Feasibility of Joining Techniques for Thermoplastic and Thermoset Polymers

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Project Introduction and Impact

When fiber reinforced polymers (FRPs) must be built too large to cast in one piece, the ability to easily join them becomes important. Current joining methods include mechanical fasteners, but may be expanded through the use of ultrasonic or friction stir spot welding.

Joining Methods:

Ultrasonic Spot Welding (USSW)

- Electric power tuned to high frequency
- Piezoelectric device converts to kinetic energy
- Kinetic energy produces local heating
- The interface between work pieces is melted and solidified locally, creating a bond

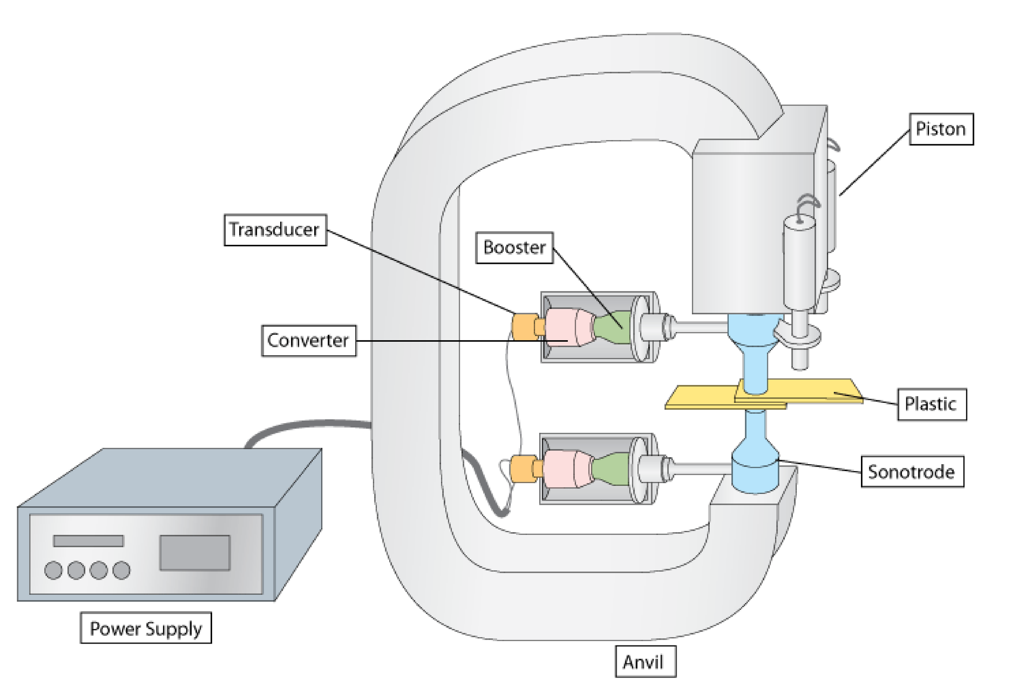

Figure 1: Schematic of Sonobond ultrasonic spot welder at SDSMT

Friction Stir Spot Welding (FSSW)

- Operates by spinning an end mill
- As the collar descends, the pin rises
- Pulls the melted material up
- The collar ascends, the pin descends, creating a flat, filled FSSW joint.

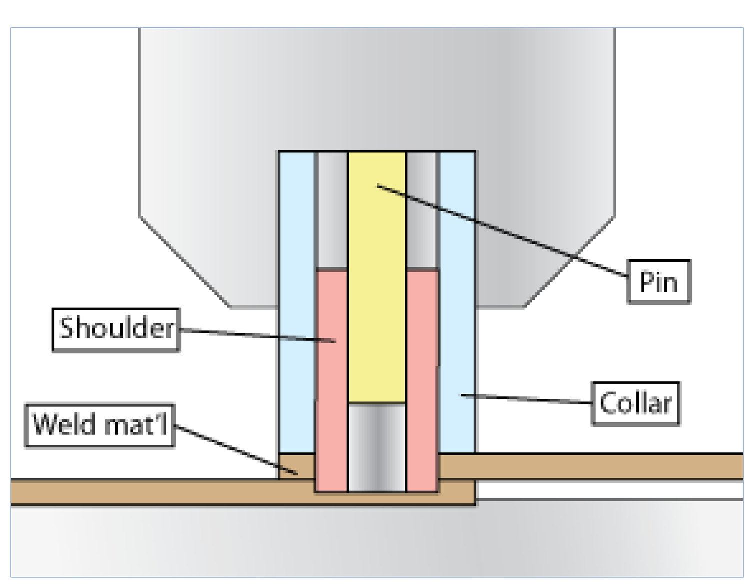

Figure 2: Schematic of the side view of the refill FSSW process

Objectives:

- Evaluate joining methods of FSSW and USSW for thermosetting and thermoplastic polymers.
- Characterize various joints via lap shear testing.

