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An Engineering Education Project: Using a Robot and Thermal Imaging to Automate and Analyze Ultrasonic Welding of Plastics

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Learning Ultrasonic Welding, Robotics and Thermal Imaging in One Fell Swoop

Summary: This *work-in-progress* report describes our objectives, rationale, implementations, and assessment plans in developing a practical robotic ultrasonic welding process as an educational hands-on project and laboratory exercises for undergraduate STEM students, and particularly Engineering Technology majors. The project combines ultrasonic welding of plastics, robotics, force sensors, rapid prototyping, thermal imaging and image processing in a practical demonstration of an industrially-important automated plastics manufacturing technology. An ultrasonic horn attached to the end of a robotic arm can be programmed to spot weld or seam weld acrylic parts. The process is monitored and optimized using a thermal imaging camera and a force sensor.

Introduction and Background. Ultrasonic welding of plastics is an important manufacturing technology for medical devices, MEMS (micro electromechanical systems), microfluidics, electronics, consumer and medical product packaging, and is increasingly used in automobile and aircraft assembly, and many other industries. In ultrasonic welding, ultrasonic waves are directed through interfaces between contacted component parts to effect a localized melting and welded bond. In addition to its use for plastics-based fabrication, ultrasonic welding has been developed for metal joining, and is also used for staking (connections made through interference fits) plastic parts. Ultrasonic welding can be used for spot welding and welding continuous seams, the latter of which is critical for making leak-free or airtight systems such as in plastic (micro) fluidic systems, e.g., for point-of-care lab-on-a-chip systems.

An ultrasonic weld is made by bringing the working surface of a horn (sonotrode) connected to an ultrasonic transducer in close contact with two workpieces that have been positioned and aligned. The vibrating horn pressed onto the surface of the workpiece(s) creates ultrasonic (10,000 to 30,000 Hz) waves that travel through the workpiece. The ultrasonic waves in combination with applied force, create a vibration-induced frictional heating at the mating surfaces of the parts, leading to surface melting and subsequent fusion.

Ultrasonic welding is a relatively fast (1 sec per weld), clean process that does not require adhesives, binding agents, solders, fluxes, or solvents. In many respects, ultrasonic welding is a ‘green’ manufacturing technology in its efficient use of material and energy, and negligible generation fumes, waste or other pollutants.

In its conventional implementation, ultrasonic welding is not very flexible and often requires customized tooling and process optimization specific to the part being welded. For this reason, ultrasonic welding has had limited in application to rapid prototyping. Further, special structural features are often designed and fabricated into the component parts to concentrate ultrasonic wave energy and facilitate their bonding.

Robotics and prototyping are high-profile subjects in contemporary undergraduate engineering and technology education. The use of ultrasonic welding for bonding and joining 3d-printed and other types of rapid protyped parts is limited because it is challenging to develop flexible positioning and actuation for highly variable parts. The advent of low-cost infrared cameras for thermal imaging provides a convenient means to visualize and analyze processes in unprecedented detail, which can perhaps provide more detailed analysis, *in situ* monitoring, and process control. Thus, although ultrasonic welding is 'clean', energy efficient, and fast (~1 second per weld), it is not yet readily adaptable for prototyping and 'one-off' jobs due to constraints on the horn and part shape. Here, we combine ultrasonic welding and robotics for a programmable welding station by attaching an ultrasonic horn (20 kHz, 1 to 600 W) to a robotic arm. As a laboratory exercise, students use thermal imaging and a dynamometer to measure forces applied to the workpiece, in order to monitor and optimize the robotic process for spot and seam welding acrylic plastic parts, and assess weld strength using a tensile stress instrument. The robotic ultrasonic welder finds application in a host student projects related to 3d printing and rapid prototyping of renewable energy projects (wind turbines, solar cell arrays) and microfluidic devices.

Educational Objectives

Robotic Ultrasonic Welding serves as a multidisciplinary The educational objectives of this project are to offer students an opportunity to integrate skills and knowledge from several engineering disciplines including:

- Plastics Engineering: Joining of polymer materials (acrylics, polycarbonate, 3d printer materials such as ABS) by ultrasonic welding.
- Robotics and Automation: The ultrasonic horn tip is guided across the areas to be welded by a programmable industrial robot.
- Rapid prototyping (3-D printing, laser cutting, CNC machining) materials and designs are used as component parts for ultrasonic welding.
- Ultrasonics and ultrasonic welding.
- Thermal imaging is used to analyze and optimize the process.
- Image analysis of heat transfer and other phenomena are modeled by visible (CCD camera) and infrared (thermal camera) videos and images.
- Materials Testing: Force sensors are used for *in situ* monitoring, and tensile stress testing is used to evaluate the strength of welds.

