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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<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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<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>
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<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)
    - Cell fracture
    - Interconnect breakage
    - Trapped bubbles
    - Thermal creep
    - Glass fracture
  - Continuous
    - Gel content
    - Peel strength
    - Stabilizer loss

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
PROCESS DEVELOPMENT

Manufacturing Practice

DISCRETE VARIABLES

- PREPARE GRAPHICAL INTERPRETATION OF DATA
- DETERMINE "ZERO FAILURE" LINE
- DEFINE BOUNDARY CONDITIONS FOR DEFECT-FREE MANUFACTURING

EXAMPLE: CELL BREAKAGE

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

![Triangular Graph]

- RESIN TEMPERATURE (°C)
- VACUUM PRESSURE (MM HG)
- BACKFILL RATE (MM HG/SEC)
- ZERO FAILURE LINE

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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 showing property lines for percent gel, temperature, and peroxide content.](image-url)
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 . . . ?"