transfer functions for feature extraction. After 31 features were extracted, pattern recognition techniques were applied to sort the features; the appropriate ones were retained for developing a classification algorithm. The algorithm is finally tested to measure its ability to determine friction weld quality. This pattern recognition process is described in reference 4.

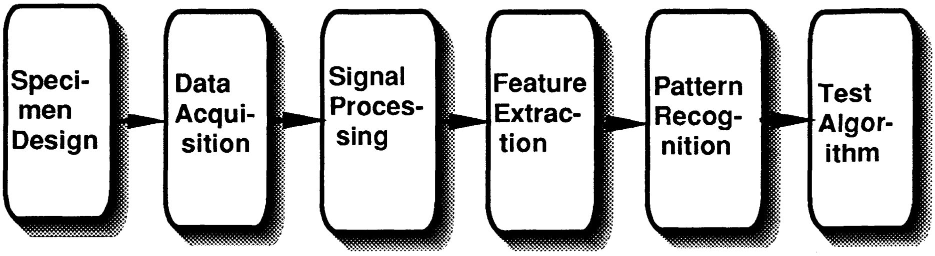

Figure 2 - Diagram of ultrasonic protocol for classifying friction welds

RESULTS

Since the goal of this study was to determine the extent base metal microstructure influences the ability to classify solid state welds, the first step was to develop a weld classifier with ultrasonic signals passing through the steel side which had the homogeneous microstructure. The results of a two space or cluster diagram type of classifier are shown in Figure 3. This figure plots the feature values for the pulse duration of the video envelope at the 60% level against the feature values for the area under the transfer function in the frequency range from 20 to 25 MHz. Note the natural clustering of the two classes. Other features might also yield natural clustering. In this optimal example the classification could be performed with the single video feature and an application of Bayes decision theory [4]. This separation of the feature vectors allows a decision boundary to be determined which would delineate the class and quality of an unknown friction weld.

By comparison, Figure 4 is the two-space diagram for the same features of the same samples but where the ultrasonic signals passed through the aluminum side. In this diagram there is no natural clustering and, thus, it is impossible to determine a decision boundary. Thus, the microstructure greatly affects the success of the classification algorithm since the only difference in the ultrasonic waveforms was caused by the microstructure of the substrate. The failure of these two features with a two-space plot as the classifier does not mean that the friction welds can not be ultrasonically classified from the aluminum side. However, such a classification process will entail more and different features and possibly a more sophisticated discriminant.

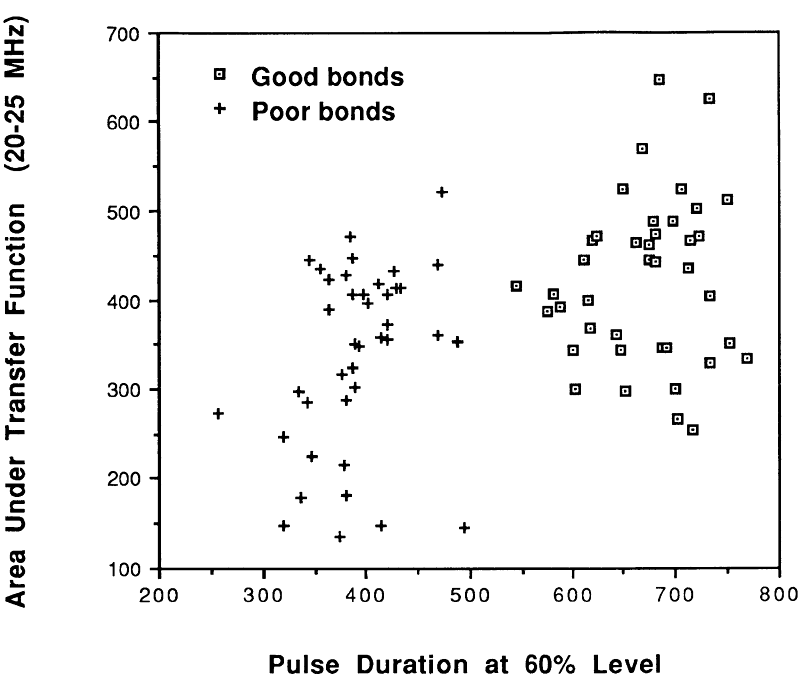

Figure 3 - Two-space diagram for ultrasonic data passing through the steel side of the specimens (natural clustering).