Description of Project

For ultrasonic welding we use an ultrasonic liquid processor (Mitronix, Farmingdale, New York; 600 Watts, 20 KHz), with a 0.125-inch (3.1-mm) diameter blunt end (microtip) probe tip "horn", normally used for ultrasonic agitation of mixtures such as cell cultures (**Figure 1**). This was an expedient due to its availability to us, but we believe many types of ultrasonic systems, including relatively inexpensive handheld systems could be used in this type of application.

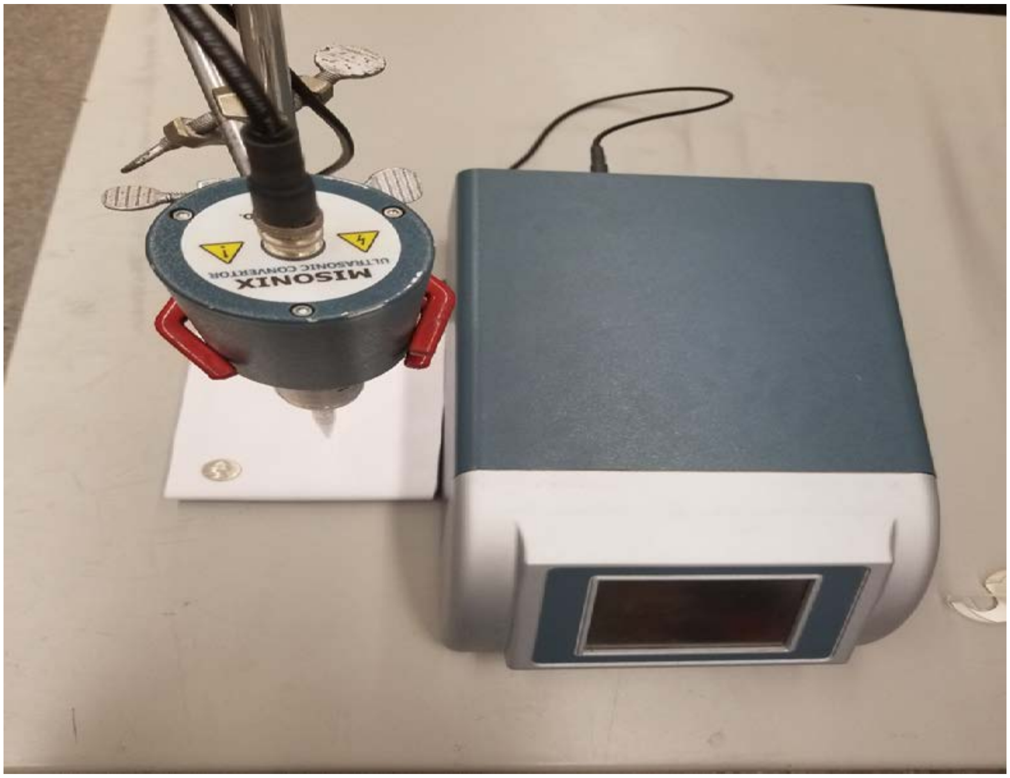

Figure 1: Commercial ultrasonic system (Misonix).

The probe touches the plastic parts with some specified force and delivers ultrasonic energy for a specified time. Figures **2** to **4** show different aspects and perspectives of the system.

Figure 2. Probe touching workpiece.

Figure 3. Clamp for probe to robotic arm.

