Investigating Acrylic Aquarium Failures

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Introduction

- A number of large aquariums have failed in public areas and in homes resulting in extremely large losses.
- With the correct engineering analysis, “how” and “why” these failures occurred can be established.
- Though this presentation is on aquarium failures, acrylic is used for numerous applications where the concepts presented may be applied.

Aquariums

- Range from 10 gallon hobby to 13 million gallon public aquariums.
- Public aquariums that are 500 – 100,000 gallons are popular in malls, restaurants and lobbies.
- Increasing number of one million+ aquariums are being constructed at zoos/aqua centers.
- Race is on to make bigger aquariums – more extreme

Aquariums – Private (1300 gal)

Aquariums – Semi-Private

Front Lobby
Source: Living Color

Aquariums – Public

Mall
Source: Living Color

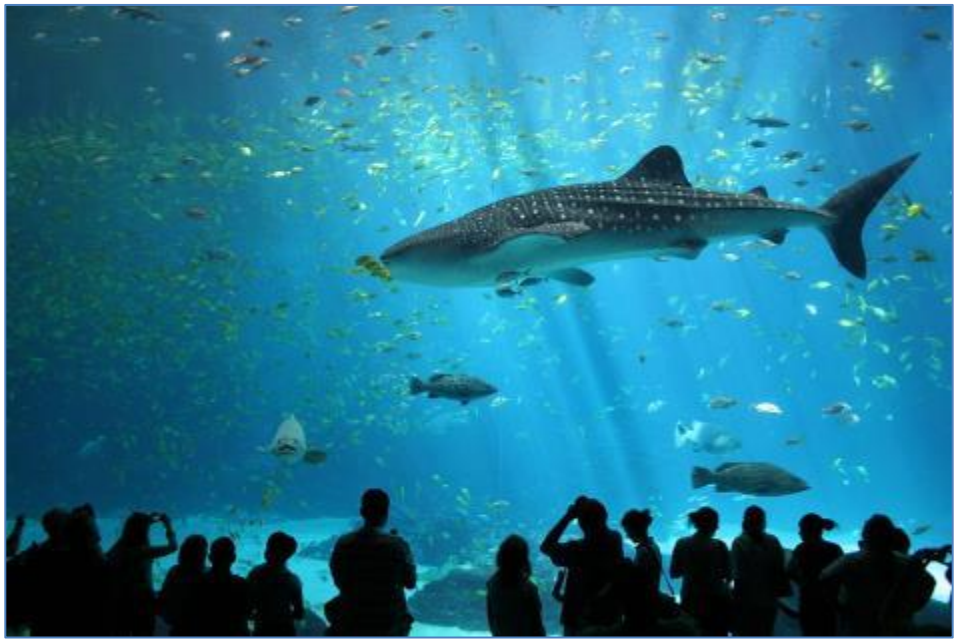
Aquariums – Public

T-Rex Restaurant
Disney

Aquariums – Public

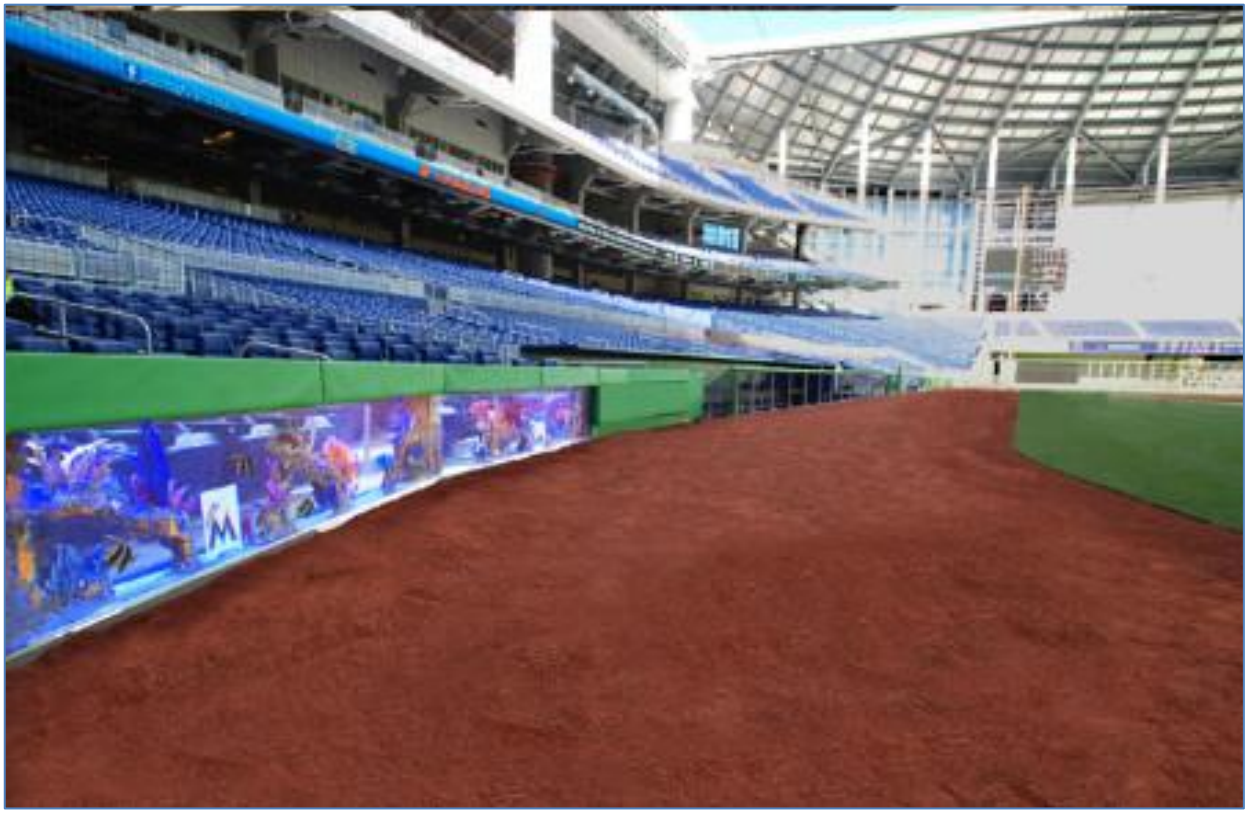
Burj, Dubai Restaurant

Aquariums – Public



Georgia Aquarium

Aquariums – Public



Marlins Professional Baseball Stadium

Aquariums/Pool – Public

Hotel
Source: Reynolds Polymer Technologies

Aquariums

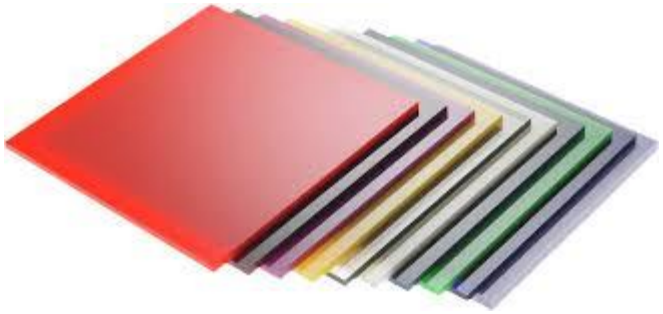
- Must perform in many different environments.
  - Sunlight
  - Thermal changes
  - Fresh and salt water
- Aquarium will be exposed to various chemicals and stresses.
  - Food materials
  - Alcohol
  - Chlorine
  - Impact (baseball, people hitting)

Material of Large Aquariums

- Made of plastic – not glass.
- Poly(methyl methacrylate) (PMMA) – a.k.a. Acrylic, Plexiglas™
- Benefits of Plastic
  - Design/shape flexibility
