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

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Abstract

The University of Texas El Paso has developed a method for embedding wire into substrates produced using various 3D printing methods. As with any project under development, there has arisen a need for data acquisition for studying system performance. As a measure toward this end, graduate students working in UTEP's W.M. Keck Center for 3D innovation have developed a multi-sensor system for their Ultrasonic Wire Embedder (USWE). 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.

Under the NASA-MUREP program, the task was undertaken to produce a MATLAB based application to filter, plot, and analyze the USWE data with the focus of identifying successful embed events. Initial analysis of data waveform quickly isolated successful events as those accompanied by symmetric load and acceleration waveforms. Additionally, application of statistical quality control methods, namely the X Bar and R control charts, when applied to the data, proved to be useful in distinguishing good quality events from those containing defects.

Introduction

The premise behind 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 force applied on the workpiece and 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 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 the measured load to mimic the measured acceleration and produce waveforms that are roughly symmetrical.

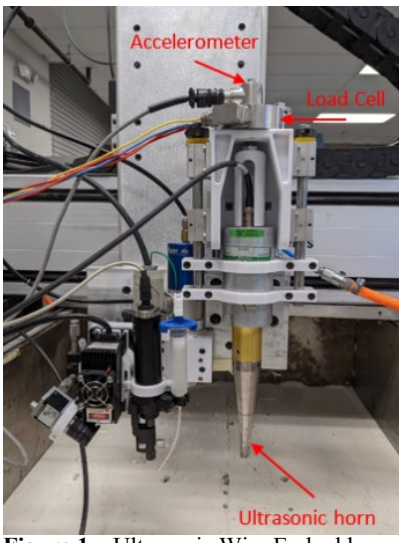

Figure 1 – Ultrasonic Wire Embedder

To visualize this occurrence, one can imagine applying pressure on a wire which is being heated. Intuitively, little force is required to embed the heated wire in a plastic substrate. The ultrasonic welding process relies on heat generated through friction. Applying large down forces will restrict the movement between the friction surfaces 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 illustrates load and acceleration waveforms produced during a successful embed while **Figure 3** displays a failed attempt. **Figure 4** shows the test coupon used for both tests with the successful embed shown on the left.

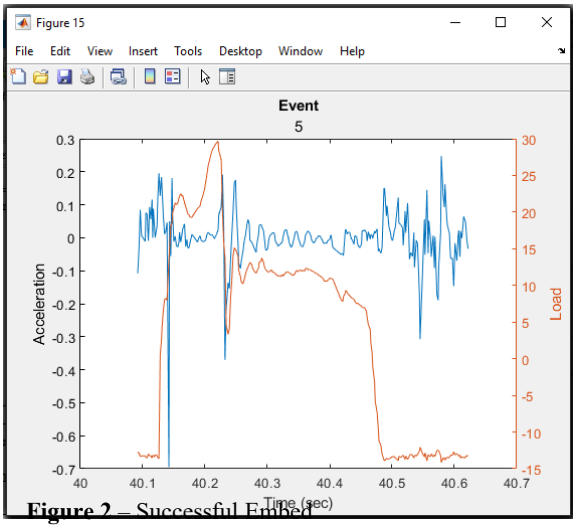

Figure 2 – Successful Embed

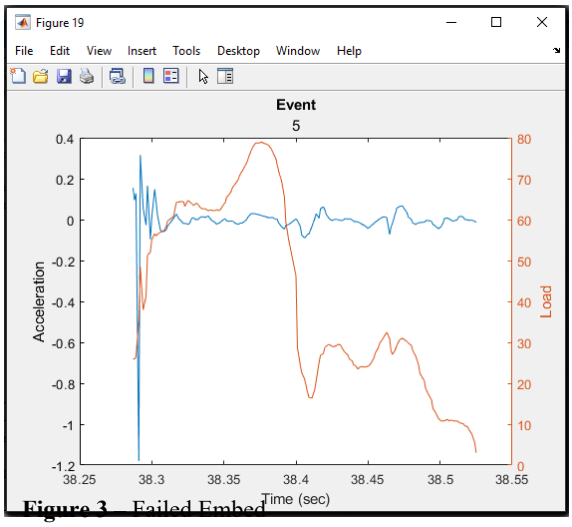

Figure 3 – Failed Embed

Statistical Control Charts

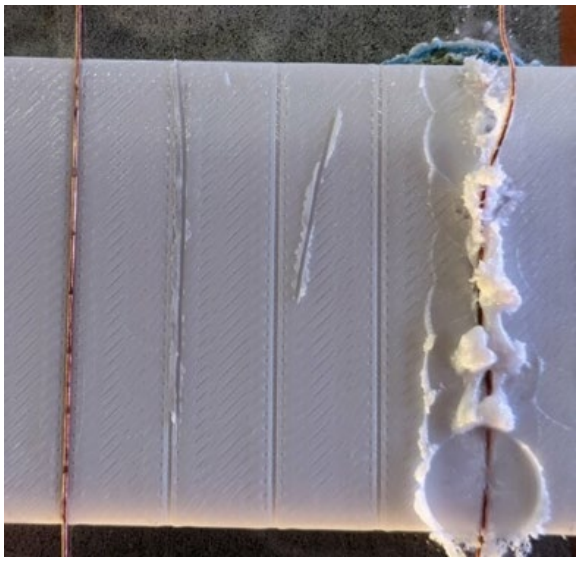

Figure 4 – Successful vs Failed Embed Events

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). Producing control charts, requires that the data be normally distributed, with known mean, and standard deviation[2]. Here, the load data does not follow a normal distribution, but acceleration data, when considered within specific ranges, does exhibit the desired quality. Mean and standard deviation are easily calculated from the collected data. The range chart depicted in Figure 5, 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. 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.

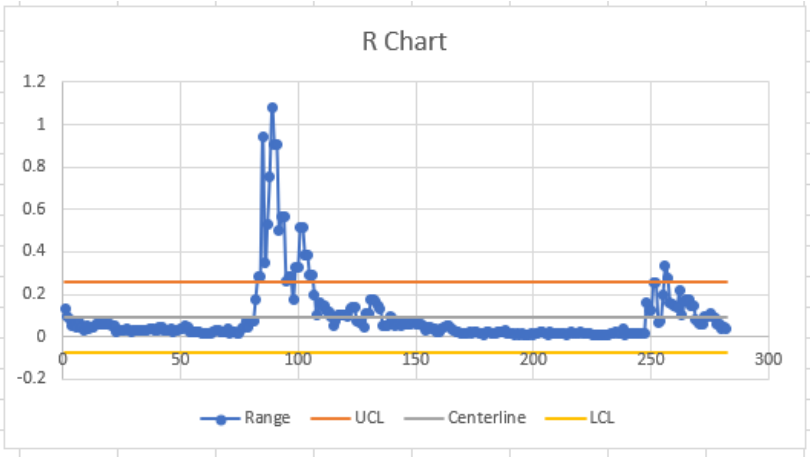

Figure 5 – Range Control Chart

Summary and 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 though 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 which was previously performed manually and required large amounts of time.

References

1. Gutierrez, Patrick, and David Espalin. *MULTI-SENSOR CHARACTERIZATION OF ULTRASONIC WIRE EMBEDDING PROCESS FOR MATERIAL EXTRUSION ADDITIVE MANUFACTURING*.
2. *Introduction to Statistical Quality Control 7th Edition*; Douglas C. Montgomery

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Juan is a student at Texas A&M University Kingsville studying Industrial Engineering. He is interested in Operations research, system optimization, sustainability, and renewable energy.

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