ENCAPSULATION PROCESSING AND MANUFACTURING YIELD ANALYSIS

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- Add - on activity to baseline contract on development of advanced encapsulation materials (Phase III)
- Not yet funded

Goals:

- Understand the relationships between:
  - Formulation variables
  - Process variables
- Define conditions required for optimum performance
- Relate to module reliability
- Predict manufacturing yield
- Provide documentation to industry
PROCESS DEVELOPMENT

Material Variables

LAMINATION POTTANTS
- ETHYLENE/VINYL ACETATE (EVA)
- ETHYLENE/METHYL ACRYLATE (EMA)

CASTING POTTANTS
- ALIPHATIC POLYURETHANE (PU)

ADHESIVES/PRIMERS
- THREE BASIC PRIMER SYSTEMS

COVER FILMS
- TEDLAR, ACRYLICS, FEP

FORMULATION VARIABLES:
TYPE AND AMOUNT OF:
- CURING AGENTS (PEROXIDES)
- ANTIOXIDANTS
- ULTRAVIOLET SCREENERS
- ULTRAVIOLET STABILIZERS (HALS)
- SELF PRIMING AGENTS

STORAGE CONDITIONS:
- TIME, TEMPERATURE, HUMIDITY, LIGHT
  AIR EXPOSURE

QUALITY CONTROL:
- DETERMINE ANALYTICAL METHODS TO VERIFY
  COMPOSITION
- PUBLISH QC SPECIFICATIONS FOR MATERIAL
  CERTIFICATION
Process Variables

(VACUUM BAG LAMINATION)

- AMBIENT CONDITIONS:
  - TEMPERATURE
  - HUMIDITY
  - BAROMETRIC PRESSURE

- VACUUM PRESSURE (INITIAL) AND TIME OF EVACUATION

- TEMPERATURE - RATE OF RISE

- TEMPERATURE - ULTIMATE

- DWELL TIME, AT TEMPERATURE

- RATE OF COOLING

- TIME/TEMPERATURE/PRESSURE INTER-RELATIONSHIP

(CASTING LIQUID SYSTEMS)

ABOVE VARIABLES, PLUS:

- 2 COMPONENT MIX TIME

- DEGASSING PRESSURE

- PUMP AND FILL TIMES

- MIX UNIFORMITY

- GEL TIME
# PROCESS DEVELOPMENT

## Quality and Performance Criteria

**METHOD:**
- Prepare test modules and/or other test specimens with change in significant variable(s)
- Determine the effect

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>CONDITION</th>
<th>TEST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant</td>
<td>Adequate cure</td>
<td>Percent gel, thermal creep</td>
</tr>
<tr>
<td></td>
<td>Trapped bubbles</td>
<td>Visual</td>
</tr>
<tr>
<td></td>
<td>Discoloration</td>
<td>Visual</td>
</tr>
<tr>
<td>Cells</td>
<td>Breakage</td>
<td>Visual, resistance</td>
</tr>
<tr>
<td></td>
<td>Interconnect</td>
<td>Resistance</td>
</tr>
<tr>
<td></td>
<td>Registration</td>
<td>Visual</td>
</tr>
<tr>
<td>Cover Films</td>
<td>Tears/Punctures</td>
<td>Visual</td>
</tr>
<tr>
<td></td>
<td>Warping/Shrinkage</td>
<td>Visual</td>
</tr>
<tr>
<td>Glass (Superstrate)</td>
<td>Fracture</td>
<td>Visual</td>
</tr>
<tr>
<td>Adhesion</td>
<td>Bond strength</td>
<td>Peel test</td>
</tr>
<tr>
<td></td>
<td>Endurance</td>
<td>Water soak (50°C)</td>
</tr>
</tbody>
</table>

Need to decide on:
- Standard test specimen(s)
- Standard test protocol
- Uniform data sets
Data Analysis

- Statistical analysis complicated by lack of uniformity in data type

- Two types of data:
  - Discrete (pass/fail)
  - Continuous
  - Cell fracture
  - Gel content
  - Interconnect breakage
  - Peel strength
  - Trapped bubbles
  - Stabilizer loss
  - Thermal creep
  - Glass fracture

For continuous data types:

- Two level factorial experiments
  (most information, fewest experiments)
- No. experiments = \(2^k\), \(k = \) no. variables
- Determines effect of single variable at two levels
- Determines factor interactions (several variables)
- Permits ranking of variables according to magnitude of effort
- Linear analysis possible for subsequent predictive capability

For discrete data types:

- Prepare scatter plot vs. variable
- Plot the zero failure line
- Use graphics to specify boundary conditions and acceptable processing "windows"
- Determine failure probabilities - binomial distribution
Manufacturing Practice

DISCRETE VARIABLES

- PREPARE GRAPHICAL INTERPRETATION OF DATA
- DETERMINE "ZERO FAILURE" LINE
- DEFINE BOUNDARY CONDITIONS FOR DEFECT-FREE MANUFACTURING

EXAMPLE: CELL BREAKAGE

\[ \text{O = PASS} \]
\[ \text{X = FAIL} \]

RESIN TEMPERATURE (°C)

BACKFILL RATE (MM HG/SEC)

ZERO FAILURE LINE

VACUUM PRESSURE (MM HG)
MANUFACTURING PRACTICE

CONTINUOUS VARIABLES

- graphical presentation also good for continuous variables
- provides boundaries for process/formulation variables based on criteria of acceptability
- easily used in manufacturing practice

EXAMPLE: PERCENT GEL
(DEGREE OF CURE)

PROPERTY LINES
70%
60%
50%

TEMPERATURE
(°C)

PEROXIDE CONTENT
(%)

DWELL TIME
(MINUTES)
PROCESS DEVELOPMENT

Future Work

- IDENTIFY SIGNIFICANT VARIABLES
  - FORMULATION
  - PROCESSING
- DETERMINE MATERIALS SPECIFICATIONS AND QUALITY CONTROL METHODS
- ASSESS EFFECT OF VARIABLE(S) AND RANK ACCORDING TO IMPORTANCE
- DEFINE FORMULATION AND PROCESSING "WINDOWS" (ZERO FAILURE)
- CONVERT DATA TO PRACTICAL ENGINEERING FORMAT
- RELATE DATA TO MANUFACTURING YIELD
  - ASSIGN PROBABILITY OF FAILURE
  - NORMAL DISTRIBUTION (?)
  - WEIBUL (?)
- PREPARE TROUBLE-SHOOTING GUIDE:
  "WHAT'S WRONG IF . . . .?"
JPL Process Sensitivity Analysis

1. Define Variables

   - PROCESSING
     - Determine Criteria of Performance
     - Uniform Test Specimen(s)
     - Uniform Test Protocol
     - Uniform Data Set

   - Discrete Data
     - Plot Data
     - Rank Variables and Cofactors
     - Brackets and Boundries
     - Bernoulli Probability Distribution
     - Graphical Presentation

   - Continuous Data
     - Factorial Experimentation
     - Rank Variable(s) and Cofactors
     - Brackets and Boundries
     - Multivariate Analysis
     - Graphical Presentation

2. Assign Probability Values-Required Criteria

3. Determine Manufacturing Yields