An Approach to Determine Minimum Amplitude Required for Ultrasonic Welding

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Ultrasonic welding is one of the most common plastic welding processes used in industry. The three most influential parameters for this process are amplitude, duration, and force. While weld duration and force are parameters that can generally be easily adjusted during process development, amplitude requirements must be considered during the design process.

Although recommended amplitude guidelines are available for many generic materials based on accumulated industry experience, use of specialized and newly developed materials is rapidly increasing. To that end, it is desired to have a method for experimentally determining the minimum amplitude required for a material. This work investigates one possible method to determine minimum required amplitude.

The amplitude provided to the weld depends on the frequency of the equipment, the specific transducer being used, the ratio of the booster, and the design of the ultrasonic sonotrode. A typical approach is to design the sonotrode with as much gain as possible, while maintaining a stress lower than the fatigue limit of the material. The amplitude can then be reduced if needed via a lower ratio booster or electronic adjustment through the ultrasonic generator.

There are some drawbacks to this approach, however:

1. Performance of the ultrasonic stack is improved when there is a similar amount of gain from the sonotrode and booster.
2. Electronic amplitude reduction via the generator reduces overall power available for welding. For example, if the amplitude were set to 50%, only 50% of the maximum power rating of the generator would be available, such as 1200W when using a 2400W generator.
3. Using a higher than necessary amplitude can often lead to unacceptable part damage. Ultrasonic vibrations may cause cracking at sharp radii or small cross-sectional area and can cause damage to films, filters, and membranes.

For these reasons, it is important to be able to define a minimum amplitude required to weld a material.

Measuring and Calculating Amplitude

The amplitude of the ultrasonic vibrations delivered to the part is the product of the amplitude that is generated by the transducer, the gain of the booster, and the gain of the sonotrode.

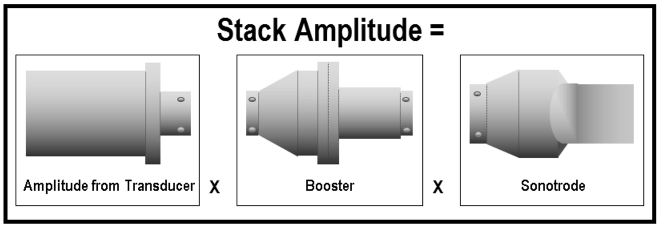

Figure 1: Stack Amplitude

The magnitude of amplitude generated by the transducer and booster gain ratio values are provided by the equipment manufacturer, but the sonotrode gain often is not. Sonotrode gain is simple to approximate, however.

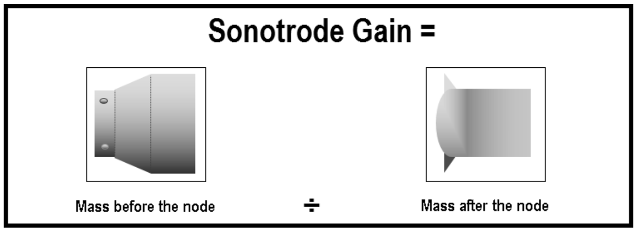

Figure 2: Sonotrode Gain

The gain of the sonotrode is the ratio of the mass before the node divided by the mass after the node. Because the material density and length are the same, this resolves to the ratio of the cross-sectional area before the node divided by the cross-sectional area after the node, usually multiplied by a factor of 0.8 to account for the transition radius from the back to the front dimensions.

Using this calculation method, the estimated amplitude of the stack used in the trials was 13.9 µm peak to peak at 100% amplitude using a reversed 1.5 ratio gain booster. The measured amplitude for this stack was 15 µm of peak to peak displacement.

Experimental Procedure

One amorphous and one semi-crystalline material were chosen to develop the minimum amplitude determination process. The amorphous material used was Polycarbonate (PC), while the semi-crystalline material chosen was Polypropylene (PP).

