Urethane Parts Failure Mode Determination, Problem Analysis and Resolution

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Agenda

1. Introduction
2. Common Types of Failures
3. Types of Root Causes
4. Root Cause Investigations
5. Failed Part Examples
   ➢ Problem description -> Analysis -> Root Cause ID -> Solution
6. Conclusions
Common Types of Failures

1. Incorrect Hardness
2. Material Failure
   - Flat spotting, blowout, fatigue, breakage, cracking, etc
3. Voids
   - Bubbles, pinholes, splits, cracks, etc
4. Non-Homogeneous Appearance
   - Swirls, stripes, laminated, layered, striations, alligator skin, spots, discoloration, etc
5. Bond Loss
6. Other
Common Types of Root Causes

Part Design

Material Choice
- insufficient physical properties
- degradation (e.g. hydrolysis, chem attack)
- tank loading error
- formulation (including additives)

Material Conditioning
- moisture contamination
- excessive heat history
- contamination in tank
- lack of agitation
- lack of de-gassing

Meter-mix Process
- off A:B ratio (stoich)
- component temperatures
- transferring to mold (e.g. time)
- poor A:B mix

Mold
- mold temperature
- contamination in mold

Bond Preparation
- hub prep (e.g. cleaning & grit blasting)
- adhesive application
- contamination on the hub
- pre-bake (time & temp)
Root Cause Investigations
And Defect Prevention

- **Technical Service**
  - Process troubleshooting, travel to customers
  - Urethanes processing labs – samples, hardness, gel time, etc
  - Physical property testing, NCO testing, moisture content, Dynamometer

- **Analytical Services**
  - FTIR, NMR, GC, DSC, TGA, etc

- **Material Choice**
  - Material selection, processing recommendations, equipment selection
  - Trial support

- **Part Design**
  - Expertise in Polymer and Mechanical design
  - Tools: FEA, wheel model, spring rate calculator, etc

- **Training**
  - On-site, in lab, at PMA, etc
  - Tech Data Sheets, MSDS’ s, Handbooks, published technical papers
Incorrect Hardness
INCORRECT HARDNESS
Soft Center

Problem Description

- Material: TDI-ester / MBCA
- Defect: Low Internal Durometer
- Clues:
  - Expected hardness – 80 A
  - Problem parts have correct hardness near the edge and soft durometer (and drifting) in the center
  - Thinner cross-sections did not exhibit the same problem
INCORRECT HARDNESS
Soft Center

Analysis

- Processing Parameters:
  - Mold temperature-104°C
  - Prepolymer temperature-100°C
  - Catalyst – Adipic Acid

- Combination of catalyst and elevated prepolymer temp resulted in high exotherm and increased temp in the middle of the part

Root Cause

- High exotherm
  - High component and mold temperatures
  - Formulation - catalyst

Resolution

- Lowered the prepolymer temp to 82C and mold temp to 100C
- Eliminated the catalyst from the formula
**Problem Description**

- **Application:** Ride Wheel
- **Material:** High performance PPDI
- **Defect:** Blowout
- **Clues:**
  - Blew out after 191 days of service
  - A wheel made with a somewhat lower performance material ran for a whole year with no failure, *but did show signs of high internal temps*
  - Higher perf. PPDI material maintains modulus at a high temps while lower perf. material loses modulus
  - The wheel design had a concave tread surface with a flat hub
**Analysis**

- **Troubleshooting / Testing:**
  - Dynamic properties - EXCELLENT

- Mech. engineer material expert reviewed part design
  - Due to losing modulus, the lower perf. material was able to redistribute the load, just enough to avoid blowout
  - Design of hub does not allow load to be distributed evenly across the width of the urethane tread, load concentrated at thin section

**Root Cause**

- Part Design

**Resolution**

- The ride manufacturer redesigned the hub with a concave surface to match the tread surface
Problem Description

- Application: Escalator Wheel
- Material: TDI-ether / MBCA
- Defect: Urethane degraded
- Clues:
  - Failed after several months
  - Used in hot and humid environment
  - Initial hardness was 95A
  - A paper clip would easily pierce the wheel surface
MATERIAL FAILURE
Urethane Degradation

Analysis

➢ Troubleshooting / Testing:
  ➢ FTIR analysis - composition actually a TDI-ester / MBCA
  ➢ Customer had not processed with the TDI-ester in a long time
    ➢ Wheel much older than initially thought

Root Cause

➢ Material Choice
  ➢ Degradation from Hydrolysis

Resolution

➢ This was obviously a wrong material choice for this application under the existing operating conditions.
Problem Description

- Application: Drive wheel for a baggage handling system
- Material: TDI-ether / MBCA
- Defect: Cracks
- Clues:
  - Cracks were perpendicular to wheel circumference (lateral)
  - Cracks developed after about one month of service
MATERIAL FAILURE
Fatigue Cracks

Analysis

- Mech. engineer material expert reviewed failed part
  - Determined from experience that these are fatigue cracks
  - Excessive strain cycling from torque causes stress riser
  - Making the tread thicker will reduce contact pressure, which should reduce the stress caused by torque
  - There is no concern for blowout failure so thicker tread should be OK
  - A TDI-ester would have better resistance to fatigue
  - Increasing stoichiometry may also improve resistance to fatigue

Root Cause

- Material Choice and Part Design

Resolution

- Recommended:
  - Replacing the ether with an ester
  - Increasing the tread thickness
  - Increasing stoichiometry
MATERIAL FAILURE
Glass-Like Cracks