  - Shatter/ impact resistant (not as brittle as glass)
  - Extremely clear
  - Joining large sections together to create huge tanks
  - Half the weight of glass
  - Chemical resistance is good
- Possible Issues
  - Scratch resistance
  - Assembly needs to be very accurate with no added stress
  - Plastic moves over time – creep/rupture
  - Chemical resistance is lower than glass
  - Extremely notch sensitive.

Other Uses of Acrylic

- Large windows
- Lighting
- Art
- Translucent roofing
- Underwater (high pressure) windows
- Hyperbaric chambers
- Tubing, cylinders, sheets……



Making Large/Thick Panels

- Casted – poured into mold. Very common.
- Continuous casted – poured on to convey belt and allowed to polymerize and cool to shape
  - Stress ~free
  - High clarity
  - High molecular weight -> high mechanical properties
- Other products can be injection molded, extruded, compression molded.

Ref: Avonite

Making Large/Thick Panels

- Shapes are heated and formed into shape
- Panels are typically placed in oven to release stresses
- Panels are then prepared prior to assembly

Ref: ATL (Aquarium Technology)

Ref: Reynolds Polymer Technology

How Large Aquariums are Made

Each Step is Critical to Ensure Failure Does Not Occur:

- Large panels are made by casting large panels into exact shape.
- Surfaces to be bonded are prepared smooth, free of particles. Sometimes a spacer is placed between curved panels.
- A syrup and/or solvent adhesive is carefully applied to both sides of spacer and sides of both panels.
- Panels fitted exactly together – not forced into shape.
- Held in place to allow molecular bonding from panel to panel.
- Bonded joint will typically retain 70 – 90% of panel strength.

