ENCAPSULATION PROCESSING AND MANUFACTURING YIELD ANALYSIS

SPRINGBORN LABORATORIES, INC.

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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
- TELDAR, 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>POTTSANT</td>
<td>ADEQUATE CURE</td>
<td>PERCENT GEL</td>
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<td></td>
<td></td>
<td>THERMAL CREEP</td>
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<td></td>
<td>TRAPPED BUBBLES</td>
<td>VISUAL</td>
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<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>
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<tr>
<td></td>
<td>REGISTRATION</td>
<td>VISUAL</td>
</tr>
<tr>
<td>COVER FILMS</td>
<td>TEARS/PUNCTURES</td>
<td>VISUAL</td>
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<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>
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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)
Vacuum pressure (mm Hg)
PROCESS DEVELOPMENT

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)

Diagram:
- Property lines
  - 70%
  - 60%
  - 50%
- Temperature (°C)
- Dwell time (minutes)
- Peroxide content (%)

467
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 CONTINUOUS DATA

PLOT DATA

RANK VARIABLES AND COFACTORS

BRACKETS AND BOUNDRIES

BERNOULLI PROBABILITY DISTRIBUTION

GRAPHICAL PRESENTATION

ASSIGN PROBABILITY VALUES-REQUIRED CRITERIA

DETERMINE MANUFACTURING YIELDS

FACTORIAL EXPERIMENTATION

RANK VARIABLE(S) AND COFACTORS

BRACKETS AND BOUNDRIES

MULTIVARIATE ANALYSIS

GRAPHICAL PRESENTATION

469