Weld Integrity of Stainless-Steel Frying Baskets

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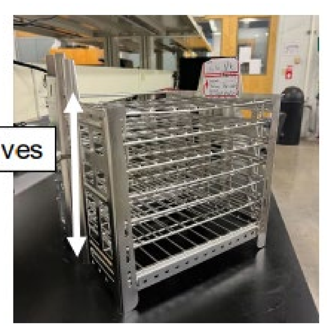
This project investigates the failure of stainless-steel wire basket T-welds. Voids were identified in the weld and attributed to incomplete penetration depth. The following weld parameters were varied: fitment, amperage, and wire size. X-ray Computer Tomography (XCT) was performed to characterize void size and shape, confirming the hypothesized lack of fusion in the weld interior. Tensile testing of samples was performed to assess the strength associated with each combination of parameters. The best combination of parameters was determined from the data collected.

This work is sponsored by a Chicken Quick Service Restaurant

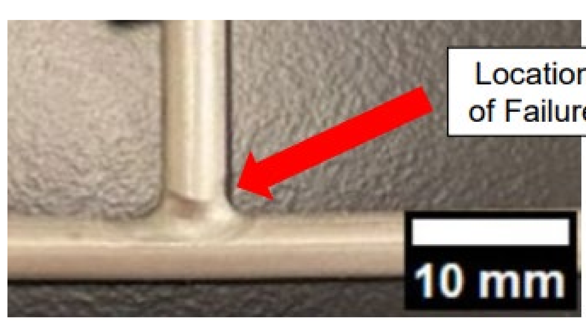
Introduction & Motivation

Problem Statement:

- Fry baskets are critical pieces of equipment in the fast-food industry
- Baskets currently last 25-50% of expected lifetime
- Broken baskets decrease production capacity by up to 33% and cost $400-$1000 dollars to replace, limiting sales and profit
- Reducing or eliminating early failure improves efficiency and profit



Fry Basket



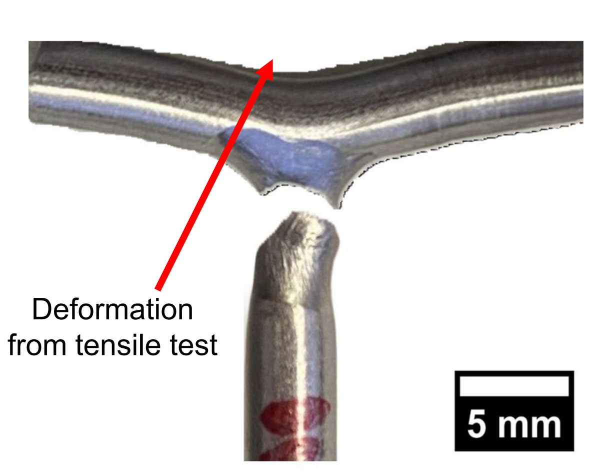
TIG-welded stainless steel wires [3]

Project Scope:

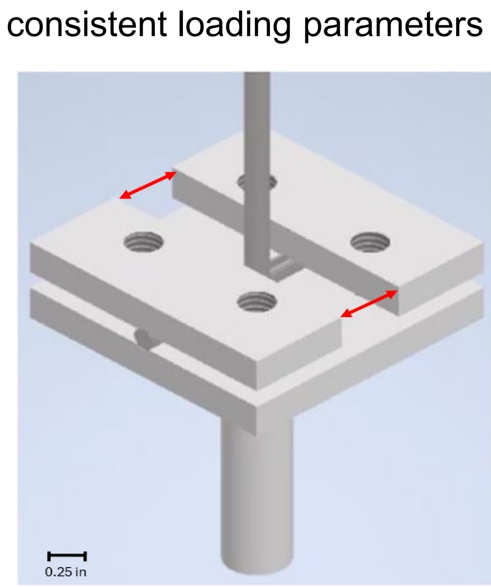
- Cause of premature failure is weld failure, with Tungsten Inert Gas (TIG) welds being the primary source of early failure
- Incomplete weld penetration correlated with decreased strength
- Investigate and tune weld parameters to ensure complete weld penetration and improve strength