Ref: ATL (Aquarium Technology)

Large Aquarium Failures

- T-Rex Disney

Large Aquarium Failures

- Gulfstream Casino – Hallandale, FL

Large Aquarium Failures

- Lotte Tower, Seoul, South Korea (5th tallest building)

Crack formation at seam

Large Aquarium Failures

- Burj Tower, Dubai (Mall attached to tallest building)

Extensive Amount of Equipment Runs & Supports Aquarium

- This equipment can be located directly below aquarium.
- Aquarium leak can result in damage to this equipment.

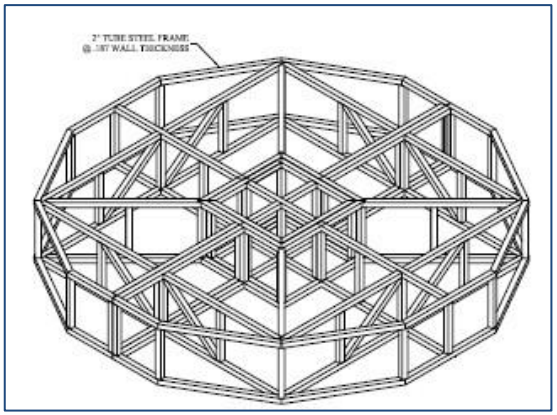
Ref: Living Color

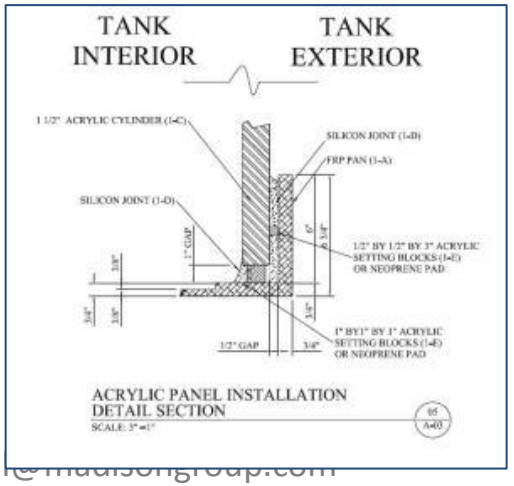
What can cause tanks to fail

- Manufacturing
  - Very good acrylic must be used
  - Shape/size has to be exacting
  - No flaws can be present in panels
  - No/little molded-in stress – result in creep of plastic
- Assembly
  - Assembly of tank is critical to ensure tight fit with no added stress
  - Panels cannot be forced together during assembly.
  - Adhesive process is critical
    - Proper adhesive.
    - Proper application

What can cause tanks to fail

- Installation
  - Loads must be distributed evenly throughout the tank.
  - Tank must be installed level with no twisting.
  - Tank stand must be solid – cannot move over time or if/when tank is bumped.
  - Joints are designed to be water tight and absorb shocks to system.
  - Correct sealant must be used (e.g. Dow Corning 795).
  - Correct amount of sealant – too little or too much can lead to failure.
  - Damage in form of deep nicks or gouges can lead to failure.





What can cause tanks to fail

- Maintenance
  - Tank should be kept clear of external loads – but design should expect some un/expected loads/impact.
  - Acrylic does have issues with certain chemicals – thicker panels and proper installation can increase resistance to chemicals. Possible issues with:
    - Alcohol
    - Acids
    - Aggressive solvents
    - Aggressive/industrial cleaners (strong chlorinated)