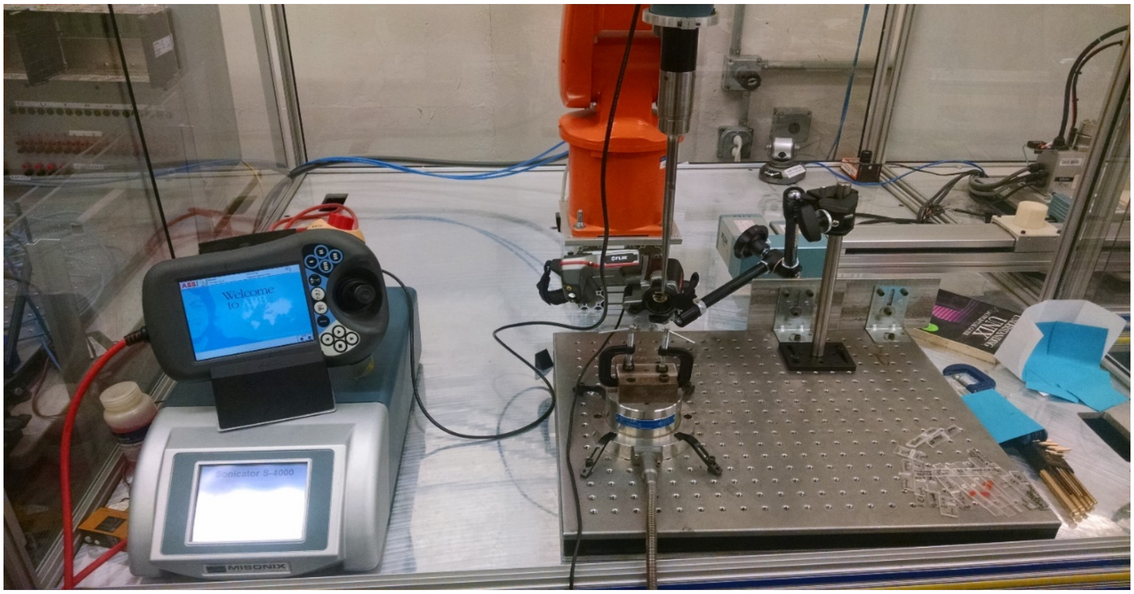

Figure 4a: Robotic Ultrasonic Welding System (with thermal camera and force sensor).

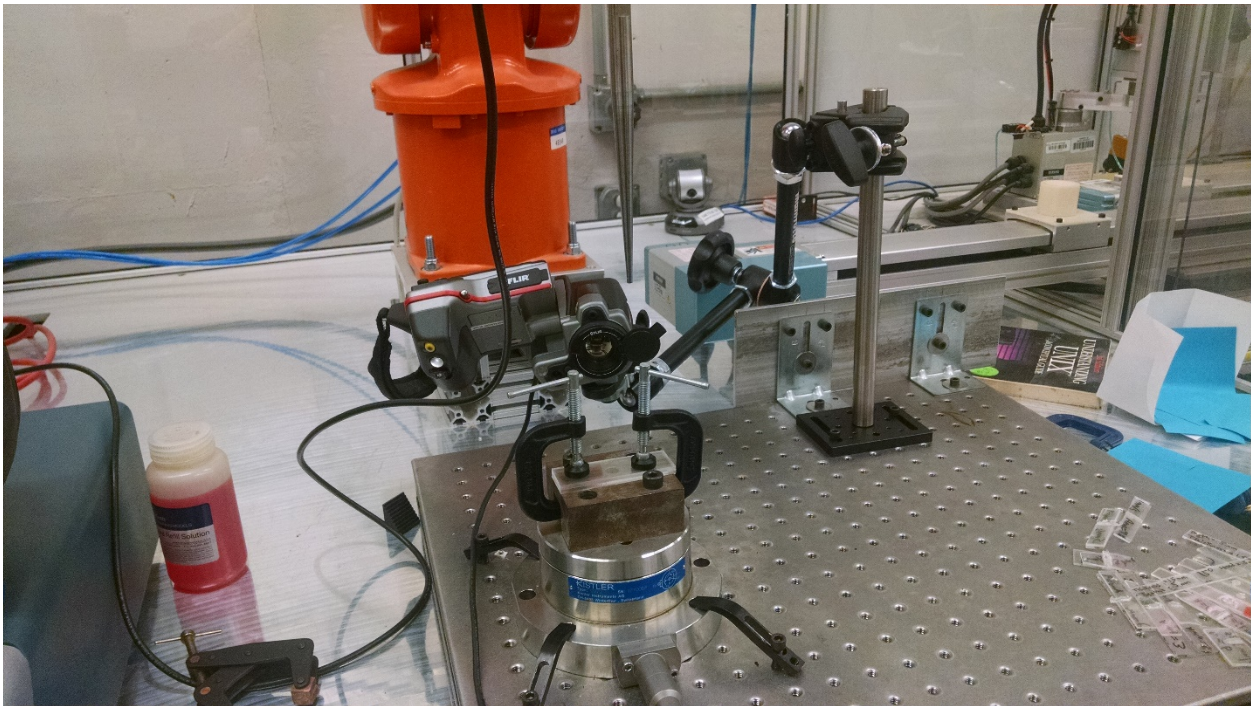

Figure 4b: Robotic Ultrasonic Welding System (with thermal camera and force sensor).

