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Getting out of the Lab: Advantages of Evaluating Coatings in a Real-World Manufacturing Environment

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Presented By:
The ChemQuest Group, Inc.

Lab to Pilot Scale Manufacturing Lines

What additional information is needed before launching a new chemistry or formulation to an end-user?

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Benefits of Testing in a Simulated Manufacturing Environment

- Catch unforeseen/unpredictable problems before your customers do.
  - Shutting down a manufacturing line is costly to the customer.
  - Is a problem a chemistry problem, or “factory” problem
- Optimize a Raw Material or a Formula
  - Iteratively formulate and test in a simulated manufacturing environment.
  - Use data to design in improved application performance for a wider range of conditions/variables from the start.
    - Film formation and aesthetics
    - Adhesion
  - Use data to design in improved curing performance for a wider range of conditions/variables from the start.
- Unique Advantage with Customers
  - Provide a data package which includes manufacturing application data

Field Applied

Factory Applied

Factors Normally Not Considered in Raw Material or Formulation Design at Lab Scale

- Applying coating on real parts helps you to uncover failure modes that you weren't aware of in the lab or through the normal battery of ASTM tests.
  - Lab generated data does not necessarily equip either the manufacturer of the coating, or the end user of the coating, with enough knowledge to solve problems when they arise.

- Part Geometry
  - Geometry and mass of part dictates heat flow dynamics, and thus evaporation and curing dynamics which translate into film surface properties (pinholes, craters, orange peel)
  - Internal Edges, External Edges (Faraday Effect with powder)
  - Convex and Concave curved surfaces
  - Vertical, angles, and horizontal surfaces

- Environment
  - Temperature
  - Relative Humidity
  - Condition of the substrate (oil, dirt, rust, etc)

Factors Normally Not Considered in Raw Material or Formulation Design at Lab Scale

- Pretreatments
  - Various manufacturers use different surface pre-treatment protocols

- Application Equipment
  - Pumps and delivery systems
    - Shear sensitivity
    - Rheology dynamics
    - Gel time/Pot Life
    - Length of hoses
    - Compatibility with internal seals

  - Spray Process and Equipment
    - HVLP, Air Assisted Airless, Airless, Rotary Bell, etc
    - Manual or Robotic
    - Atomization, wetting, and quality of film formation
    - Overspray, transfer efficiency, and waste

Factors Normally Not Considered in Raw Material or Formulation Design at Lab Scale

- Curing Dynamics
  - Thermal Mass and Thermal Conductivity of Component
    - Changes in curing dynamics
      - Heat sink causes rapid cooling
      - Heat mass causes under-curing if component isn't brought up to temperature.
    - Curing
      - Curing Type –
        - IR/Flash
        - Convection (Electric, Gas)
        - UV (Low Pressure arc lamp, microwave fusion, LED)
        - Ambient
      - Airflow During Cure

Some Case Studies

- Aerospace – Shut down entire 1 million square foot manufacturing process because TDS of their coating recommends 30%RH or above. But the material was never tested in production below 30%RH.
- Composite Panel Manufacturer – Unexpected curing of coating on the production line not observed in the lab due to sheer force introduced by the pneumatic pumps used to spray the material.
- Structural Component– Premature failures post-manufacturing were occurring in the field. Needed to understand the relationship between the radical swings in humidity and temperature in their manufacturing facility and the curing speed.
- Container Manufacturer – New coating, needed to understand how application spray distance, rotation speed, air pressure, nozzle tip size, solvent package, etc. influenced the presence of optical defects in the coating. Iterative formulation design and testing on the manufacturing line.

Some Case Studies

- Resin Manufacturer – Needs to understand the effect of “heat mass” on total energy requirements for cure in order to demonstrate the value of their curing chemistry (environmental sustainability/energy input is a selling factor)

- Film Manufacturer – Iterative design and formulation process. Formula developed in the lab, but lab scale application did not perfectly translate to manufacturing coating line. Oven length, temperature gradients, air flow, types and amounts of solvents were all variables that couldn’t be modeled at the lab scale. Formula adjustments made after production runs.