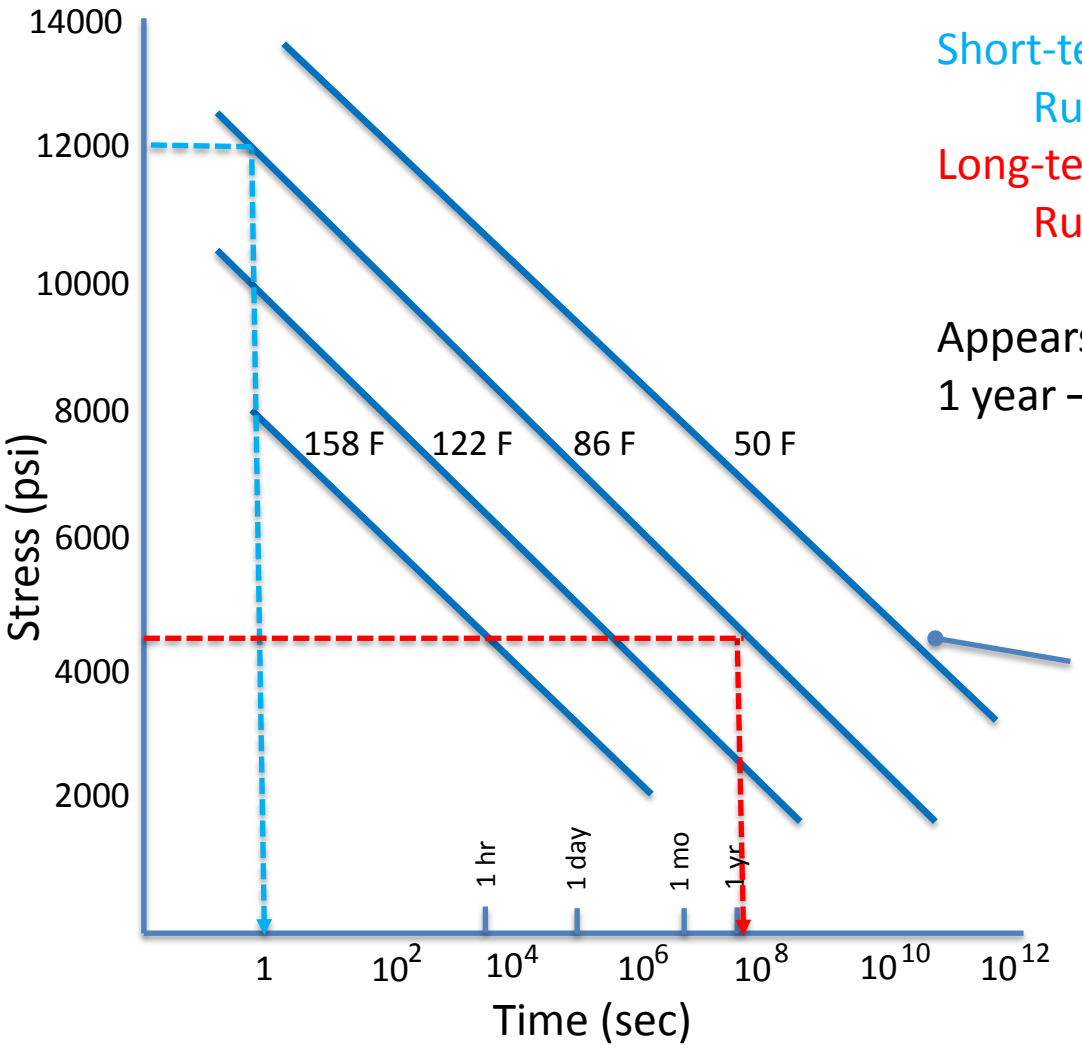
Failure can, and usually does, occur months or years after tank has been exposed to root cause of failure.

Strength of Acrylic Decreases Over Time

- Most aquariums are over designed with significant panel thickness.
- The typically design factor of safety for this application is 11 – 14x.
- At room temperature, the design stress for a 10 year life is 1500 psi [10.3 MPa] and for 20 year life it is 650 psi [4.5 MPa].
- The maximum flexural strain is typically 7%, but should be kept well below this.
- The creep rupture strength of acrylic will decrease significantly over time – see next graph.

Creep Rupture Curve for Acrylic

Time to failure for specified stress, at various temperatures



Short-term (1 second):

Rupture Stress: 12000 psi

Long-term (1 year):

