Thermal Cyclic Damage of Stainless Steel Frying Baskets

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A quick service restaurant (QSR) chain observed certain fryer baskets breaking at near half their projected life expectancy. The focus of this project was to design and build a jig for thermal cycling samples. With a jig constructed to conduct thermal cycling experiments successfully, x-ray tomography was performed on sectioned samples to assess the starting microstructure and changes. While no changes in microstructure were observed, potentially in part due to a low quantity of cycles performed due to time constraints, structural issues were discovered with voids in weld sites of the basket. Voids cause large stress concentrations which may be promoting crack growth.

This work is sponsored by:
Quick Service Restaurant Chain

Background

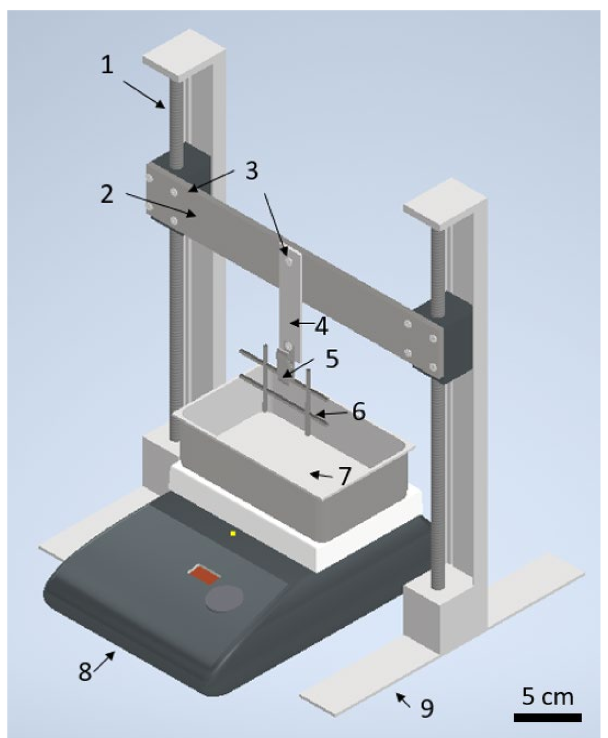
Certain fryer baskets used by an anonymous QSR were projected to work in the restaurant for around a year, but the baskets instead fractured around 6 months into use. Multiple different factors may play into early fracture: corrosive wear, thermal expansion-related fatigue on joints, and inherent mechanical issues were addressed as possible causes of early fracture.

In stainless-steel baskets, there is a possibility during welding for localized heating effects to produce chromium carbide particles, which have the potential to weaken the surrounding area. Additionally, the most common stainless to use for products like fry baskets, stainless steel 308, has a slightly dissimilar thermal conductivity to the metal used for weld fill, stainless 316. This discrepancy may cause one to absorb heat faster, and as a result expand and contract more quickly when exposed to drastic changes in temperature. This inequal expansion may then cause cyclic strain at boundaries between the two metal types, which ultimately may contribute to mechanical weakening and ultimately fracture.

To test for changes in material structure, a jig was constructed with the purpose of uniformly exposing and removing a basket sample to and from a bath of oil, heated to temperatures resembling those reached during fry times in a restaurant.

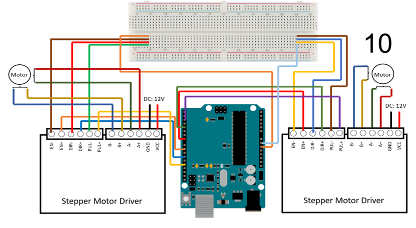
To internally image samples, x-ray computed tomography (XRCT) was used, a technique of firing x-rays at a sample from multiple angles to construct a cross-sectional 2d image of the inside of a sample using differences in returned energy and how far the x-ray travels. These 2d images are then layered to create a comprehensive 3d model of the sample being scanned.