Tensile Testing

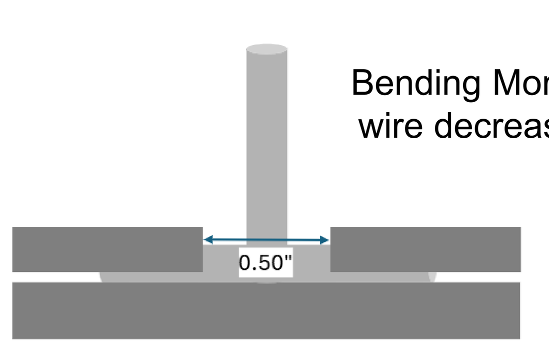
- Specialized tensile rig allows for uniaxial tensile testing
- Decreased gap to prevent excess bending before failure
- Two tensile rigs designed to ensure consistent loading parameters for both sample diameters



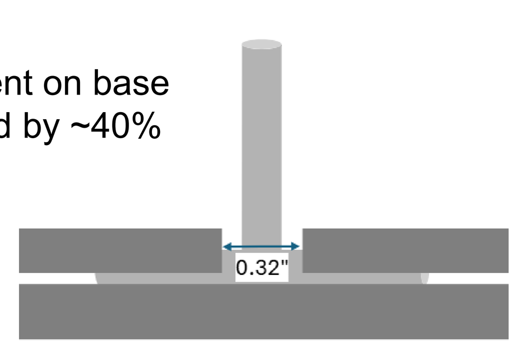
Excess bending deformation of samples tested in previous tensile rig [3]


Decreased gap in new tensile rig [3]

Bending Moment on base wire decreased by ~40%



Large gap in old tensile rig

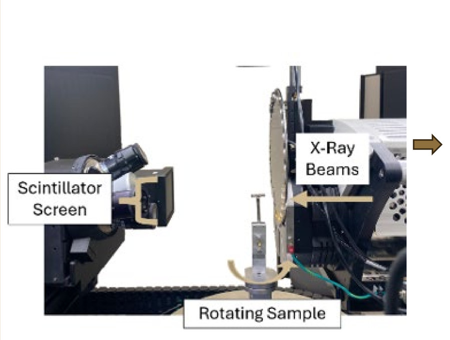


Reduced gap in new tensile rig

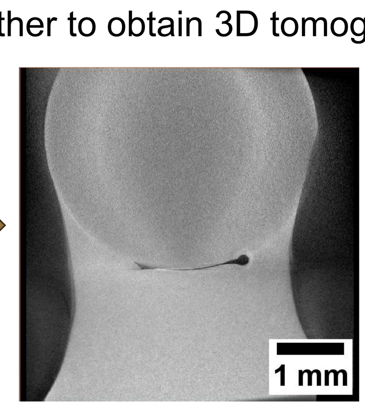
X-Ray Tomography

How XCT works:

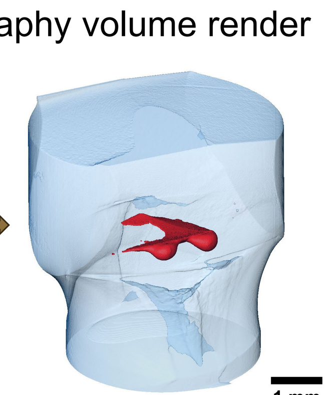
- Camera rotates around sample, taking orthographic scans at each angle
- 1600 scans taking for one sample
- Scans are spliced together to obtain 3D tomography volume render



XCT Testing Schematic showing projector, receiver and mounted sample [3]



Orthographic Projection of weld XCT scan oriented with the T of the weld end-on



Processed tomographic image with void defect (*red*) inside the weld (sample G1)