- Industrial Coating in Corrosive Environment– Importance of film formation and DFT on edges on large steel structures. Welds, edges (internal and external), pipes, channels, etc. No sagging on vertical surfaces for thick layers. Formulation design must include rheological control and surface tension control, along with actual testing on real-world parts with actual application equipment.

Some Case Studies

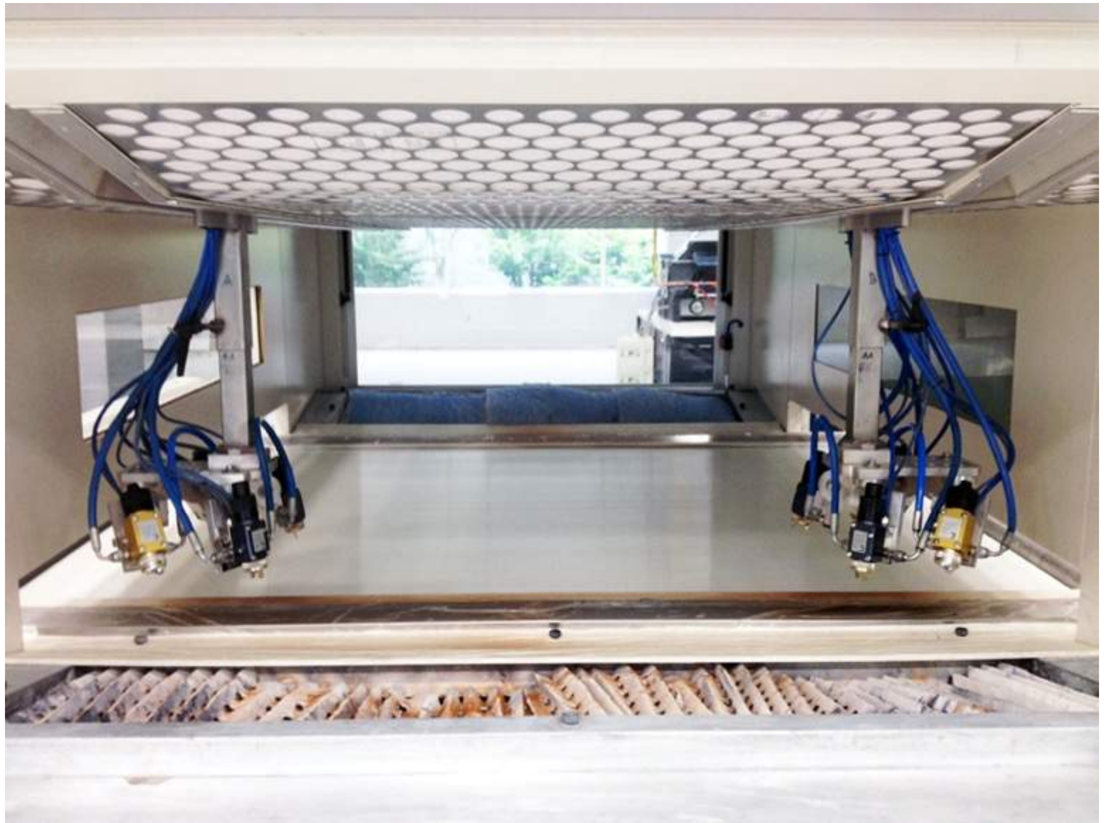
- Electronics Industry – Application process is absolutely fixed. Viscosity, rheological dynamics, surface tension, and inter-material compatibility are all critical. Iterative formulation design using the actual application equipment on the actual final product is critical for formulation design.

- Automotive – Testing the geometric uniformity of cross-linking over a large surface area. Large panels and parts sprayed using the actual application equipment on a hang-line system, and testing the uniformity of the cross-linking reaction on a 2-dimension grid mapped to the surface.

- Waste Management – What happens to the coating that doesn't make it to the part? Optimize formula for better transfer efficiency. Can the coating be re-captured and used?