Rupture Stress: 4500 psi

Appears strength reduces by 60% in 1 year – in reality it does not

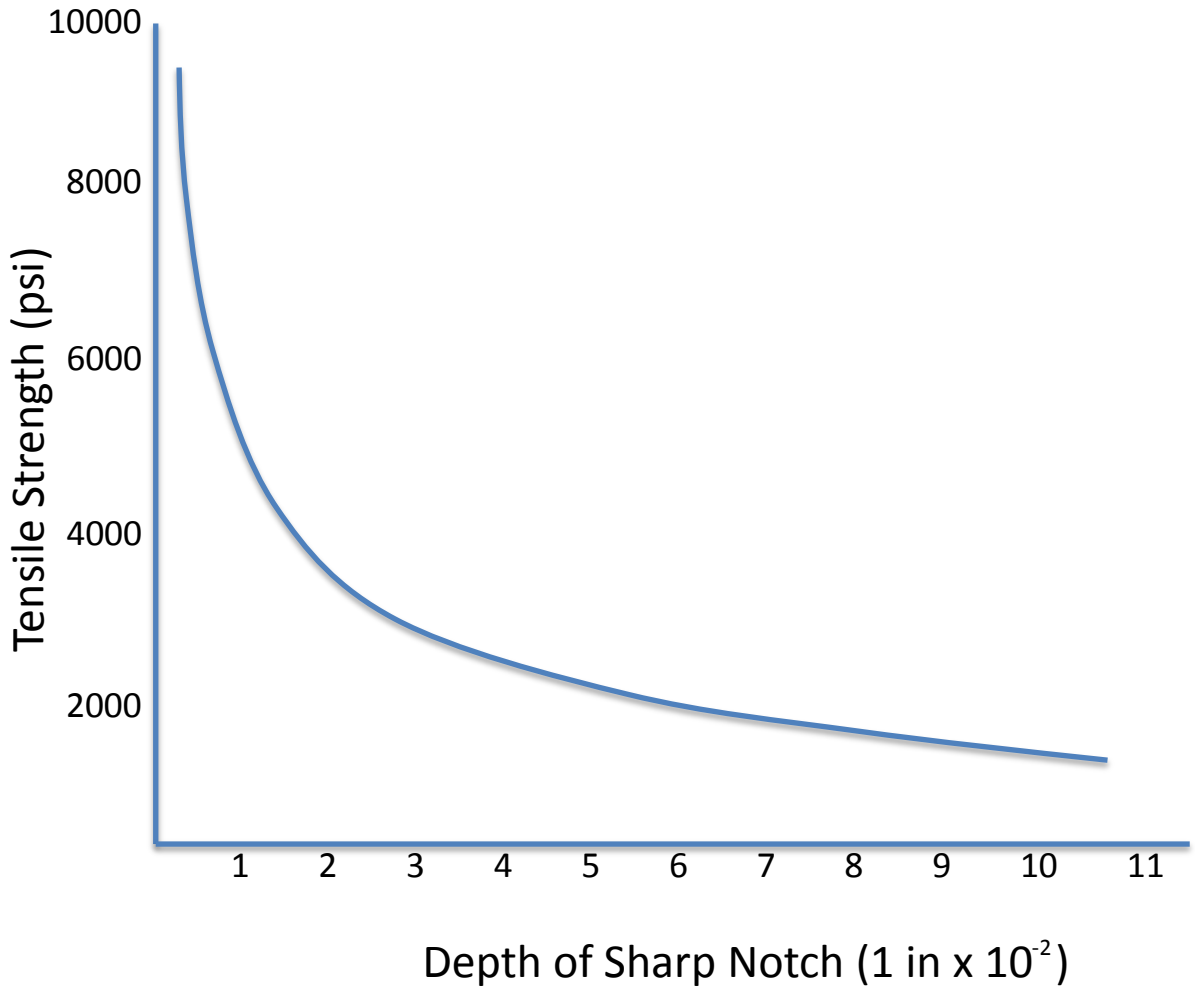
Point where material will rupture

Ref: Lohr, Willson, Hameker, Stewart, AIAA/ASME Proceedings, March, 1967

Acrylic is Notch Sensitive

- Care must be taken during production, installation and while in service that the acrylic panel does not experience sharp notches.
- Sharp notches can result in crack propagation over time and lead to catastrophic failure.
- The tensile strength reduces tremendously as depth of notch increase.
- A sharp notch/scratch 0.01 in [0.25 mm) depth can decrease the tensile strength of the panel by 50% - see next graph.
- Thickness of panel and factor of safety typically account for expected pedestrian scratches.