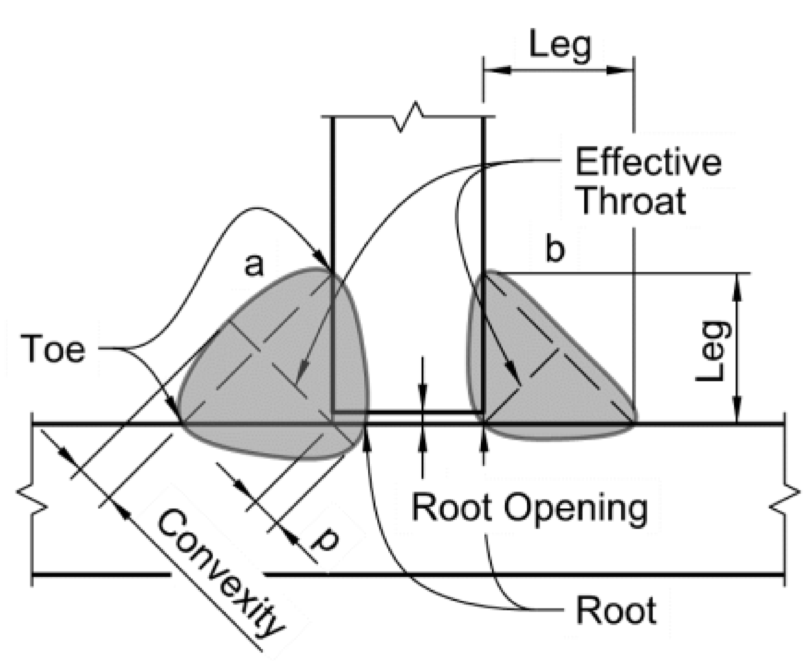
Benefits of XCT for Weld Defect Analysis:

- Characterizes volume and sphericity (shape parameter) of the weld defect non-destructively
- Subsequent tensile testing may be performed on the same samples to determine the relation of defect size and shape to tensile strength

Weld Parameter Analysis

Fitment Parameter:

- Weld fitment determines the root opening of the weld to intentionally leave a gap between the pieces during welding.
- A larger root opening (looser fitment) can allow for better weld penetration by increasing filler flow to the weld interior. [1]



Components of a T-weld diagram showing root opening [4]

Current Parameter:

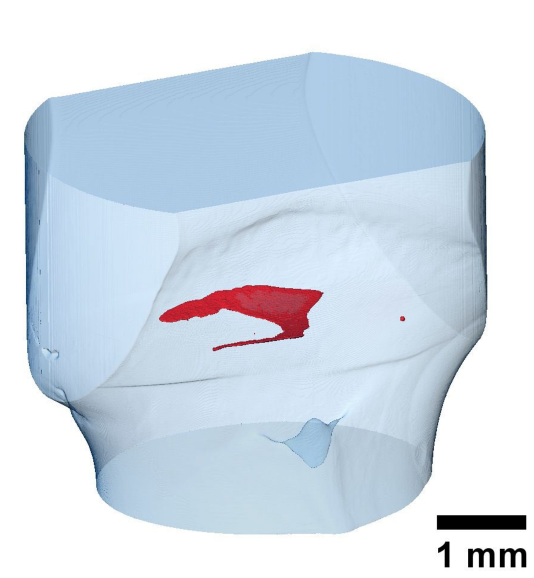
- Current applied to during welding affects weld strength and influences weld penetration. [2]
- Higher amperages can increase penetration by putting more energy in the liquid phases, but they also can introduce spatter and irregularities in welds, leaving void spaces.

Sample Testing Order

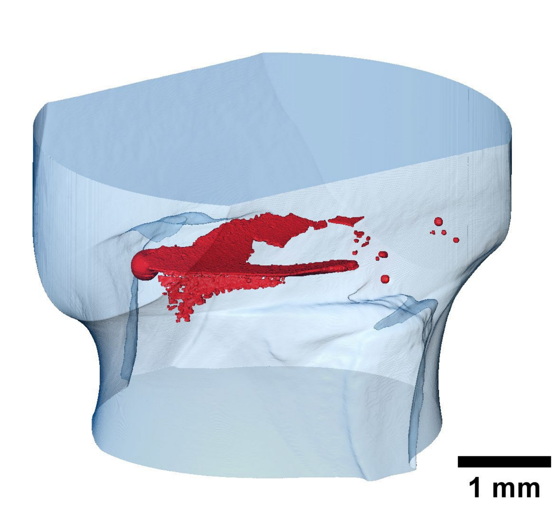
- Samples with lower wire diameter were chosen to be scanned first as it reduces XCT exposure time.
- Fitment type was chosen as the most important parameter as it was determined to have the largest effect on weld strength.
- Amperages were chosen by manufacturer as possible currents for welding.