- Disagreement Between Field Performance and TDS – What's causing the loss in mechanical performance? Chemistry, or application?

Pilot Scale Manufacturing Equipment for Application of Coatings



- Reciprocal Spray for Coating Flat Substrates in Large Format

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Pilot Scale Manufacturing Equipment for Application of Coatings

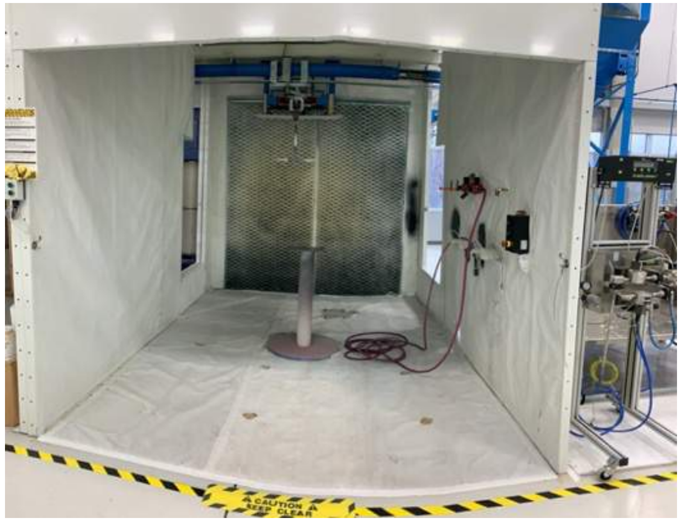
- IR, UV, Convection

UV (Arc-bulb, LED, and Microwave Fusion

Pilot Scale Manufacturing Equipment for Application of Coatings

Multiple Curing Options

Programable Stop/Start Line



Wet Spray Booth

Electrostatic Powder Booth

- Stop in Booth Hangline System for 3D Geometric Shapes

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Pilot Scale Manufacturing Equipment for Application of Coatings

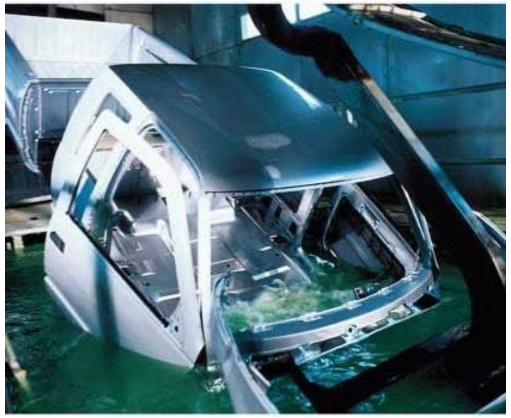
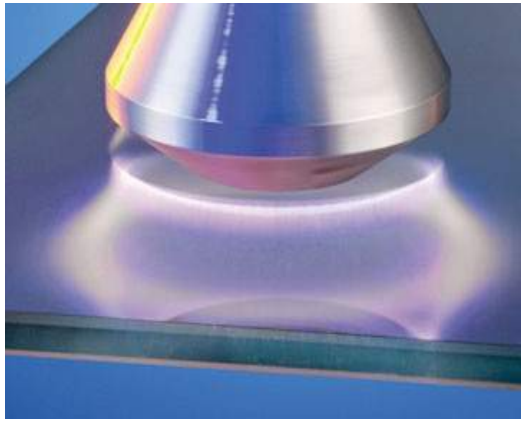
- Cross-Draft Spray Booth → Factory Applied and Field Applied

Pretreatment of Substrates

Four Main Categories

- Mechanical methods - such as sanding and grit blasting, power washing
- Chemical means – solvating contaminants for removal from the surface (Solvent wipe, vapor degrease, water wash)
- Surface Modification - caustics/acids(etching), conversion coatings
- Energy Treatments - corona, flame and plasma, short-wave UV activation



