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)
- ANTI-OXIDANTS
- 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 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>POTENTIAL</td>
<td>ADEQUATE CURE</td>
<td>PERCENT GEL</td>
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<td></td>
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<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>
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<tr>
<td>CELLS</td>
<td>BREAKAGE</td>
<td>VISUAL, RESISTANCE</td>
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<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>
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<td></td>
<td>WARping/SHRINKAGE</td>
<td>VISUAL</td>
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<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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<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
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

\[ \text{O = Pass} \]
\[ \text{X = Fail} \]

- Resin temperature (°C)
- Backfill rate (mm Hg/sec)
- 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)

![Diagram showing property lines, temperature, dwell time, and peroxide content](image)
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

DETERMINATE CRITERIA OF PERFORMANCE

UNIFORM TEST SPECIMEN(S)

UNIFORM TEST PROTOCOL

UNIFORM DATA SET

DISCRETE DATA

PLOT DATA

RANK VARIABLES AND COFACTORS

BRACKETS AND BOUNDRIES

BERNOULLI PROBABILITY DISTRIBUTION

GRAPHICAL PRESENTATION

ASSIGN PROBABILITY VALUES-REQUIRED CRITERIA

DETERMINE MANUFACTURING YIELDS

CONTINUOUS DATA

FACTORIAL EXPERIMENTATION

RANK VARIABLE(S) AND COFACTORS

BRACKETS AND BOUNDRIES

MULTIVARIATE ANALYSIS

GRAPHICAL PRESENTATION