XCT Tomography Volume Renders

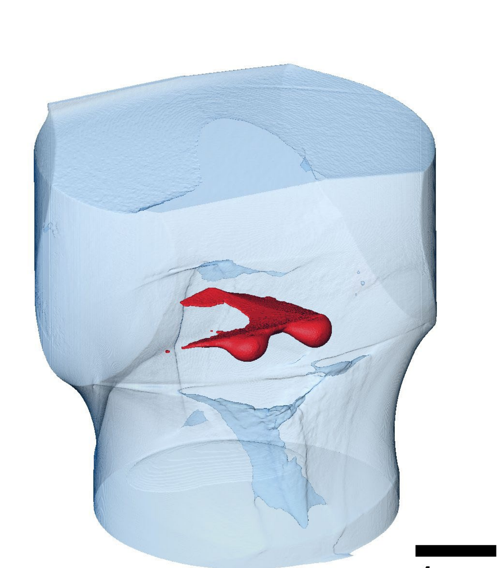
- Central voids shone in red.
- All scans are from 0.148" diameter sample.



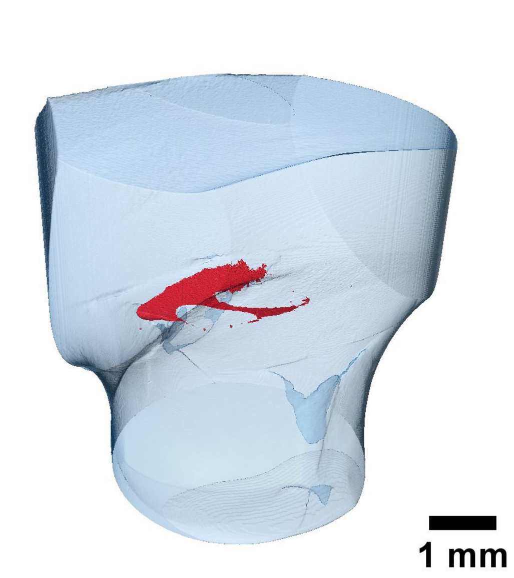
XCT scan of sample E1 weld with parameters: 100 Amps, Tight Fitment