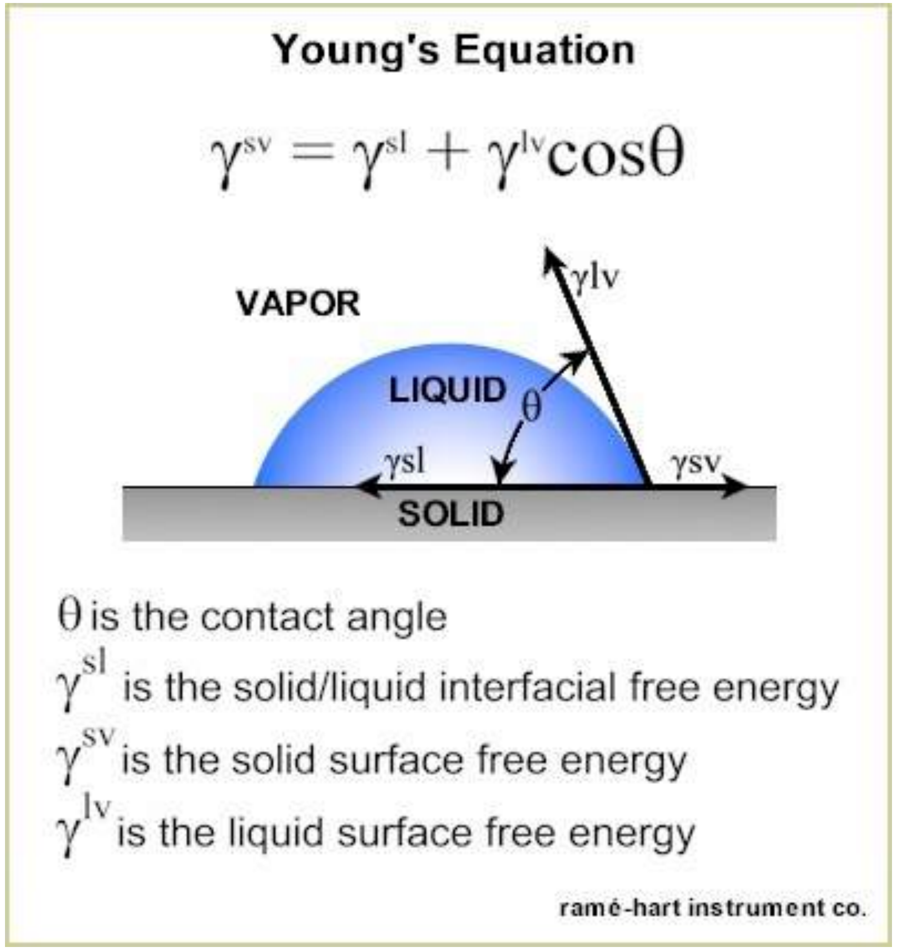



Pretreatment of Substrates

Spreading
Coefficient
$S = \sigma_S - \sigma_L - \sigma_{SL}$

For wetting

$$\sigma_S > \sigma_L + \sigma_{SL}$$