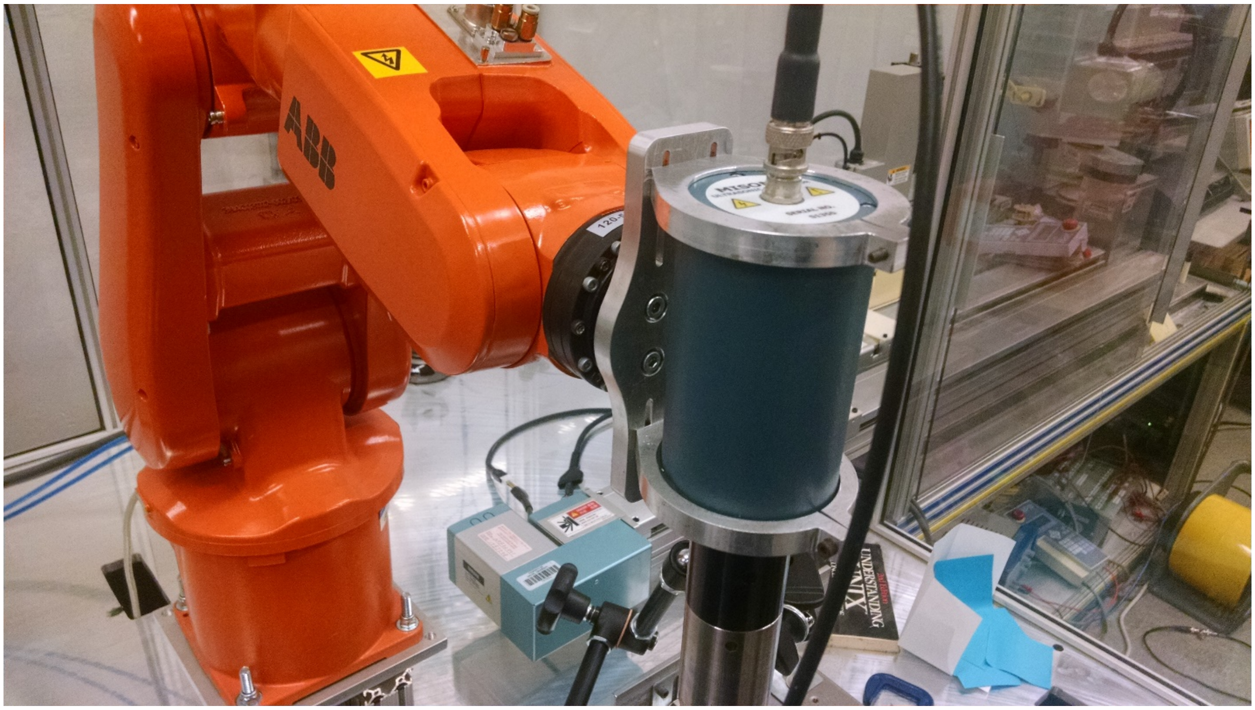

Figure 4c: Robotic Ultrasonic Welding System (with thermal camera and force sensor).

Figure **5** shows thermal images (made from infrared camera videos) of the ultrasonic welding process which allows the temperature profile of the process over the time span of the welding to be measured. **Figure 6** shows the force and temperature evolution during the ultrasonic welding. In seam welding (6c), in contrast to spot or point welding (**6a** and **6b**) the probe is moved along a programmed path. The strength of ultrasonic welds can be assessed with a tensile stress test (**Figure 7**).