The Melt-Match® feature on the Dukane servo-driven ultrasonic welder was well suited to enable a determination of minimum amplitude required for welding due to the integrated ability to halt downward motion and link force measurement data to ultrasonic vibration data. Essentially, the Melt-Match® feature allows the sonotrode to make contact with the part and stop at a position associated with a set trigger force. While maintaining this position, ultrasonic vibrations are initiated while not applying any additional force or downward motion to the parts. Once a drop in force is measured, indicating that the polymer has begun melting, then the welder begins its downward motion.

The important aspect of this feature is that it allows a distinct measure of the time at which melting begins in the material given a set amplitude and applied force. This measurement can be taken as the time difference between the point at which ultrasonic vibrations are initiated and the point at which a drop in force is registered, hereafter referred to as “time to melt initiation.” This time to melt initiation was plotted versus a variety of amplitudes for each material. Additionally, parts were tensile-tested to check to determine the effect of amplitude on weld strength.

Results and Discussion

The time to melt initiation and the tensile strength were plotted versus amplitude (Fig. 3). Interestingly, while PP showed a gradual increase in strength and recudion in time to melt initation as ampitude was increased, PC showed a distinct amplitude at which melt initiated, below which melt did not initiate.

One might suspect that the amorphous material would have shown the gradual change, as it gradually softens with increasing temeprature after the glass transistion temperature and that the semi-crystalline material would show the abrupt change in behavior after the melting temrature is reached.

The gradual shift of the semi-crystalline PP might be due to the extreme softness of this material or, possibly the amplitudes used were not in the correct range to see a sharp shift in behavior. Further experiementation at lower amplitudes, and perhaps incorporating temperature measurement of the joint would be warranted.

Conclusions

This work provides a framework for an experimental method to determine minimum required amplitude for any material. The strong correlation of time for the material to begin melting, as noted by a drop in force, to weld strength indicates that this testing method to estimate minimum required amplitude is viable.

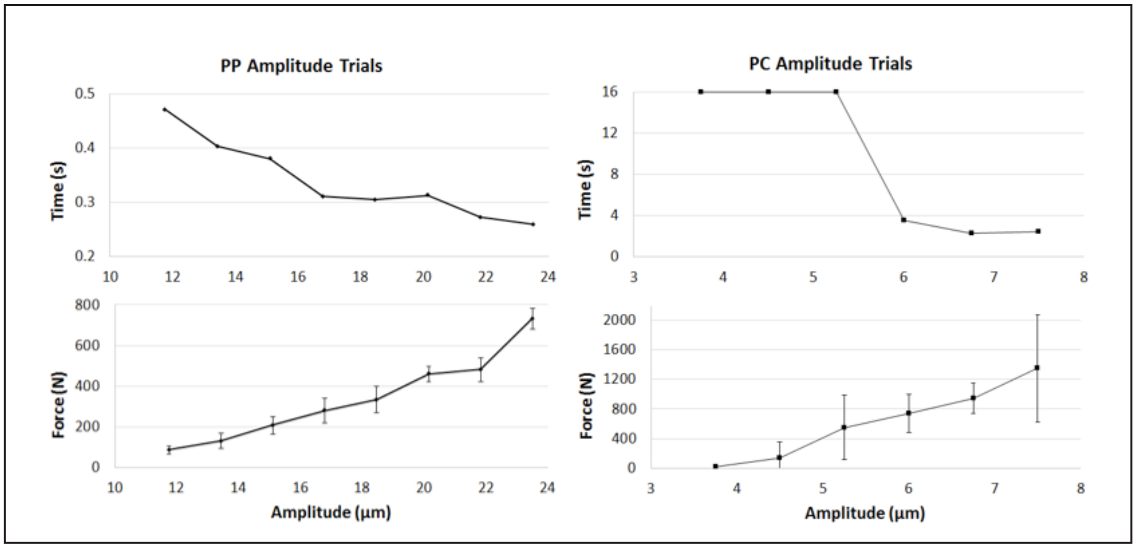

Figure 3: Amplitude vs. Time to Melt Initiation and Tensile Strength for Polypropylene and Polycarbonate

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