Problem Description

- Application: Wheel
- Material: TDI-ether
- Defect: Cracks
- Clues:
  - Cracks developed earlier than expected life
  - Cracks grew quickly once they appeared
  - Cracks resemble shattered glass
  - The sample sanded easily leaving very smooth surface.
MATERIAL FAILURE
Glass-Like Cracks

Analysis

- Troubleshooting / Testing:
  - FTIR analysis - *composition is TDI-ether, no contamination*
  - Chlorine analysis – *very low stoichiometry*

Root Cause

- Meter / Mix Process
  - Off A:B Ratio

Resolution

- Parts made at the correct stoichiometry performed as expected
Voids
Problem Description

- **Application:** Wheel
- **Material:** PPDI / 1,4-BDO
- **Defect:** Internal Cracks
- **Clues:**
  - These cracks haven’t been visible on the wheel’s surface and appeared after the wheel was machined on a lathe.
  - The cracks were mainly present in the larger wheels.
  - Variations in mold and resin temperatures didn’t produce any appreciable improvement.
  - The mixing was very good although this was a hand batching process.
VOIDS
Internal Cracks

Analysis

- It was determined that the curative (1,4-BDO) was slightly wet.
- Normal drying did not resolve the problem.

Root Cause

- Material Conditioning
  - Moisture Contamination

Resolution

- Careful drying of the curative using molecular sieve and using it immediately after drying resolved the problem.
Problem Description

- **Application**: Mining Screen
- **Material**: 90A TDI / MBCA
- **Defects**: Looked like Cracks
- **Clues**:
  - The cracks had characteristic rounded edges
  - The problem occurred only in the small aperture screens
Analysis

- Careful wiping of the mold eliminated the cracks.
- The cracks would also disappear by raising mold and material temperature.
- Mold release was collecting in the bottom of the V shaped sections of the mold, creating puddles.
- The mold release is not miscible with the reacting mass and is being displaced by heavier, higher viscosity urethane mix.
- This created liquid barriers between the urethane streams, preventing complete fill with urethane and creating rounded edges.
VOIDS

Root Cause

- Mold
- Contamination in Mold

Resolution

- Smaller amounts and more uniform application of the mold release resolved this problem.
Non-Homogeneous Appearance
Problem Description

- Application: Unknown
- Material: MDI-ether / 1,4-BDO
- Defect: Internal Layering
- Clues:
  - Cross-section appeared laminated
  - Problem was intermittent
  - Processed by meter-mix machine
  - Transferred to mold in a bucket
  - Each part weighs several pounds
Problem description

- Application: Swim Fin
- Material: TDI-ether / MBCA
- Defect: Brown Spots
- Clues:
  - Randomly located
  - Appeared only after the fin was tested in a swimming pool
NON-HOMOGENEOUS APP.
Spots

Analysis

➢ Troubleshooting / Testing:
  ➢ Chlorine analysis on spots – 140% stoich
  ➢ Chlorine analysis yellow areas – 95% stoich

Root Cause

➢ Poor A:B mix

Resolution

➢ Improved mixing eliminated the appearance of dark spots
Problem Description

- Application: Wheel
- This wheel had one small area where there was no adhesion of the urethane to the hub.
- This happened with about every fifth wheel. It didn’t happen at all for the other four wheels.
Analysis

- The cores were heated in an air circulating oven with five cores being in the oven at one time.
- There were baffles in the sides of the oven to better diffuse the air.
- One of the cores was almost always located next to a hole in the baffling.
- The mold and core temperatures were 260°F.
- The adhesive was present on the metal core.
- The input air temperature was higher than the set temperature causing a palm sized area on the core to overheat and over-cure the adhesive.
BOND LOSS

Root Cause

- Bond Preparation
  - Prebake (over-heated bonding agent)

Resolution

- Additional baffle was installed in the oven to divert the air flow.
BOND LOSS
Problem Description

- Application: Wheel
- Material: TDI PTMEG / MOCA
- Bond failed between Layers of Adhesive
- The Adhesive Is Chemlok 219 and Chemlok 213
- This Adhesive combination requires pre-baking at minimum of 2hrs at 120°C where the metal core needs to be at this temperature.
- The core was large and it was kept in the oven for a total of 2hrs at 120°C. The core never reached the required temperature.
BOND LOSS

Root Cause

- Bond Preparation
  - Prebake (under-heated)

Resolution

- Extending the time in the oven and measuring core temperature to ensure proper preparation resolved the problem.
Process Based TSS

• Preparation is the key to success
• Processes help us prepare
• Some processes that are being used/being developed in NALA are
  • CRM
  • Technical Key Account Plans (KAP)
  • STS priority planning
  • Emphasis on project planning and project management (example)
  • Product Database
  • Trial kits (equipment) and checklists
  • Lab work before trials
• Along with preparation, most importantly we need a well trained TSS team.
Summary

- A TSS problem can be due to multiple reasons and many times these reasons are unique to a customer/process.
- A problem can have multiple causes.
- First step is to draw the process flow diagram for the customer and also the supply chain diagram.
- Run through each step before zeroing in on a certain process step or a supply step. Looks at all possible failure modes in each step (briefly).
- Once step is determined a deeper dive into the step is necessary. Analyze every piece of equipment/material involved in the step to understand the problem.
- Experience with cast PU will shorten analysis time/problem detection time.
Questions?