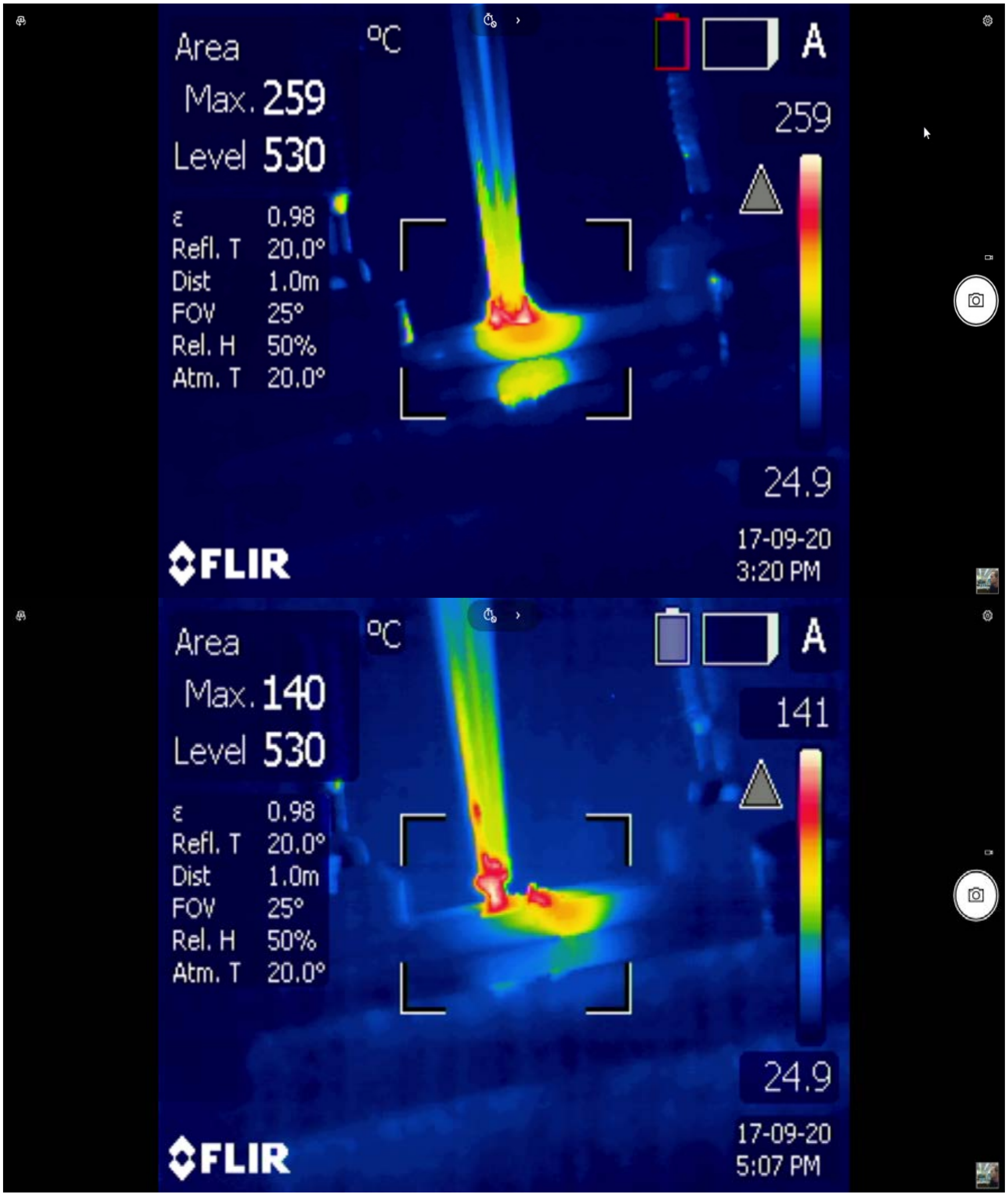

Figure 5: Thermal images of ultrasonic welding process.

