Ultrasonic Plastic Welding: Joint Comparison for Valox 325

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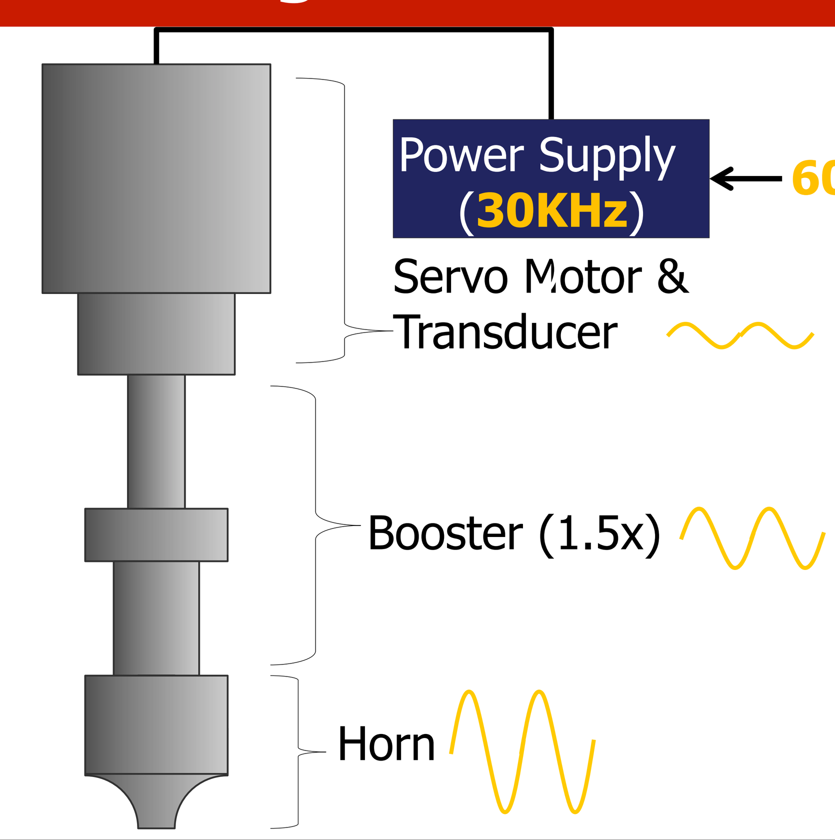
Background

•Ultrasonic Welding is a common vibrational joining process
- •Part lids are welded to cylindrical samples using shear joints, or machined energy directors near the rim of the lid, much like a projection that is either pointed or round
- •Parts are sandwiched between the base and an ultrasonic horn and vibrated at a frequency from 20kHz to 40kHz
- •Vibrational friction and hysteresis heating between chains of polymer molecules causes the energy director to melt
- •Very fast and moderately strong welds are produced

•Valox 325 parts with different joint designs will be examined
- •Form of semi-crystalline Polybutylene Terephthalate (PBT)
- •Unfilled non-flame-retardant general purpose grade used for automotive body parts, electrical switches, and more



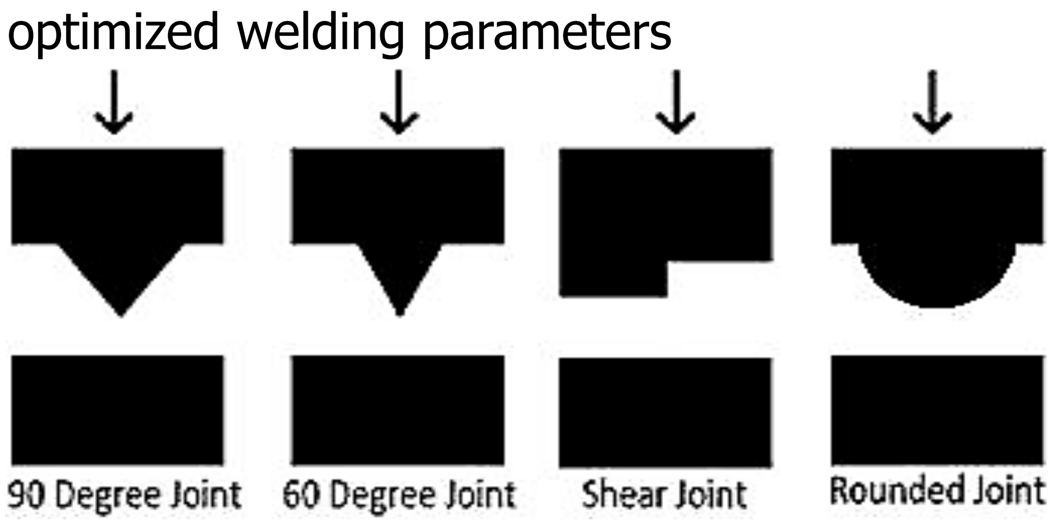
•The figure on the left shows a basic layout of an ultrasonic "stack" featuring a transducer to produce a low-amplitude, high-frequency vibration (30kHz)
•The booster takes the amplitude of this vibration and increases it by factor of 1.5
•The horn, or sonotrode, efficiently transfers the acoustic energy into the parts
•This acoustic energy causes the part to vibrate, which melts the machined energy director and triggers the welding process
•The plastic molecules rearrange, approach the surface, wet out, diffuse, and randomize upon solidification and a weld is completed