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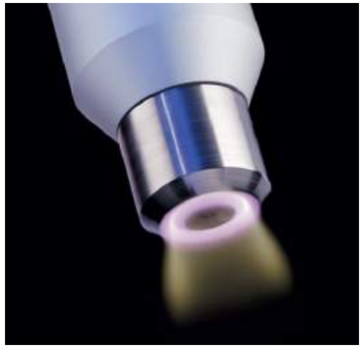
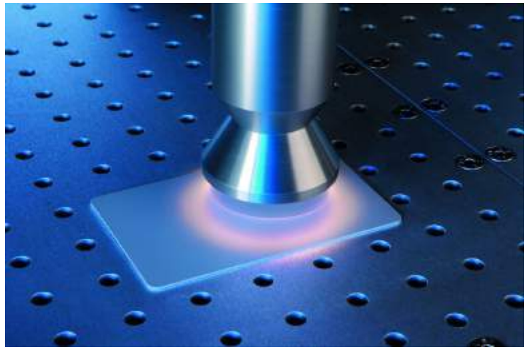
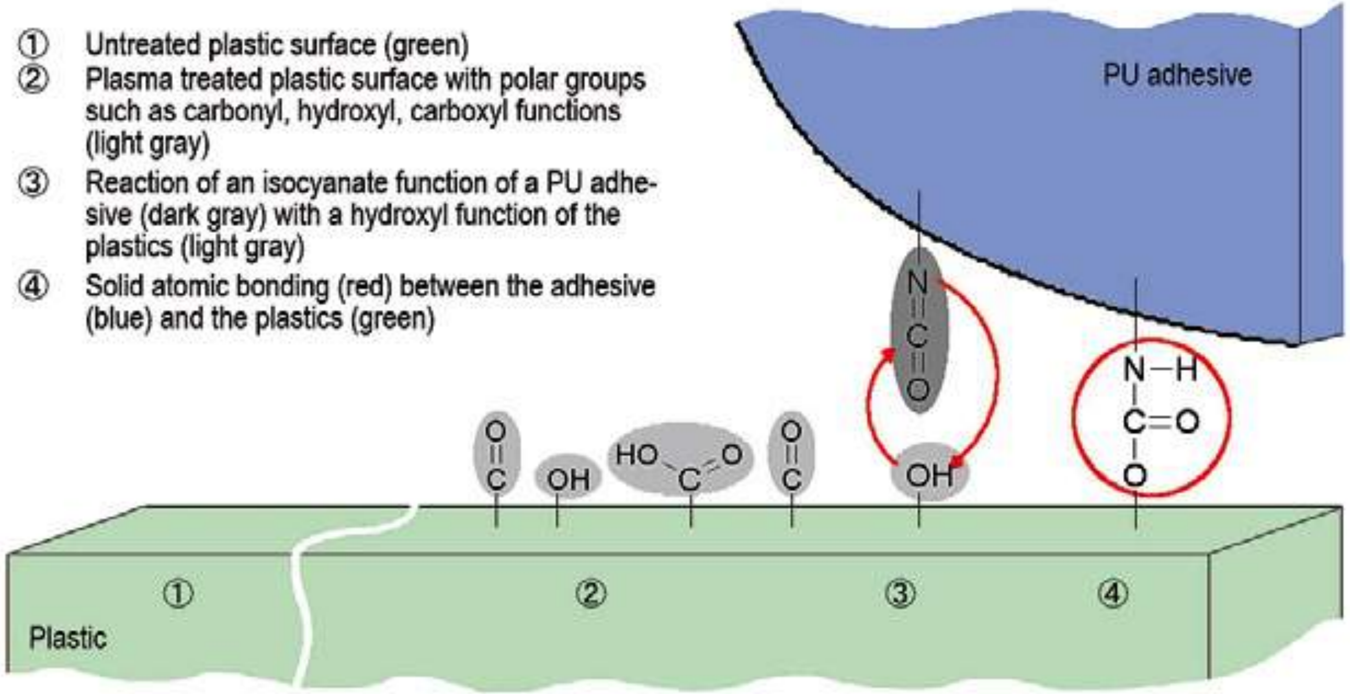
Pretreatment of Substrates