Experimental Procedure



Thermal Cycle Jig Design

1. Linear rail guides
2. Aluminum cross bar
3. Fasteners
4. Aluminum extender
5. Stainless steel clip
6. Fry basket sample
7. Steam pan
8. Hot plate
9. Aluminum stabilizing plate
10. Arduino wiring



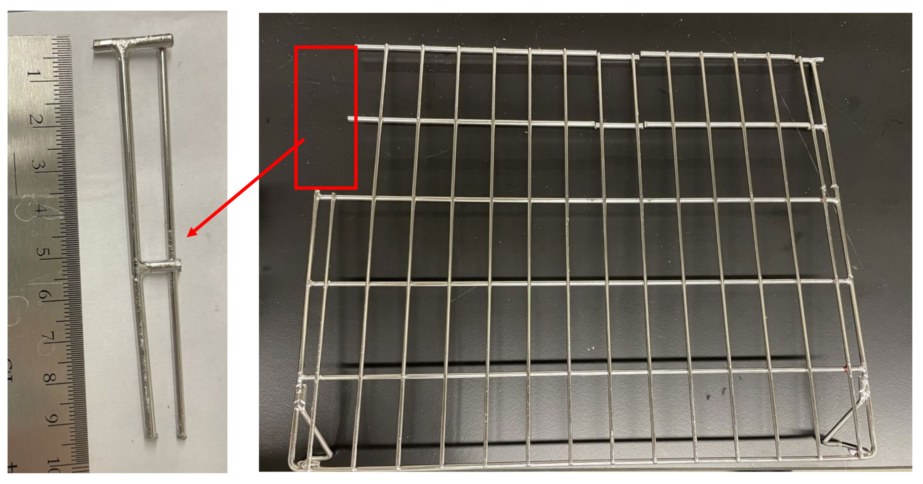
Arduino Code

- Programmed with Arduino IDE using C++ programing language
- Single cycle
  - Lowers to hold sample 4 minutes in oil
  - Raises to hold sample 2 minutes in air

Sample and Thermocouple Setup

- Vertical sample orientation in clip
- Thermocouple clipped to extender with tip touching bottom right weld

Sample Preparation

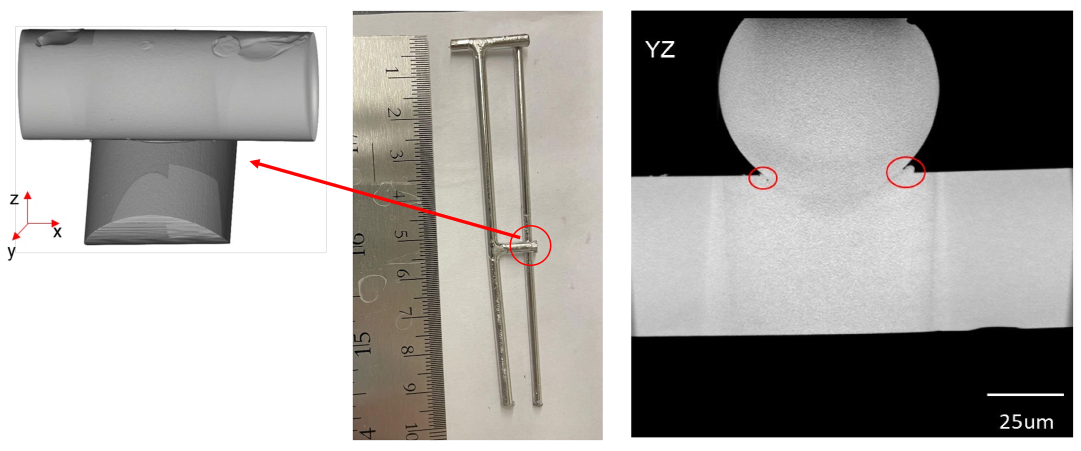


- Samples cut using a Dremel with a carbon fiber reinforced cutting wheel
- 3D images rendered using x-ray tomography
- Weld temperature collected via thermocouple

