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
  - TELAR, 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>TRAPPED BUBBLES</td>
<td>THERMAL CREEP</td>
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<td></td>
<td>DISCOLORATION</td>
<td>VISUAL</td>
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<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>
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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>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):
    - 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
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)

VACUUM PRESSURE
(MM HG)

BACKFILL RATE
(MM HG/SEC)

ZERO FAILURE LINE
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

- Define variables
  - Processing
  - Material
- 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
- Continuous data
  - Factorial experimentation
  - Rank variable(s) and cofactors
  - Brackets and boundaries
  - Multivariate analysis
  - Graphical presentation
- Assign probability values-required criteria
- Determine manufacturing yields