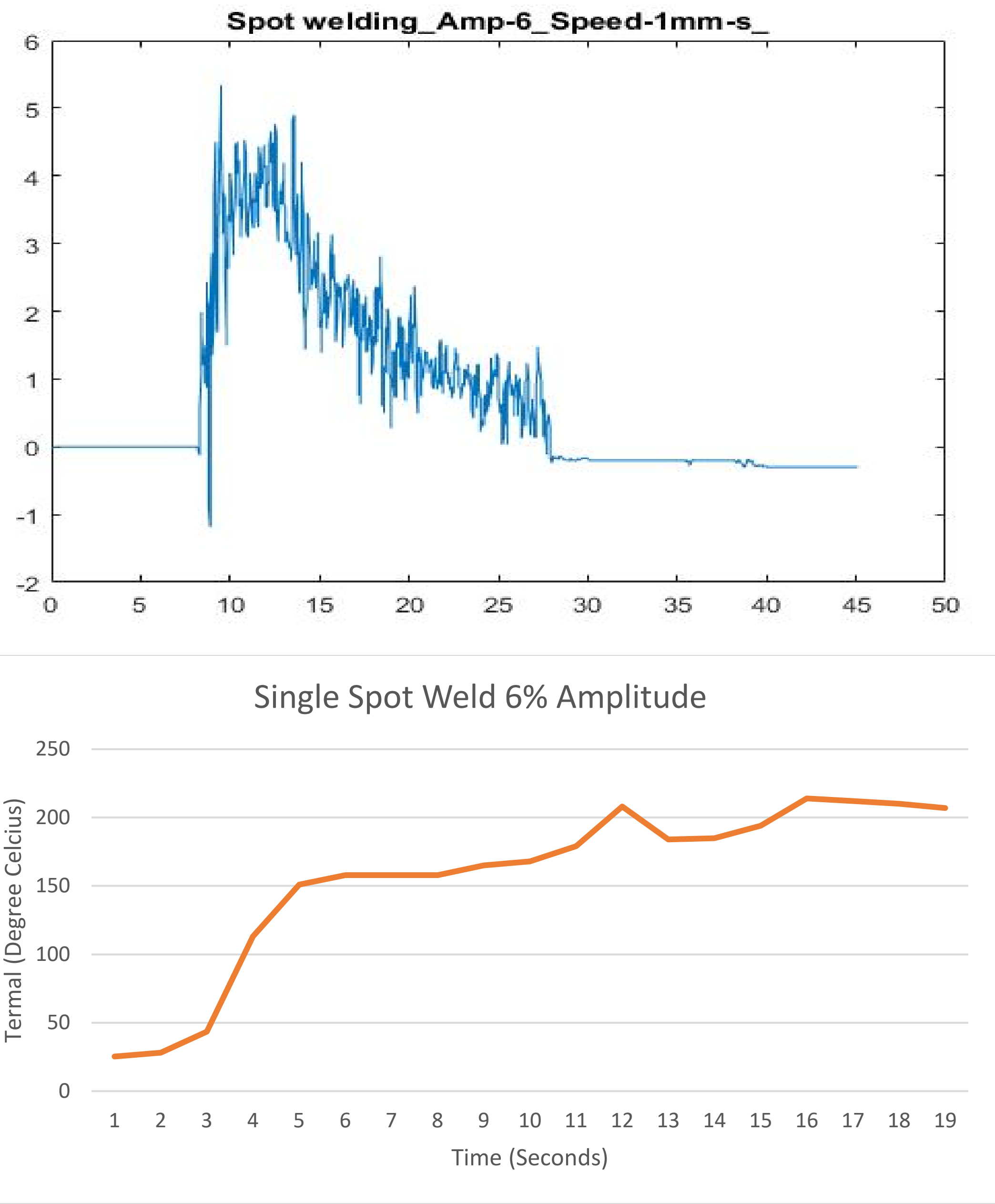

Figure 6a: Force and temperature vs time during low-power *spot* welding (6% power).