XCT scan of sample F1 weld with parameters: 80 Amps, Tight Fitment

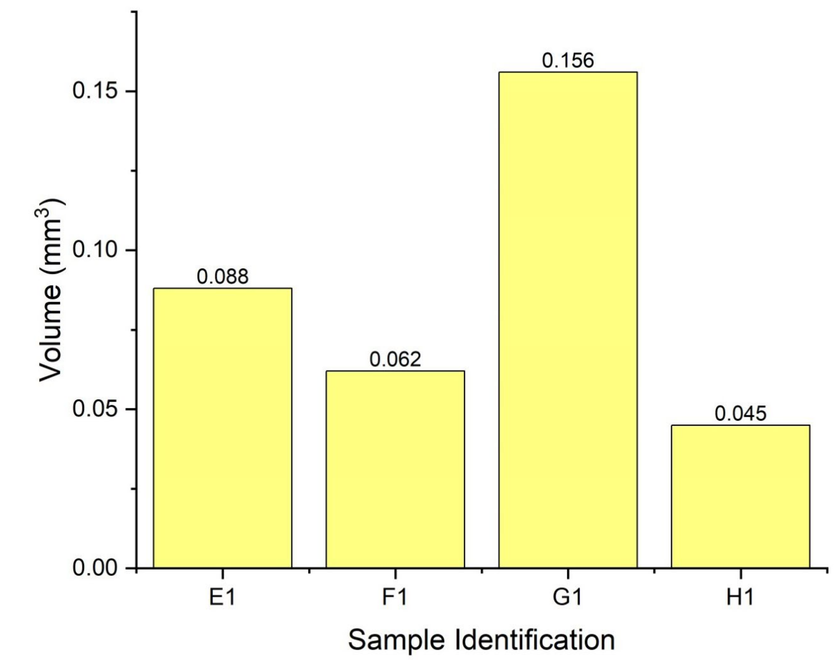


XCT scan of sample G1 weld with parameters: 100 Amps, Loose Fitment

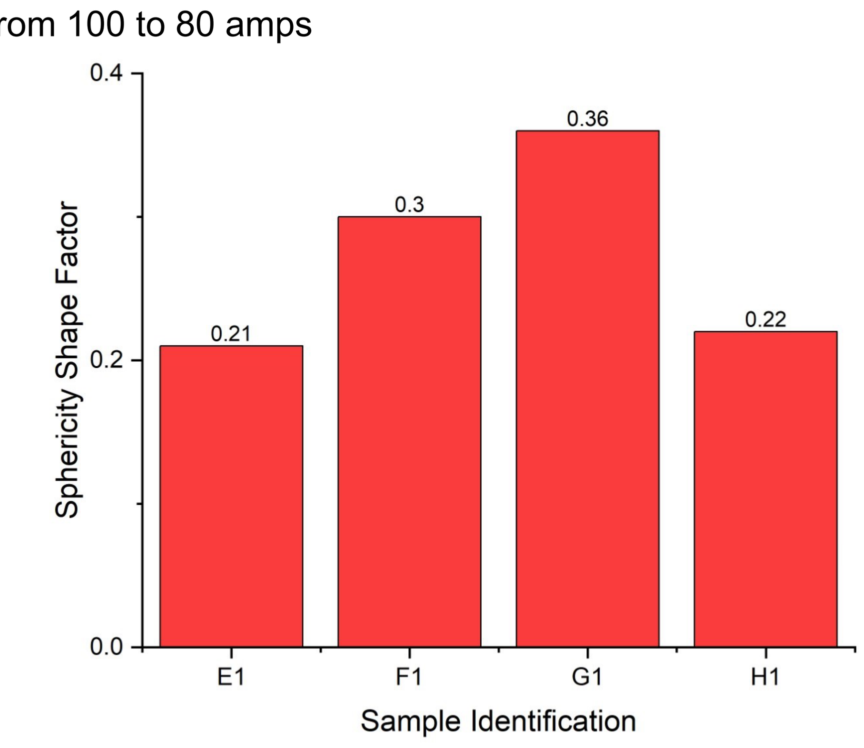


XCT scan of sample H1 weld with parameters: 80 Amps, Loose Fitment

Results



- The volume of the void within weld decreases the amount of load bearing material in weld
  - Increases stress concentration and decreases weld strength
  - Some decrease of volume correlated with decrease in current from 100 to 80 amps



- Sphericity has weak positive correlation with weld strength, as spherical voids reduce crack propagating stress concentrations [3]
- Sphericity calculation shown in equation below:

$$\psi = \frac{\pi^{1/3}(6V_p)^{2/3}}{A_p}$$

Ψ = sphericity factor
V_p = void volume
A_p = void surface area

Conclusions

- Definitive conclusions have not yet been reached; more sample scans and tensile tests will need to be performed to make more meaningful conclusions.
- Incomplete weld penetration defects were found across all weld parameters as a flat central void. Acting as a root opening crack, crack growth would cause failure at lower than predicted loads.
- Full penetration welds would eliminate root opening and greatly increase the strength of the weld by removing the common weld defect across our samples.
- To achieve full penetration welds, geometry of the joined pieces should be changed to one of the geometries shown immediately right.

Acknowledgements & References

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References

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2. D. Sugitani, M. Masahito, "Experimental Study on Effects of Root Gap and Fillet Size of Welds on Joint Strength", *Quart. J. Japan Weld. Soc*, 31 104-108 (2013)
3. A. Tomkins, B. Jennings, J. Stegmann, M. Berman, D. Sinclair, N. Chawla, "Failure Analysis of Stainless-Steel Frying Basket Welds", *Purdue Materials Engineering Senior Design Project.* (2024)
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