Motivation

•Part design is often based on industry lore, rather than scientific results
•Need for research-based design recommendations for joining Valox 325
•Joint designs are typically 60° or 90° energy directors (EDs), or a shear joint, although a round ED could potentially supersede these types

Objectives & Approach

Overarching Goal: To compare the following ultrasonic joint designs on the basis of strength, microstructure, and melt-flow characteristics using optimized welding parameters



•The energy director allows the acoustic energy to be focused into a set location to control melt
•Energy directors and shear joint were tested for greatest tensile failure load

•The figure above shows the four different joint designs which were compared in this experiment
•To analyze weld strength, pull testing was performed to compare average failure loads of different sets of welds
•Cross-sectional analysis, as well as melt-flow characteristic analysis was performed using an optical light microscope and observing the weld profiles of each joint design in terms of flash and weld quality
•Visual inspection was also used to observe excess flash and weld defects

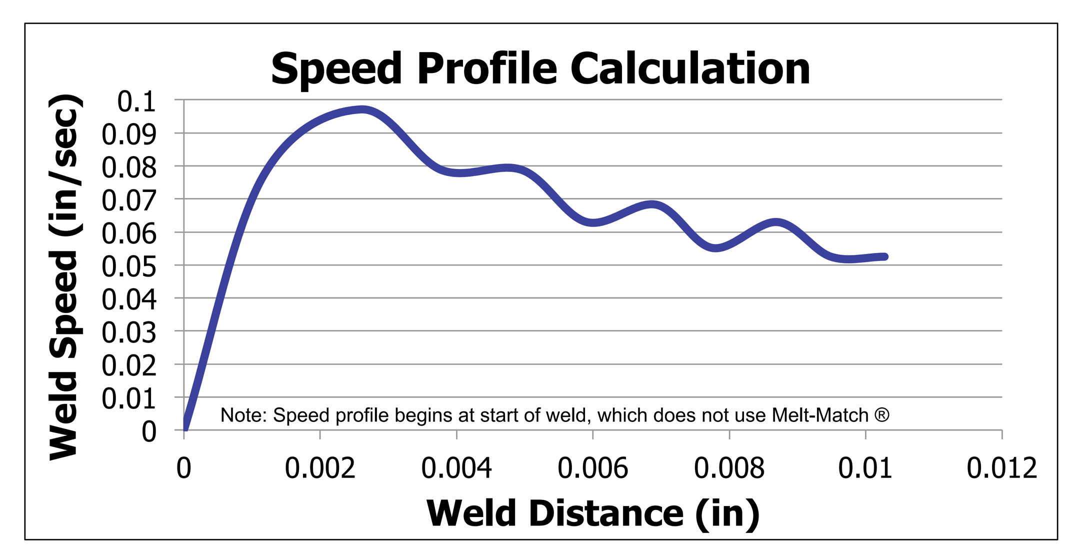
Conclusions

1. Shear Joint
   - Showed the least dependence on speed & force profile overall
   - Showed an increase in strength at higher speeds at constant velocity
2. 90 Degree Energy Director
   - Increased strength with "Ideal" force profile
   - Showed a good balance of strength without forming defects on parts
3. Round Energy Director
   - Performed best under theoretically calculated velocity profile
   - Performed especially well with low upset force
   - Improved most using low force velocity profile (sharp EDs stronger)
   - Showed a good balance of strength without forming defects on parts
4. 60 Degree Energy Director
   - Performed especially well with low upset force
   - Increased strength with "Ideal" force profile
   - most part deformation due to rapid heat generation and melt-flow
5. Overall Findings
   - All constant velocity sets showed an increase in strength for a slower weld speed, except for shear joint
   - A profiled velocity was able to increase the failure load of every ED
   - For nearly every profiled velocity set, the rank in failure load for joints was the same with 60° > 90° > Round > Shear, possibly due to differences in bonding area of weld cross-sections
   - Constant velocity trials showed an inconsistent ranking of EDs
   - Longer weld times resulted in higher failure loads for each joint type
   - Flash and deformation were directly correlated with high failure loads