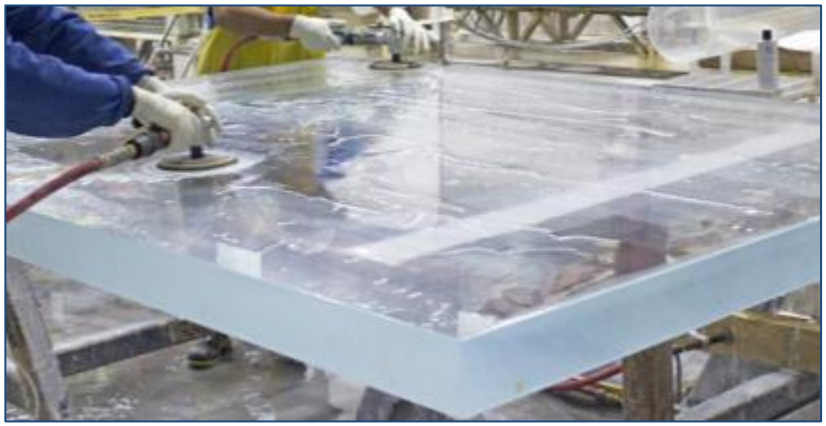
Acrylic is Notch Sensitive

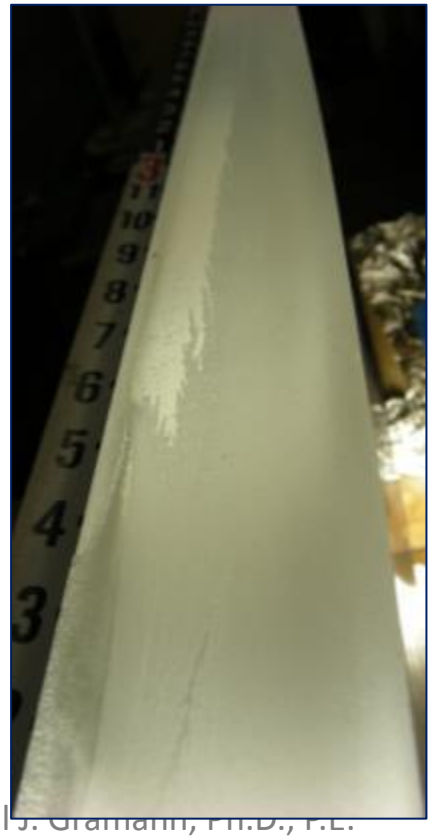


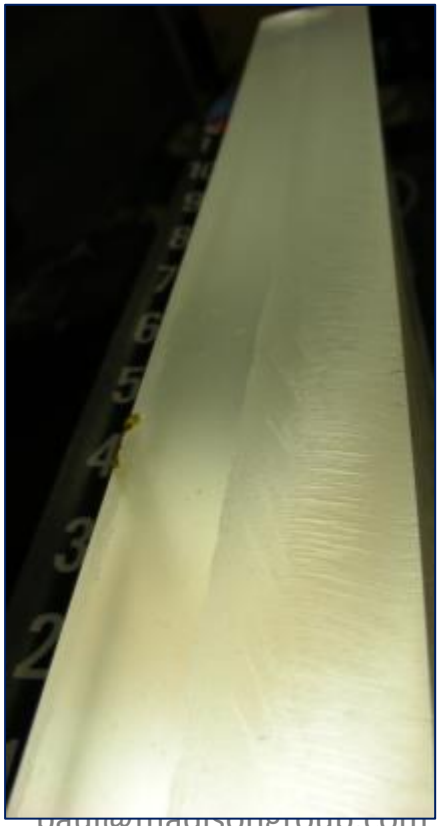
Ref: Berry, J.P., "Brittle Behavior of Polymeric Solids," Fracture Processes by Polymeric Solids, Interscience, 1964.