X-Ray Tomography of Welds

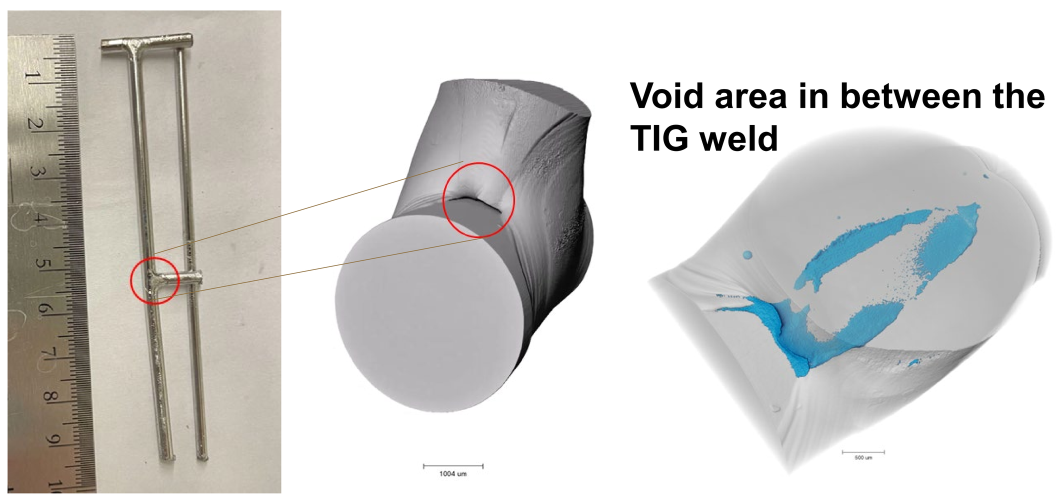
Pressure Welds

- No gap between the wires in the middle of the weld
- Gaps at side of welds where cracks can initiate

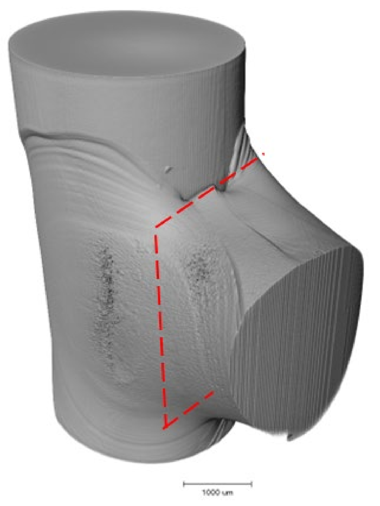


TIG Welds

- Large gap between the two wires causes large stress concentrations
- Insufficient welding throughout weld and visible on the edge

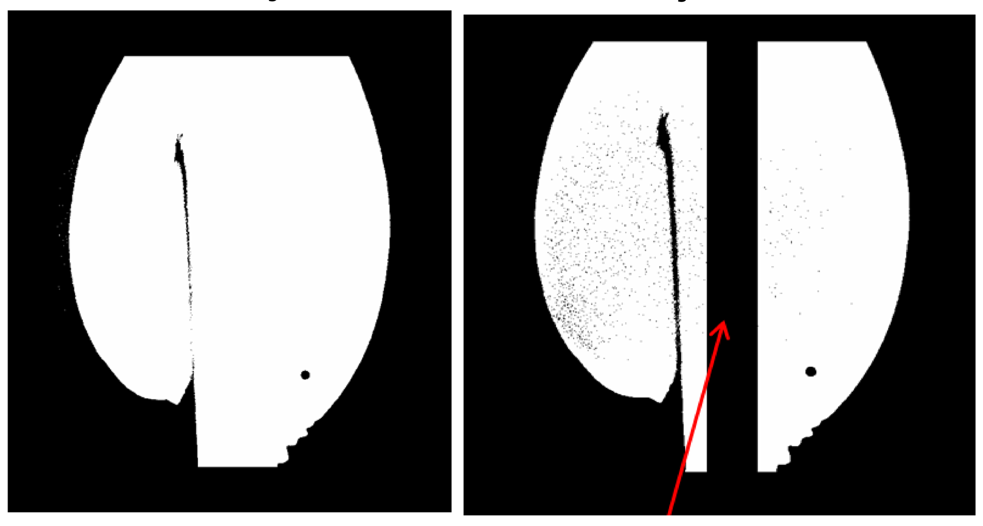


Void Area Effect on Stress



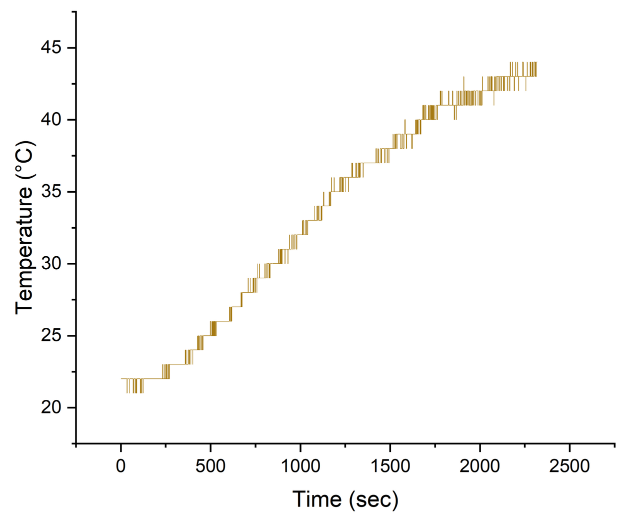
- Ideal total area bonded area = A1
- Actual area = A2
- Ratio of the two areas as calculated
  $A1/A2 = 1.5$
- Stress if total area is bonded
  $\sigma 1 = F/A1$
- Actual stress
  $\sigma 2 = F/A2$
- Increase in Stress
  $\sigma 2 = 1.5\sigma 1$