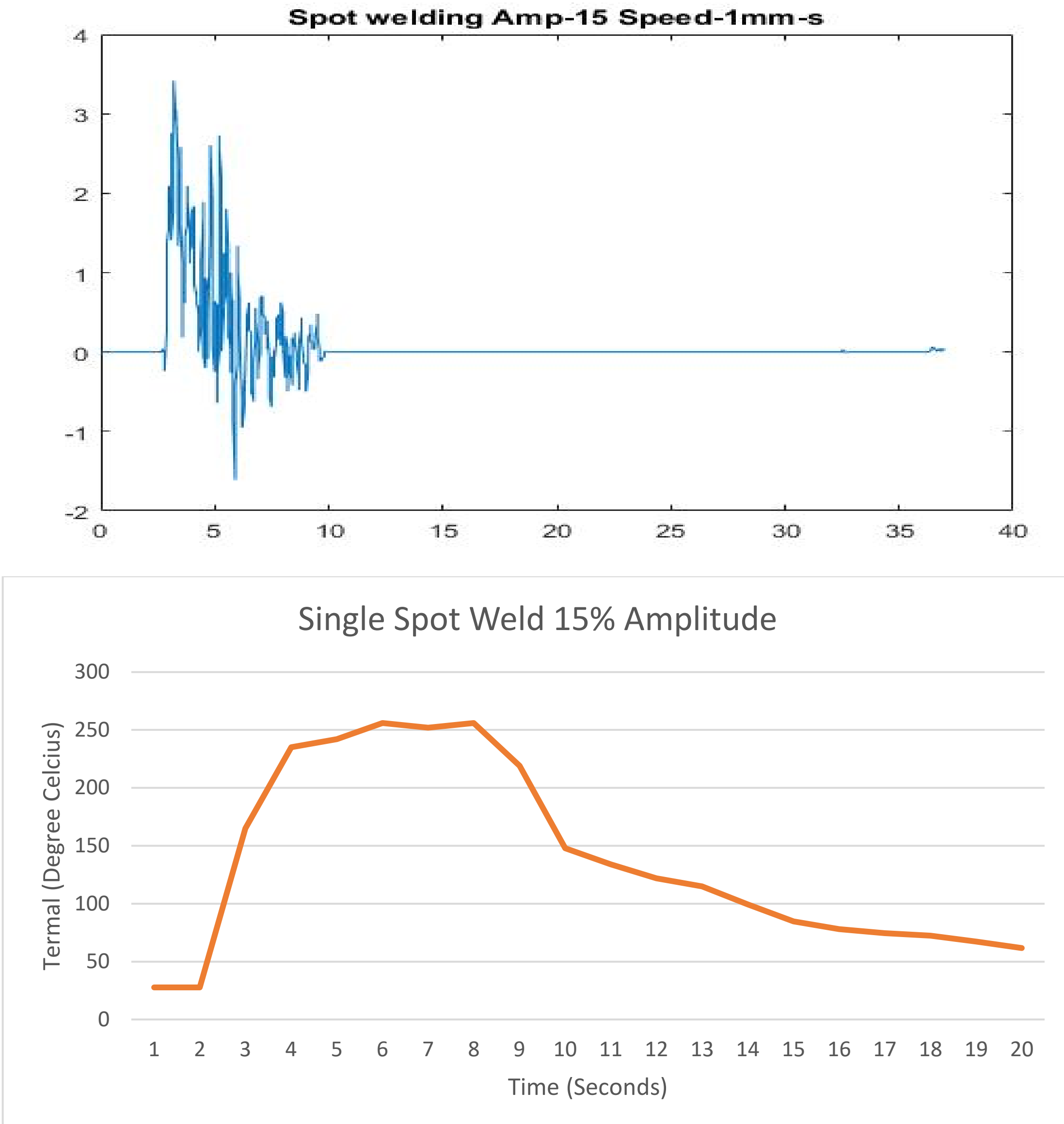

Figure 6b: Force and temperature vs time during low-power *spot* welding (15% power).

