An analysis of Ultrasonic Wire Embedding Data and Waveform Congruency to Identify Process Quality in Additive Manufacturing

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Abstract

Additive Manufacturing draws more attention due to its potential role in real-world applications. Embedding wires in plastic substrates using different additive manufacturing techniques is a new and promising idea to change the electronics industry. This project focused on processing and analyzing data collected by a multi-sensor system that was developed for the Ultrasonic Wire Embedder (USWE) as part of the additive manufacturing processes. The ultrasonic wire embedder is the primary device for performing the embed function and data acquisition is performed using an accelerometer, load cell, and power supply. A MATLAB-based application was developed to filter, plot, and analyze the USWE data with the focus of identifying successful embed events. With the MATLAB-based application, it can conduct initial analyses of data waveforms to quickly isolate successful events as those accompanied by symmetric load and power waveforms. Additionally, statistical quality control methods, such as the X Bar and R control charts, were applied to analyze the data. The results demonstrate that these methods are useful in distinguishing good-quality events from those containing defects.

Introduction

The premise behind the construction of the USWE data acquisition system is the idea that process quality can be determined quantitatively. In fact, several factors have emerged supporting this ideal. Namely, successful embedding events were found to be accompanied by symmetrical acceleration and load waveforms. The finding suggests a relationship between the force applied to the workpiece and the freedom of motion exhibited at the ultrasonic horn. It can then be suggested that quality is determined by these two factors while remaining independent of the power level applied.

Waveform Symmetry

Figure 1 shows the USWE[1] unit used to perform the wire embedding process. It stands to reason that applying a large down-force will restrict the range of motion of the horn which must vibrate rapidly to create the heat needed to embed wire in a plastic substrate. A smaller down-force allows load to mimic acceleration and produce waveforms that are roughly symmetrical.

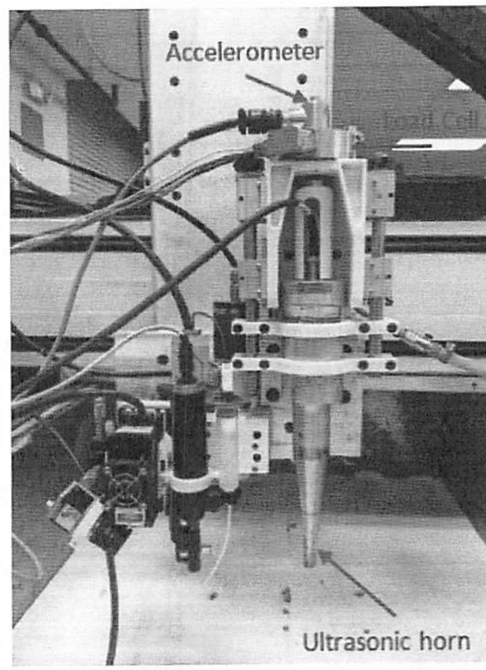

Figure 1: Ultrasonic Wire Embedder

To visualize the process, one can imagine applying pressure on a wire which is being heated. Intuitively, since the wire is being heated, little force is required to embed the wire in plastic. Now imagine that to heat it, the wire had to be rubbed rapidly with a round metal tube. The friction created by rubbing the two objects being the source of the heat. Applying large down forces would allow less freedom for the surfaces to move across each other and therefore produce less heat. The large load would finally cause excessive embed force once the wire reached sufficient heat to melt the substrate and thereby creating a failed embedding event.

Figure 2 shows load and acceleration waveforms produced during a successful embed and a failed attempt. Figure 3 shows the test coupon used for both tests.

