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 DEVELOPMENT

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 INTERRELATIONSHIP

(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>
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<tbody>
<tr>
<td>POTTANT</td>
<td>ADEQUATE CURE</td>
<td>PERCENT GEL, THERMAL CREEP</td>
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<tr>
<td></td>
<td>TRAPPED BUBBLES</td>
<td>VISUAL</td>
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<tr>
<td></td>
<td>DISCOLORATION</td>
<td>VISUAL</td>
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<tr>
<td>CELLS</td>
<td>BREAKAGE</td>
<td>VISUAL, RESISTANCE</td>
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<td></td>
<td>INTERCONNECT</td>
<td>RESISTANCE</td>
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<td>REGISTRATION</td>
<td>VISUAL</td>
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<tr>
<td>COVER FILMS</td>
<td>TEARS/PUNCTURES</td>
<td>VISUAL</td>
</tr>
<tr>
<td></td>
<td>WARping/SHRINKAGE</td>
<td>VISUAL</td>
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<tr>
<td>GLASS (SUPERSTRATE)</td>
<td>FRACTURE</td>
<td>VISUAL</td>
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<tr>
<td>ADHESION</td>
<td>BOND STRENGTH</td>
<td>PEEL TEST</td>
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<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
PROCESS DEVELOPMENT

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

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

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)

DWELL TIME
(MINUTES)

PEROXIDE CONTENT
(%)
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

- Define Variables
  - Processing
  - Material
- Determine Criteria of Performance
- Uniform Test Specimen(s)
- Uniform Test Protocol
- Uniform Data Set
- Discrete Data
  - Plot Data
  - Rank Variables and Cofactors
  - Brackets and Boundaries
  - Bernoulli Probability Distribution
  - Graphical Presentation
- Continuous Data
  - Factorial Experimentation
  - Rank Variable(s) and Cofactors
  - Brackets and Boundaries
  - Multivariate Analysis
  - Graphical Presentation
- Assign Probability Values-Required Criteria
- Determine Manufacturing Yields