What can cause tanks to fail

- Poor Bonding







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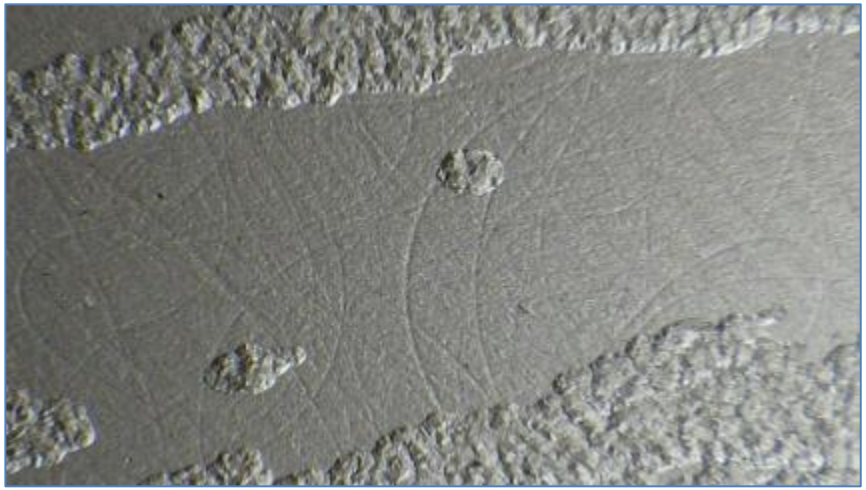
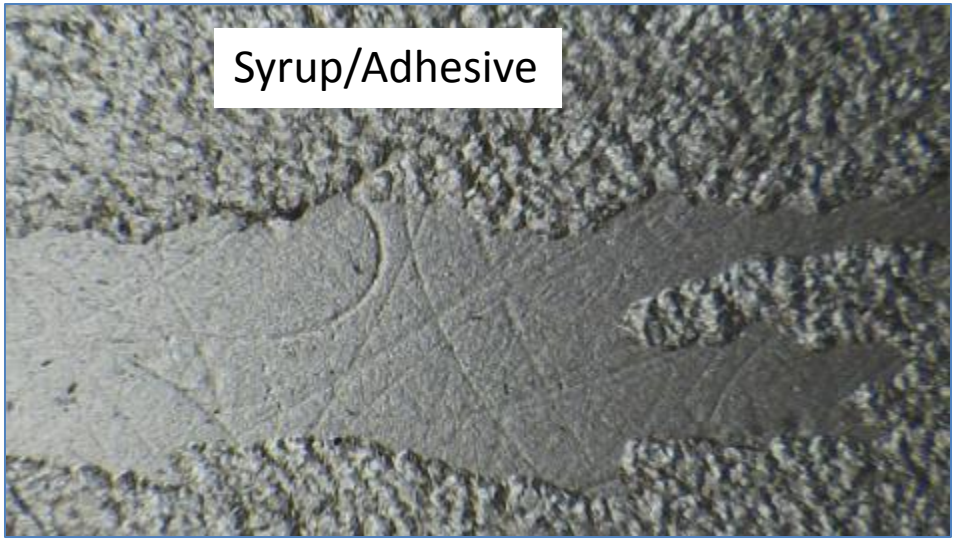
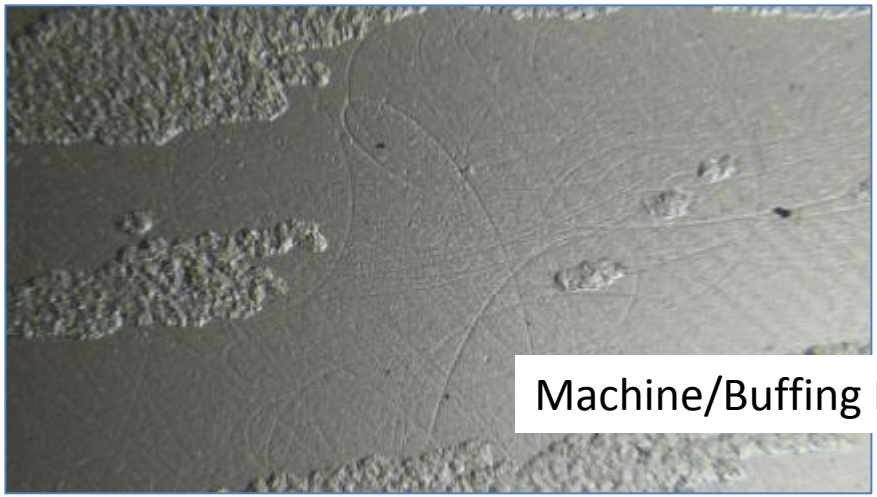
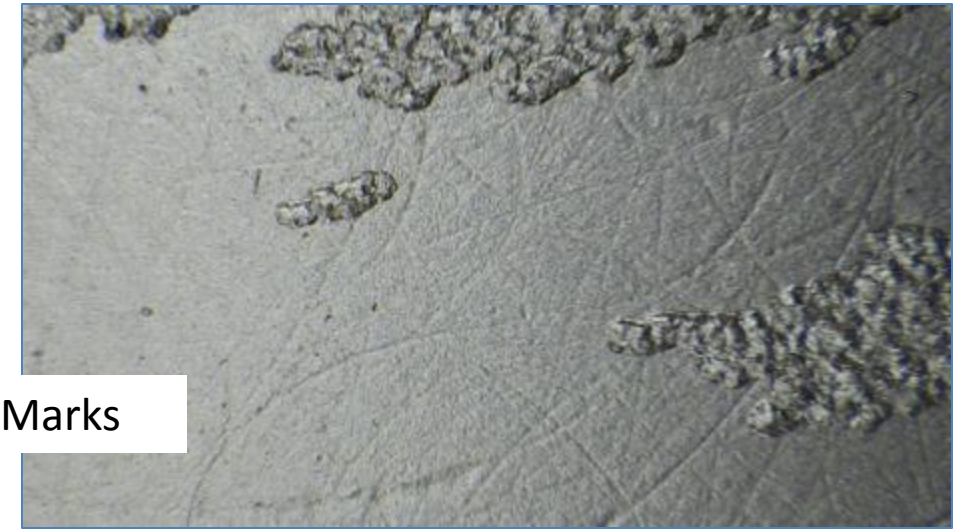








