College of Engineering
Department of Mechanical & Industrial Engineering

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School of Electrical Engineering & Computer Science

To Predict ▶ To Design ▶ To Perform

ME, ECE Capstone Design Programs

Team #15: 3D Printed Part Design and Build with Arc-Welding Metal Deposition

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Objective

The purpose of this project was to **design and build a pressure vessel with a maximum allowable working pressure of 300 psi** according to the American Society of Mechanical Engineers Boiler and Pressure Vessel Code. The build and design considered the limitations and improvements in the vessel manufacturing process afforded by using a Wire-Arc Additive Manufacturing (WAAM) Device.

Background

- Wire-Arc Additive Manufacturing Device designed and built by a 2016 Capstone Design team.
- Universal Robots UR5 robotic arm coupled with a Miller Continuum 350 GMAW welder.
- Weld beads were printed using a short-circuit welding process, 0.035" ER70S-6 weld wire, and 90% Ar – 10% CO_2 shielding gas.

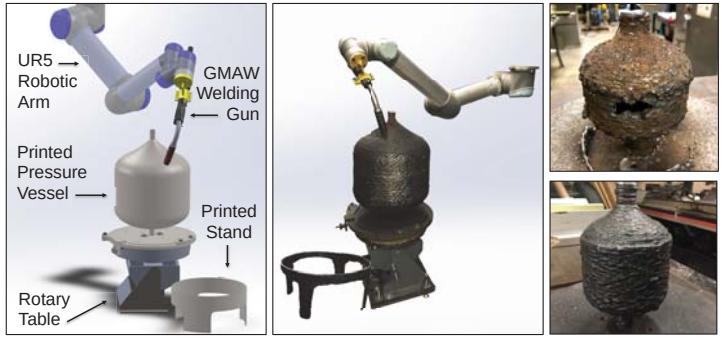
Manufacturing

Rotary table	Pause between layers	Tool Center Point (TCP) Reset	Heat & clean print before restarting
• Reduces UR5 orientation singularities • Increases print envelope	• Controls heat input rate allowing stiffer bead to form	• Allows print restarts • Allows reset without removal of build plate	• First bead showed better deposition • Allows bead to better adhere to print

Safety Considerations

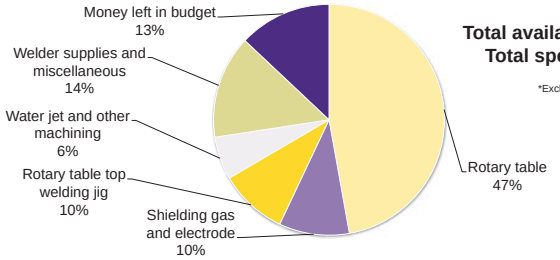
Pressure vessel	Concern: Pressure vessel fails unexpectedly
	Consequence: rupture creates harmful debris
	Mitigation: do not approach vessel while pressure testing, wear appropriate personal protective equipment while testing
WAAM device	Concerns: weld fume concentration, flying debris, flash burns, high voltage equipment, autonomous industrial robotic use
	Consequences: metallosis, cuts/burns, electrical shock, eye damage, bruises/damage to equipment
	Mitigation: remain outside of safety enclosure, revamp ventilation, emergency stop systems

Embodiment



Labeled model of the WAAM Device, its real-life counterpart with the 12" vessel, and an unsuccessful and successful print of a 4" vessel.

Budget



Total available: $4000
Total spent*: $3481

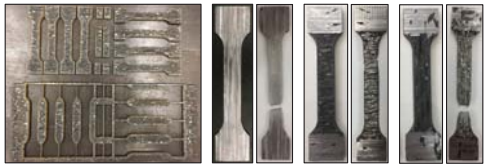
*Excludes $1810 spent on industrial computer

Engineering Specifications

Category	Constraint	Goal
Print Performance	Print's tensile strength	85% of parent material
	Print repeatability	1% of vessel diameter
Pressure Vessel	Maximum allowable working pressure	300 psi
	Test Factor of Safety	1.3

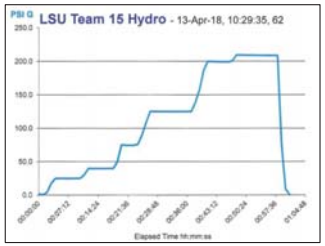
Testing & Analysis

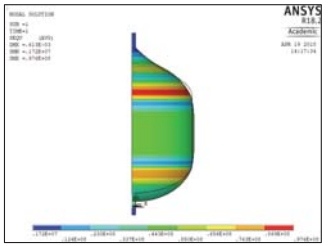
Left to Right:
- Samples for tensile, microstructure, and hardness tests
- Machined tensile test
- Vertical tensile test
- Horizontal tensile test



	Ultimate tensile strength [ksi]	Yield strength [ksi]	Print resolution width [in] (95%)
Sample Average With **Machined** Surface*	72.4	53.4	N/A
Sample Average With **Printed** Surface*	60.6	43.8	0.210 ± .01**
SA-350 Carbon Steel (Forged)	70	36	N/A

*Averages taken from two machined samples and two printed samples, respectively.
**Sample of 20 measurements for each test.





- Test prints and pressure vessels were printed by the WAAM Device using a short-circuit welding process to characterize its capabilities and printed material properties.
- 12" vessel leaked when pressurized to 210 psig. Radiography and hydrostatic tests were conducted at Smith Tank & Steel Inc.
- Finite Element Analysis performed on 12" vessel geometry found a factor of safety of 4.2 assuming uniform printed material characteristics.

September	October	November	December	January	February	March	April
Designed working safety system	Ran printer for test welds	Material tests on welds Finalized vessel design	Purchased rotary table	Test piece with overhangs	Printed test shell	Printed test head Printed shell, head, stand	Printed pressure vessel Pressure vessel test

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