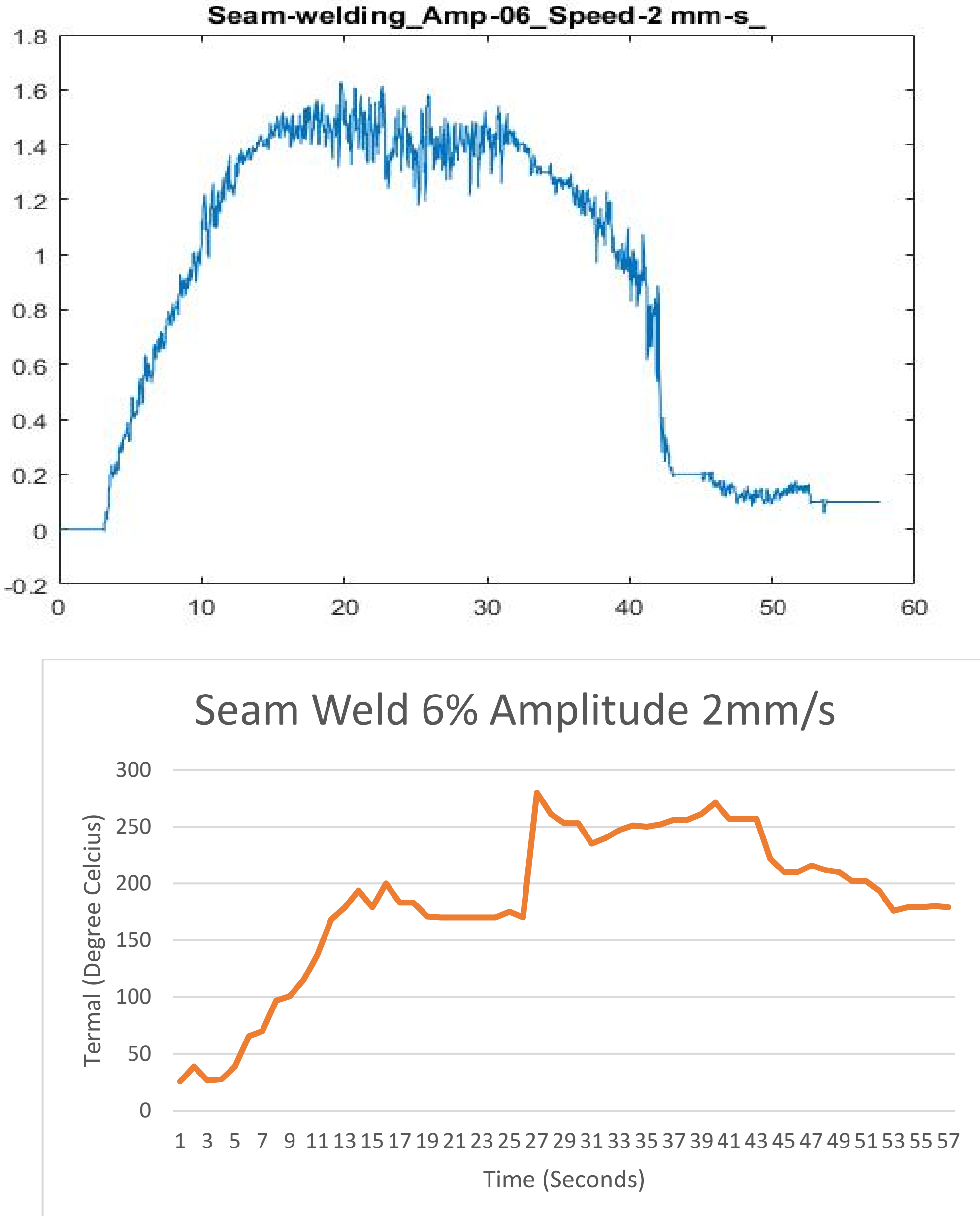

Figure 6c: Force and temperature vs time during low-power *seam* welding.

Figure 7: Stress testing of ultrasonic welded plastic parts.

Educational Objectives

This work will serve as a component of educational laboratories in Green Manufacturing, Robotics, and Quality Assurance. For most schools that have laboratories, the additional equipment used here can be acquired for modest cost (ultrasonic power supply and probe: $1000 to $3000, thermal camera: $1000 to $3000). These experiments make little demands on floorspace, and generate virtually zero waste. A lecture on the principles, characteristics, and applications of ultrasonic welding will precede the laboratory session. The laboratory objective will be to explore parameter space for welding (applied force, ultrasonic power, contact time), for specified acrylic plastic or polycarbonate workpieces. Students will work in groups of 3 or 4. Laboratory sessions will be scheduled for 2 to 3 hours. A structured format laboratory report will be submitted a week after completing the laboratory session.

Students learning will be assessed in the framework of our course evaluations, including program educational objectives and pre- and post-testing, as well as self-evaluations and surveys. Results will be presented at ASEE Conferences, where we will report in sufficient detail descriptions and operations for dissemination to other schools and institutions, along with student assessments and feedback.

Discussion and Summary

Ultrasonic welding provides a topical and instructive case study for industrial applications of robots. We are incorporating many aspects of engineering science and technology including 3d printers and rapid prototyping, thermal imaging, sensors, and applications for microsystems and microfluidics. We believe students will be motivated to see the use of robotic automation that greatly expands the scope and cost effectiveness of an important industrial process. The use of thermal imaging adds a new dimension to robotics education and also provides visual learners with intuitive understanding of the underlying process mechanisms.

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