ENCAPSULATION PROCESSING AND MANUFACTURING YIELD ANALYSIS

SPRINGBORN LABORATORIES, INC.

P. Willis

• 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

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**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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</thead>
<tbody>
<tr>
<td>POTTANT</td>
<td>ADEQUATE CURE</td>
<td>PERCENT GEL</td>
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<tr>
<td></td>
<td>TRAPPED BUBBLES</td>
<td>THERMAL CREEP</td>
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<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>
</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>
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<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

0 = PASS
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
(%)
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**