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 anlytical 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 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>
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<tbody>
<tr>
<td>POTRIANT</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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<tr>
<td></td>
<td>TRAPPED BUBBLES</td>
<td>VISUAL</td>
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<tr>
<td></td>
<td>DISCOLORATION</td>
<td>VISUAL</td>
</tr>
<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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<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>
</tr>
</tbody>
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**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
  - Interconnect breakage
  - Trapped bubbles
  - 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 \( (^\circ \text{C}) \)

BACKFILL RATE \( (\text{mm Hg/sec}) \)

ZERO FAILURE LINE

VACUUM PRESSURE \( (\text{mm Hg}) \)
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

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 Boundaries
        - Bernoulli Probability Distribution
      - Graphical Presentation
        - Assign Probability Values-Required Criteria
        - Determine Manufacturing Yields
    - Continuous Data
      - Factorial Experimentation
        - Rank Variable(s) and Cofactors
        - Brackets and Boundaries
        - Multivariate Analysis
        - Graphical Presentation

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