Results & Discussion

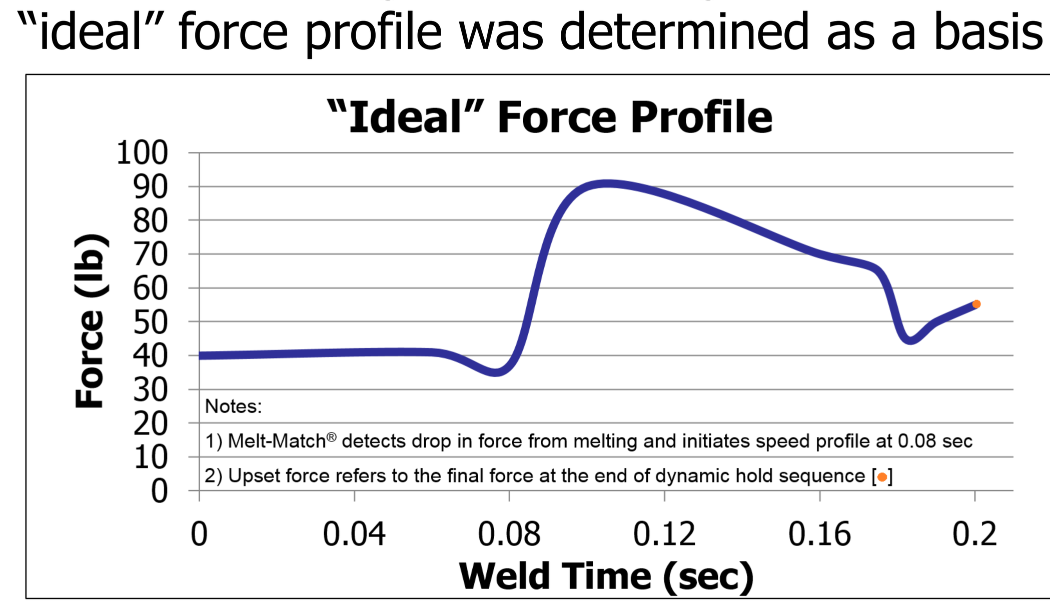
•To optimize welds, a speed profile was calculated using the following formula in Mathcad software:

$$\theta_{j+1,i} := \frac{Q_i \cdot \Delta t}{\rho \cdot C_p} + \frac{\Delta t}{\Delta x^2}\cdot\kappa\cdot\left(\theta_{j,i-1}+\theta_{j,i+1}\right) + \left(1-2\cdot\frac{\Delta t}{\Delta x^2}\cdot\kappa\right)\cdot\theta_{j,i}$$



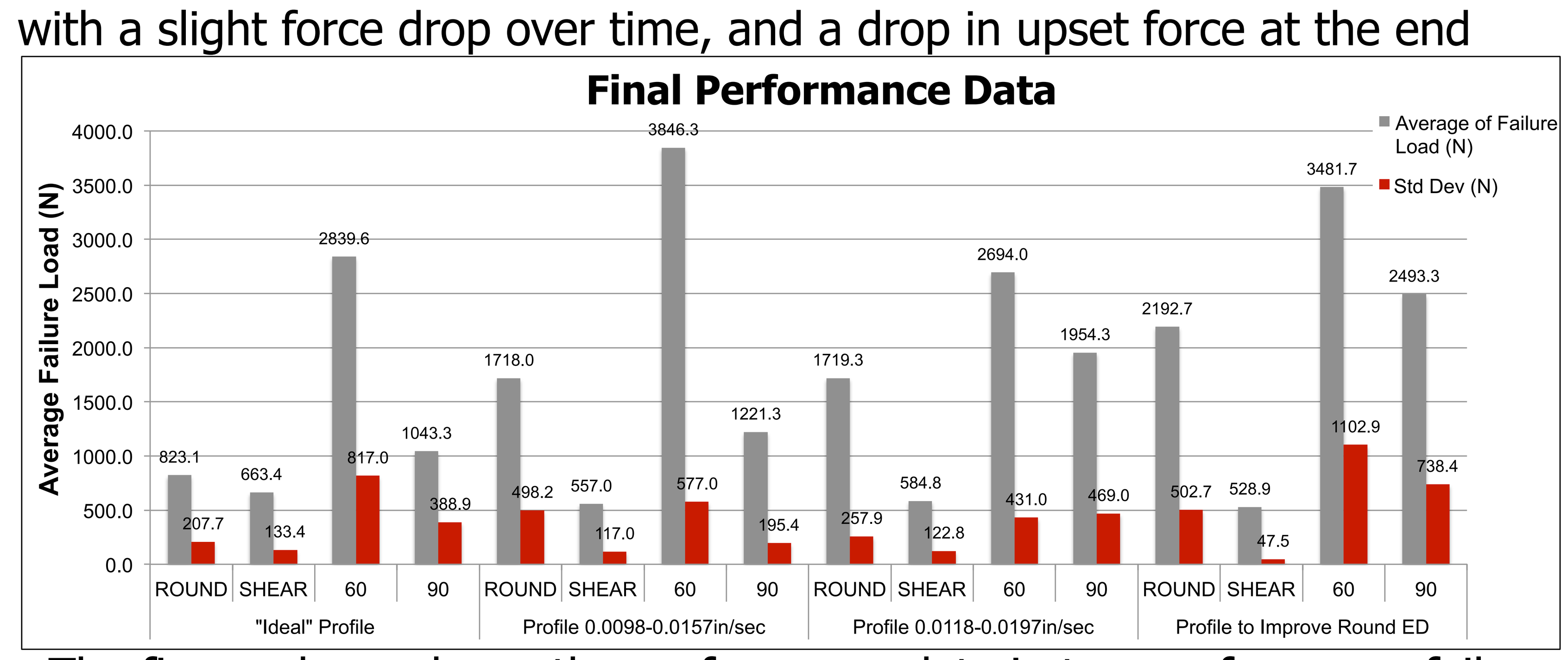
•The formula above relates heat generation with time and weld distance for a given material
•Figure on the left shows the theoretically calculated speed profile (assumption is for a square energy director)