Procedure

Materials

Thermosets:

- Crosslinked polymer network
- Do not melt
- Little known for USSW and FSSW in industry

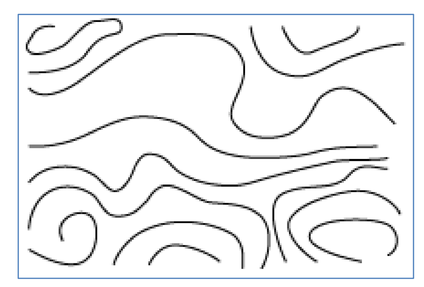

Figure 3: Schematic of a linear polymer network

EPON 828:DETA, a thermoset epoxy

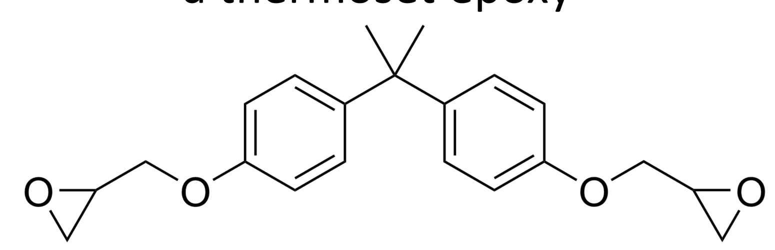

Figure 4: Chemical structure of EPON 828 (Public Domain)

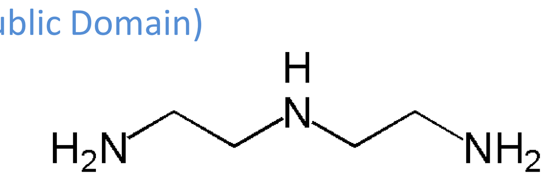

Figure 5: Chemical structure of DETA (Public Domain)

Thermoplastics:

- Linear polymer chain network
- Melt when heated
- Well known for USSW and FSSW in industry

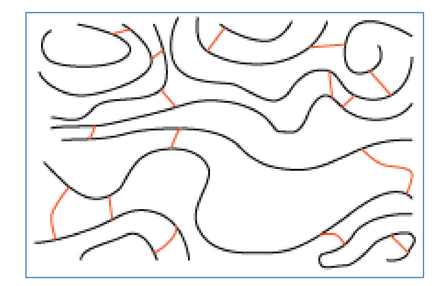

Figure 6: Schematic of a crosslinked polymer network

Polycarbonate (PC): a common thermoplastic

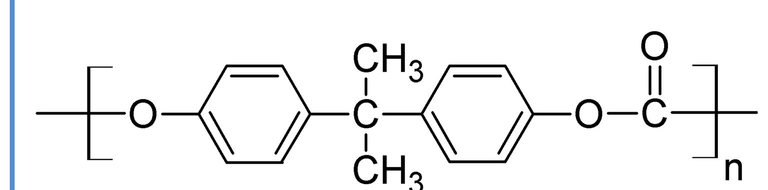

Figure 7: Chemical structure of polycarbonate (Public Domain)

Sample preparation:

- Created an aluminum master mold using a CNC mill for final samples of dimensions 1"x 4"x1/16"
- Made silicone molds from the master
- Poured epoxy into the silicone molds, curing at 24h room temp, 24h 35 °C, 1h 135°C
- Polycarbonate samples were cut to size with a band saw and the burrs were shaved off with a razor