Ideal total area at the TIG weld joint | **Actual area at the TIG weld joint**



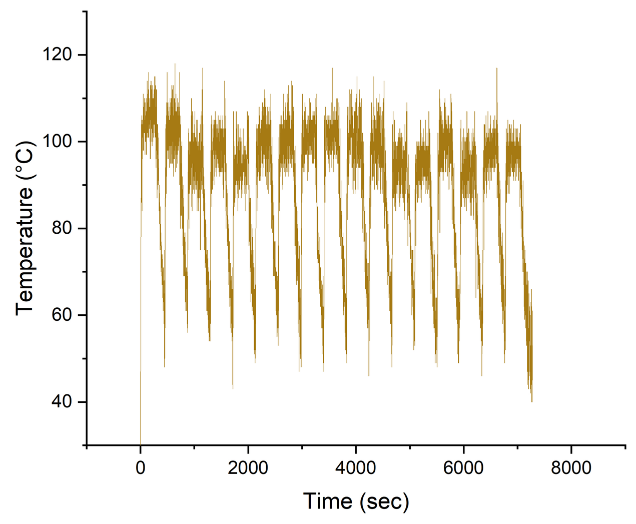
Region of no-contact

Thermal Cycling Weld Temperature



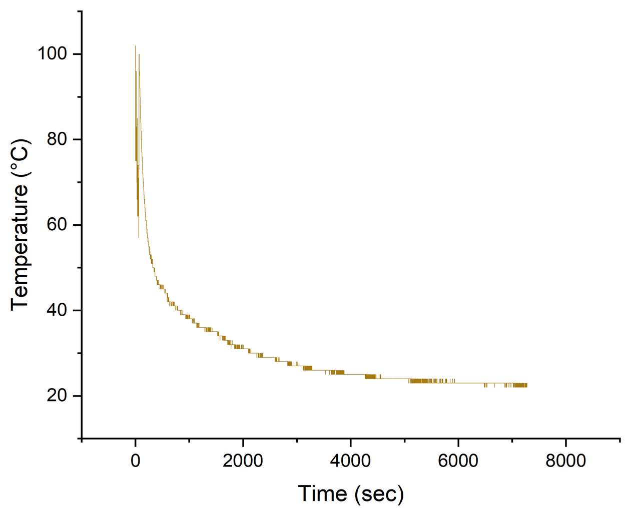
Hot Plate Heating

- The ambient temperature became about 40°C once the oil reached cooking temperature



Cycles

- Average temperature of sample in oil about 112°C
- Average temperature of sample out of oil about 45°C



Complete Cool down

- Sample takes 1 hr 23 min to cool to room temperature

*All temperatures displayed are approximate.

Discussion

The creation of the thermal cycling jig proved to give replicable cycling abilities, as was seen in the consisted weld temperature data collected. With the ambient temperature becoming around 40°C upon heating of the oil, the weld was unable to cool to room temperature, although a difference of about 67°C was achieved between positions.

The tomography, however, did prove very useful at characterizing the basket welds in a non-destructive fashion, allowing for the observation of the structure of the baskets; most critically, it allowed observation of the voids present between the wires at weld joints. This error with the baskets could singlehandedly decrease performance of the baskets mechanically and is likely to play a large role in premature fracture of the baskets prior to their expected failure.

These voids are likely to act as a location for local stresses to accumulate, which may then be exacerbated by effects of thermal cycling such as thermal expansion stresses at weld joints. It is likely a combination of these two effects which so drastically decreases the lifetime of the baskets short of the expected longevity.

Conclusions

- Produce replicable procedure for thermal cycling basket samples
  - Average sample temperature in and out of oil 112°C and 45°C respectively
- Tomography indicates large voids in welds from incomplete welding
  - Most likely cause of failure
- **Recommendations**
  - Further analysis of thermal cycling effects on weld sites
  - Add a cooling element to thermal cycling to increase temperature change
  - Investigate weld strength and compare to size of voids from insufficient penetration depth

References

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