•Speed profiles were adjusted for to help improve process and performance, while trigger force, hold time, and melt detect were also adjusted
•After pull testing and analyzing failure loads for the first group of welds, an "ideal" force profile was determined as a basis for parameter optimization

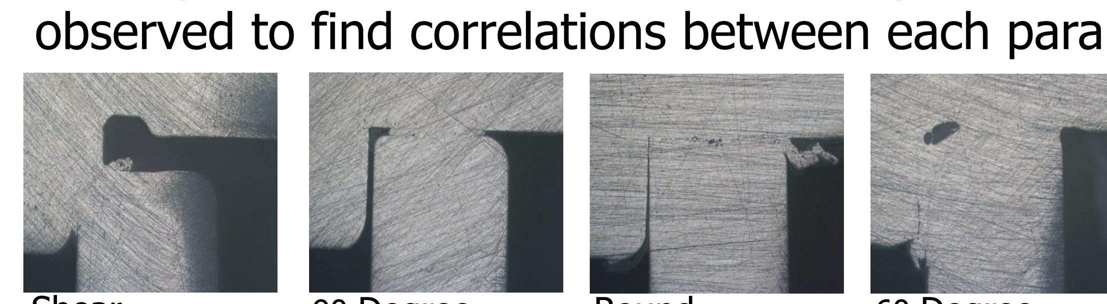


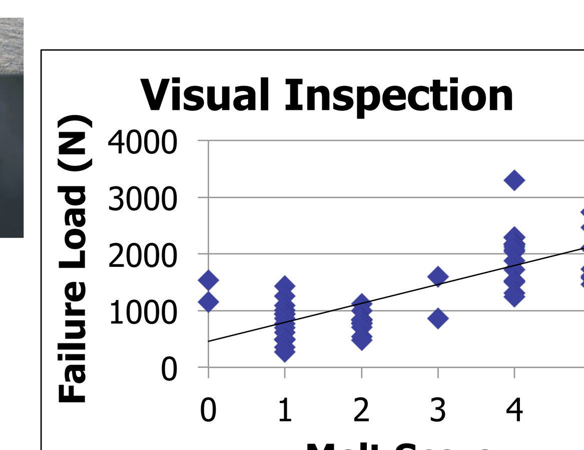
•The figure on the left shows the "ideal" force profile, meaning it yields the highest failure loads based on the first set of data
•Profile was adjusted several times (primarily used 90° ED) for improved performance

•Findings from the first group of trials showed that welds performed better with a slight force drop over time, and a drop in upset force at the end



•The figure above shows the performance data in terms of average failure load for each data set in the second (final) group of weld trials
•Weld parameters such as weld time, speed, force, and energy were observed to find correlations between each parameter and failure load





•The figure above shows the polished cross-sections of each welded joint design at 25x magnification for analysis of melt-flow
•The figure to the right shows the visual inspection each weld that used the round energy director
•The "melt score" is a way of ranking visual defects, such as markings on the weld lid and excess melt at the interface (0 being no markings or flash)