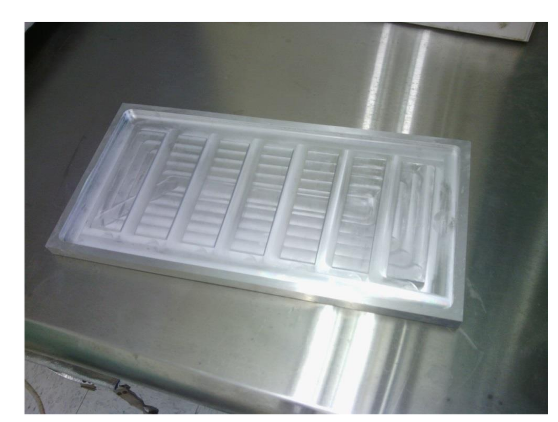

Figure 8: master mold

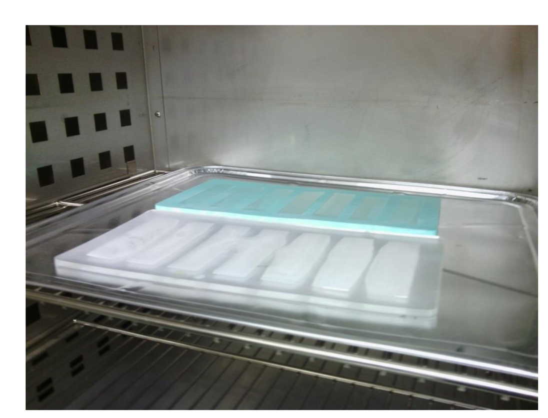

Figure 9: Silicone molds in oven

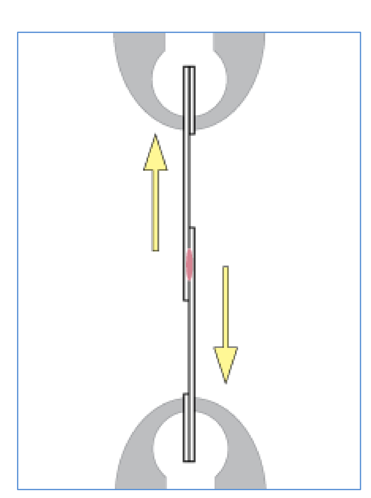

Figure 10: Schematic of a lap shear test

Welding:

- USSW was completed with 1/8" PC and a Sonobond custom ultrasonic welder.
- FSSW was completed at varying spindle speed, time and depth, and pressure.

Testing:

- Lap shear tensile test.
- Samples were tested at 0.05 in/min and peak loads were recorded

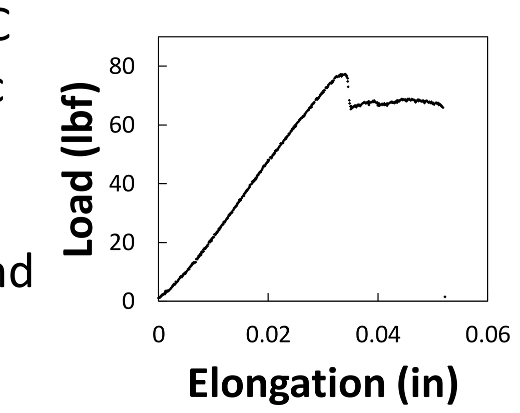

Figure 11: A representative PC load vs. elongation graph from lap shear testing.

Results

USSW

- Weld strength peaked at 1500 Joules of weld energy (time multiplied by power)
- Welds with 1500 J of energy seemed to be the strongest
- Problems with the ultrasonic welder prevented epoxy samples from being tested

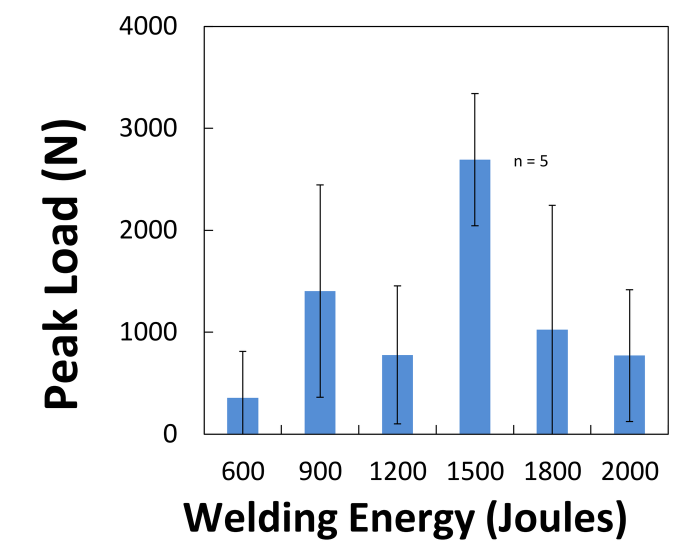

Figure 12: Peak loads of USSW of 1/8" PC from lap shear testing. Error bars represent one standard deviation. (Navaraj Gurung)

FSSW

- FSSW of epoxy caused samples to shatter and lap shear testing was not possible.