Methods/Tools to Help Determine the How and Why

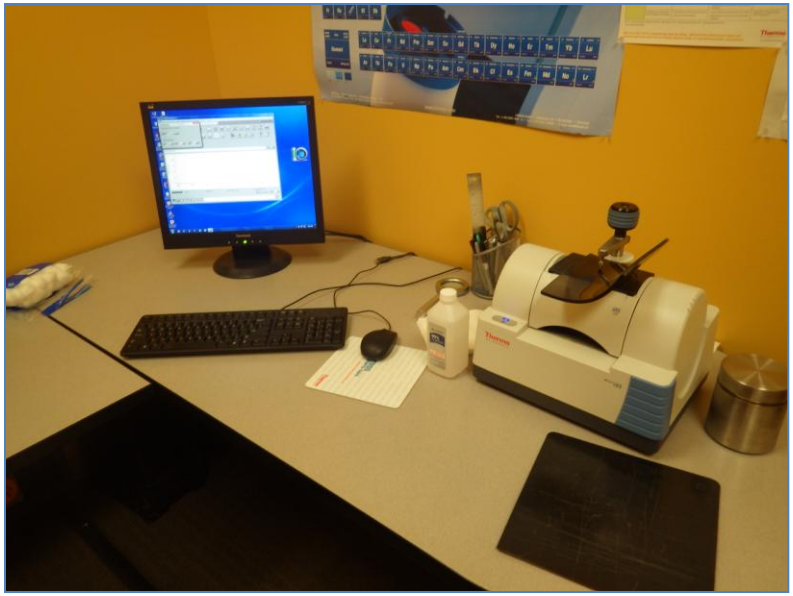
- There are a number of testing methods to help the engineer - all may not need to be conducted.
- Understanding what tests to perform and the information these tests provide is important during the failure analysis.
- How to conduct a failure analysis/inspection of a failed aquarium should not be underestimated.
- Knowledge on the behavior of plastics is critical to understand why the failure occurred.

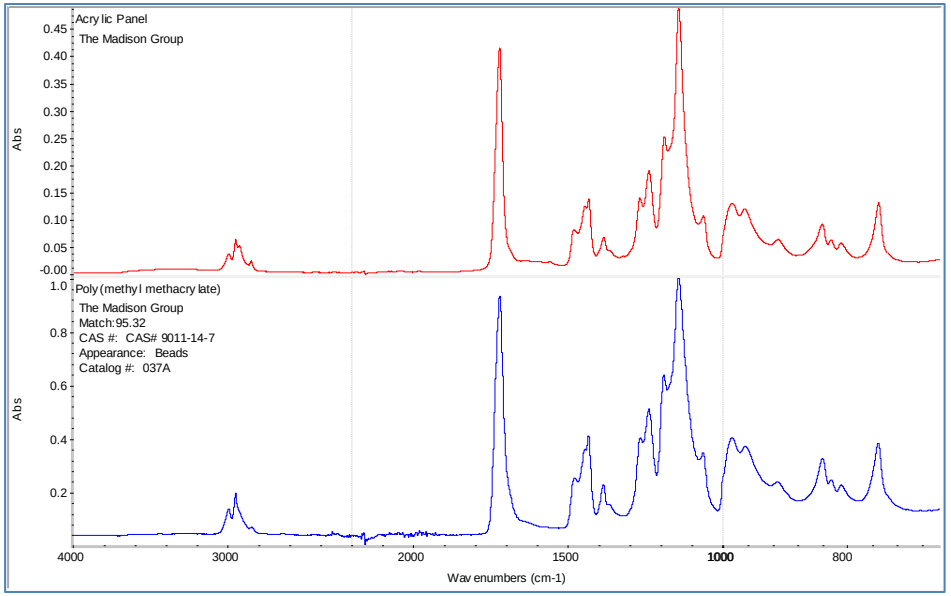
Microscopy

- Microscopy allows the engineer to examine the fine features of the crack.
- Help the engineer fine the crack initiation location. This could be critical to determine “why” the failure occurred.
- Help the engineer determine if the crack progressed slowly initially (propagate from an internal flaw) or was it a high energy event (e.g. impact).
- Provide information on the condition of the acrylic (e.g. manufacturing issues).

FTIR

- Fourier transformation infrared spectroscopy (FTIR) allows for the identification of organic compounds and some inorganic.
- Used to identify type of plastic, possible additives/fillers and foreign substances that may deleterious to the acrylic.
- Used to identify sealants and other materials on the acrylic panel.





Material Property Analysis

- Various methods can be used to provide information on the mechanical properties of the panel.
- Tensile testing following ASTM D 638 will provide the following information modulus, strength & strain at yield, elongation at break, among other data.
- The drop in modulus as the temperature increases can be found using dynamic mechanical analysis (DMA).
- Lifetime prediction can be done using structural analysis, tensile testing and DMA.

Summary

- The popularity of large acrylic aquariums has grown in recent years in both residential and commercial settings.
- Catastrophic failures can result in significant property damage and, in rare instances, even personal injury.
- Potential causes of acrylic tanks are generally related to manufacturing, installation, maintenance, or a combination thereof.
- The correct engineering and testing can help determine “how” and “why” failure has occurred.

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