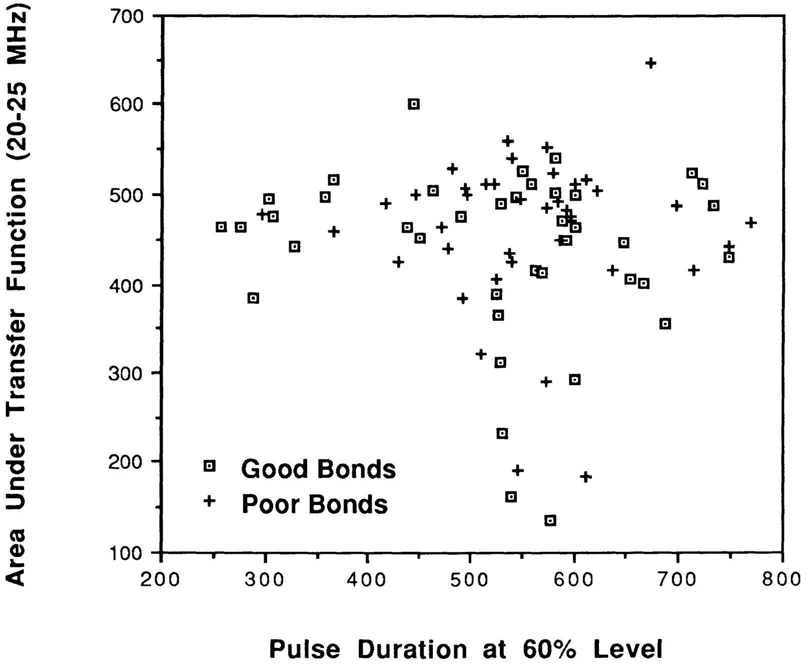

Figure 4 - Two-space diagram for ultrasonic data passing through aluminum side of specimens (no clustering).

Table 1 - Results of ultrasonically classifying friction welds with feature extraction and pattern recognition techniques.

	Results	Features	Algorithm
304L-1050	Good: 100% Poor: 100%	4, 30	Two Space Plot
1050-304L	Good: 100% Poor: 75%	4, 8, 11, 23	Fisher Linear Discriminant
304L-6063 Al	Good: 100% Poor: 100%	9, 12	Two Space Plot
6063 Al -304L	Good: 85% Poor: 70%	4, 5, 9, 12	Fisher Linear Discriminant

Feature 4:	Pulse duration at 60% level of video envelope
Feature 5:	Energy content of video envelope
Feature 8:	Skewness of video envelope
Feature 9:	Kurtosis of video envelope
Feature 11:	Center of Gravity of RF spectrum
Feature 12:	Dispersion of RF spectrum
Feature 23:	Center of gravity of analytic spectrum
Feature 30:	Area under transfer function from 20 to 25 MHz

The final step in this study was to classify the friction weld samples for both types of aluminum and from both sides. The results of this work including the features, the classification success, and the type of pattern recognition algorithm are displayed in Table 1.

Notice that ultrasonic interrogation from the steel side for both types of aluminum provided signals which could be easily processed to classify the friction weld condition. In contrast, interrogation from the aluminum side produced signals that were distorted, and extracting pertinent classification information from them was more difficult. For example, in the case of the specimens made with 1050 aluminum, four features were needed and still only 75% of the poor waveforms were correctly classified with a Fisher Linear discriminant. Likewise, the same situation existed for the 6063 aluminum samples only the results were worse, ie., only 85% of the good and 70% of the poor specimens were correctly classified.

CONCLUSIONS

The base metal microstructure has a significant influence on the ultrasonic waveform and our ability to process said signal to correlate its characteristics with the quality of the friction weld. The inhomogeneous microstructure of the aluminum in our study distorted the reflected ultrasonic signal and complicates the feature extraction and pattern recognition procedures. A successful classification procedure should involve clever data acquisition and signal processing to minimize the waveform distortion caused by variations in the microstructure.

ACKNOWLEDGMENT

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REFERENCES

1. Thomas, G. H., and Spingarn, J. R., "Ultrasonic Evaluation and Imaging of Tube Closure Welds," Proc. Review of Progress in Quantitative Nondestructive Evaluation, Vol. 6B, edited by D. O. Thompson and D. E. Chimenti, 1986.
2. Thomas, G. H., and Spingarn, J. R., "Ultrasonic Nondestructive Evaluation of Solid State Welds," Proc. Review of Progress in Quantitative Nondestructive Evaluation, Vol. 7B, edited by D. O. Thompson and D. E. Chimenti, 1987.
3. Armstrong, B. L. et al, "Ultrasonic Analysis of Inertia Welds," Proc. Review of Progress in Quantitative Nondestructive Evaluation, Vol. 5B, edited by D. O. Thompson and D. E. Chimenti, 1985.
4. Duda and Hart, Pattern Classification and Scene Analysis, John Wiley and Sons, New York, 1973.