Table 1: Data from FSSW attempts on epoxy.

Plunge rate in/min	Plunge Depth (mm)	Time to Depth (sec.)	Spindle Speed (RPM)	Pressure (psi)	Comments
2.2	3.7	4	100	100	majority of sample shattered, but some bonding
2.2	3.7	4	50	100	Machine head crushed the sample
1.9	3.25	4	100	100	epoxy shattered
4.0	4.93	2.9	500	60	Crushed the sample, shattered
1.0	3.73	8.81	100	60	Shattered, but bonded some

Figure 13: FSSW of epoxy.

- FSSW of polycarbonate produced stable bonds which were tested in lap shear.

Figure 14: FSSW on polycarbonate.

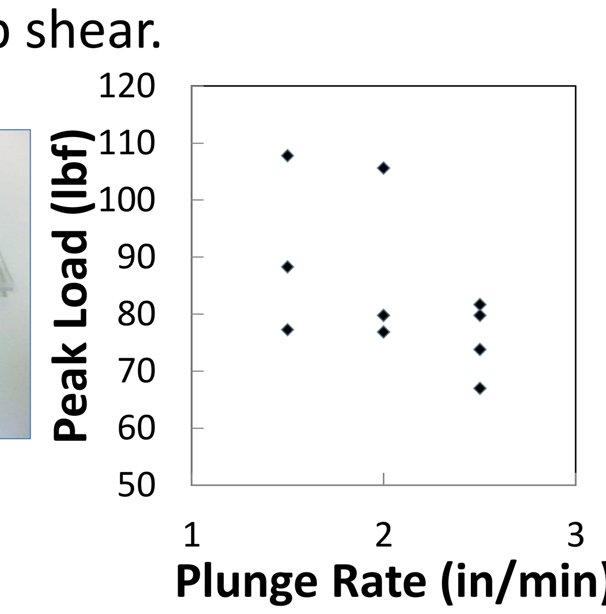

Figure 15: Peak load vs. plunge rate with a constant spindle speed of 150 RPM for PC.

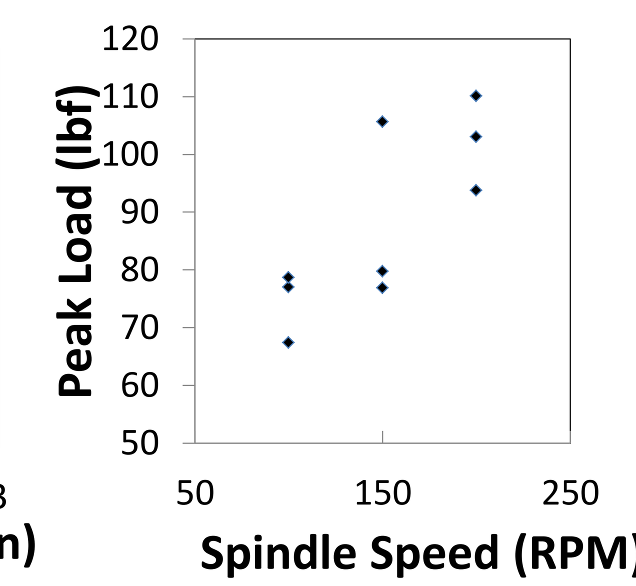

Figure 16: Peak load vs. spindle speed with a constant plunge rate of 2 in/min for PC.

Discussion & Conclusions

- The feasibility of USSW and FSSW of polycarbonate and epoxy is studied. Polycarbonate was successfully joined with both methods. Epoxy was not successfully joined with FSSW, and due to instrument issues, was not able to be joined with USSW
- The PC demonstrated ductile behavior during welding, while the epoxy demonstrated brittle failure
- The amount of heat generated during both joining techniques plays a crucial role in welding and should correspond to the glass transition and melting temperatures of the materials for a successful bond

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