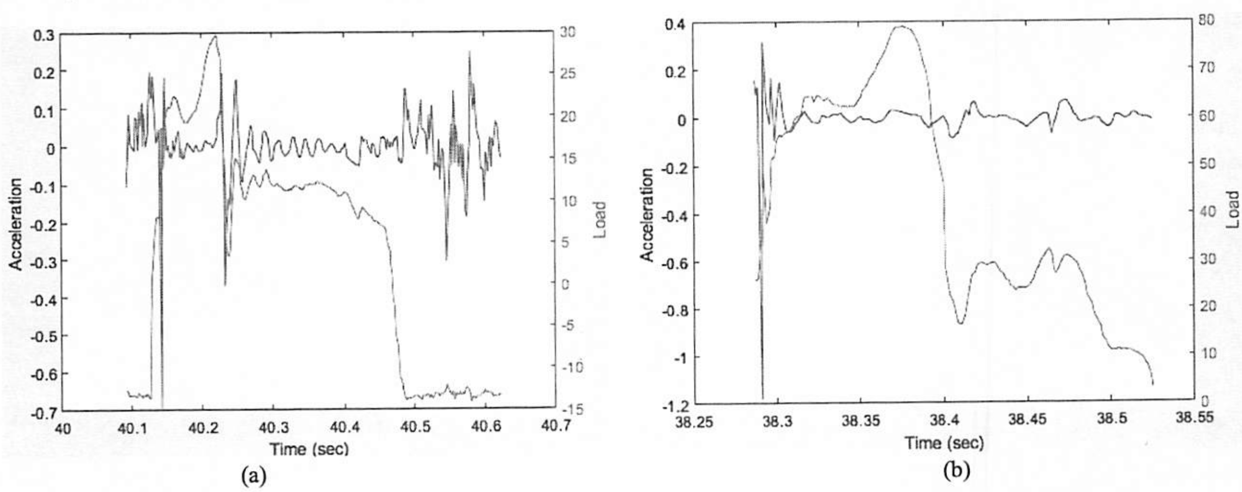

Figure 2: load and acceleration waveforms produced during: (a) a Successful Embed and (b) a Failed Embed.

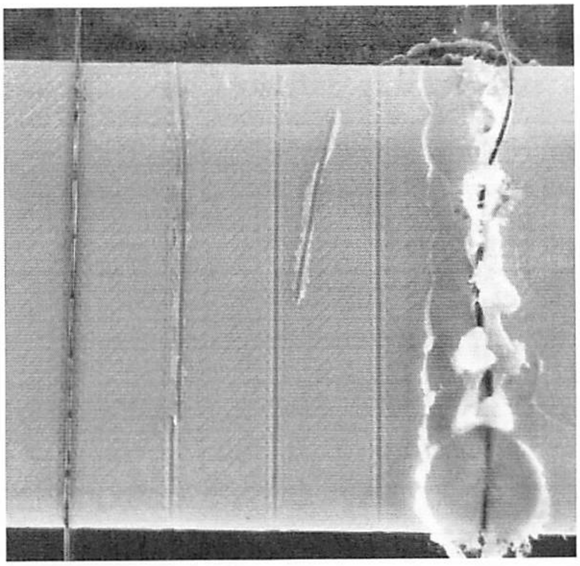

Figure 3: Successful Embed (left) versus Failed Embed (right)

Statistical Control Charts

Statistical control charts can be used to determine graphically whether a process is in control (operating satisfactorily) or out of control (operating outside of desired range). To use data for the purpose of producing control charts, the data must be normally distributed, the mean must be known, and the standard deviation must be known[2]. Load data does not follow a normal distribution. Acceleration, when considered within specific ranges does exhibit the desired quality. Mean and standard deviation are easily calculated from the data. The range chart depicted in Figure 4, considered for the entire event, shows a process which is largely within the upper and lower control limits despite starting well over the upper limitation. The portion which exceeds the limits can be attributed to bounce caused by a powered ultrasonic horn meeting the substrate. Though statistical control charts are useful tools for evaluating quality control, the nature of the data allows for its application towards one aspect while excluding the other.

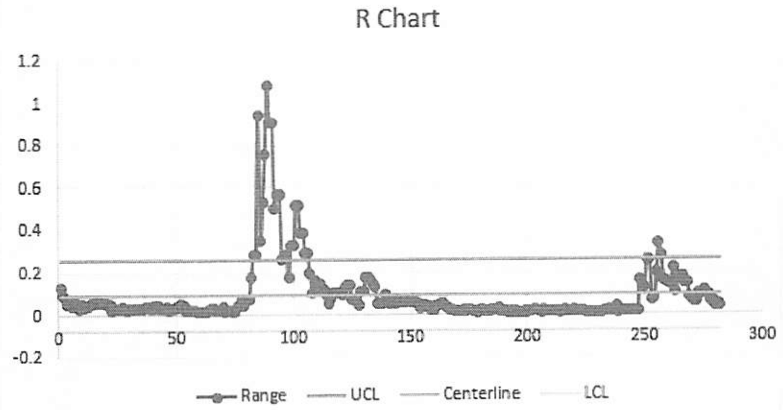

Figure 4: Range Control Chart

Since both are inherently dependent on each other, it may not be considered a reliable tool because it is possible to record a smooth acceleration under an excessive load. Since excessive loads have been shown to cause failed events, the chart would then prove unacceptable.

Conclusions

As with many processes, the quality of the USWE unit can be measured quantitatively. Though the form of the raw data is heavily laden with noise factors, the tool developed for its assessment can greatly reduce associated overhead. The plots produced by the tool can help operators quickly evaluate system performance using a single plot. Additionally, the tool can export the filtered data in a neatly indexed matrix which can be used to develop a set of parameters for operating within acceptable limits. The use of statistical charting methods was excluded from the tool due to the random nature of much of the data through other statistical evaluations could be considered as additions to the tool. In all, the tool allows the quick and easy evaluation of USWE data. A process that was previously performed manually and required large amounts of time.

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2. *Introduction to Statistical Quality Control 7th Edition*; Douglas C. Montgomery

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