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 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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</thead>
<tbody>
<tr>
<td>POTTANT</td>
<td>ADEQUATE CURE</td>
<td>PERCENT GEL</td>
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<tr>
<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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<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>
</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
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

\[
\begin{align*}
0 &= \text{PASS} \\
X &= \text{FAIL}
\end{align*}
\]

![Diagram showing a ternary plot with symbols indicating pass and fail conditions, and a line marking the zero failure region. The axes are labeled as follows: Resin Temperature (°C), Vacuum Pressure (mm Hg), and Backfill Rate (mm Hg/sec).]
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 (%)

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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 . . . ?"