- Open Air Plasma Pretreatment – Cleaning and Surface Activation

Environmental Effects

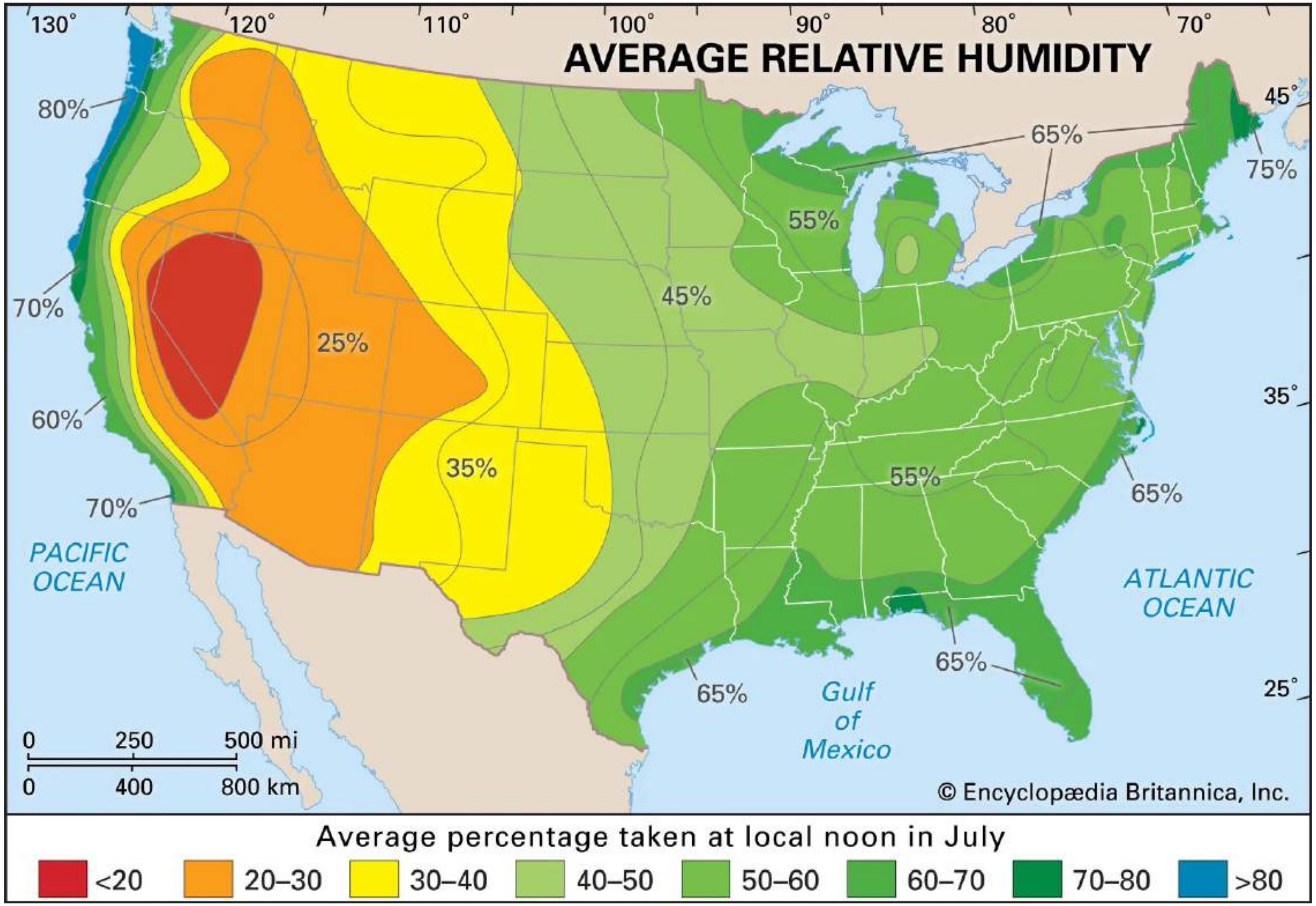
Direct quote from a major formulator and innovator in the paints and coatings market:

"Both decorative and industrial coatings are used and applied under a wide range of environmental conditions. We don't control the conditions under which our customers apply our coatings, whether they are applied in the field or under factory conditions - which are never perfectly controlled either. On the other hand, our customers are looking for consistent performance and experience with our products, so having the ability to test the performance of our products when we are designing them, so that we can both understand and design our coatings to have the robust and consistent performance that we want our customers to have, is important.

We want to avoid our product failing, if we only test at 70 degrees or 35 degrees and one humidity condition, we have no idea what our customers will get under their real-world conditions.

We generally under-assess the impact of environmental variations on the properties our customers will see with our coatings because we haven't had a good robust way to test them. Having that capability will really aid us in the design and development of our products. This is a competitive differentiator."

Geographical Variations in Temp and RH



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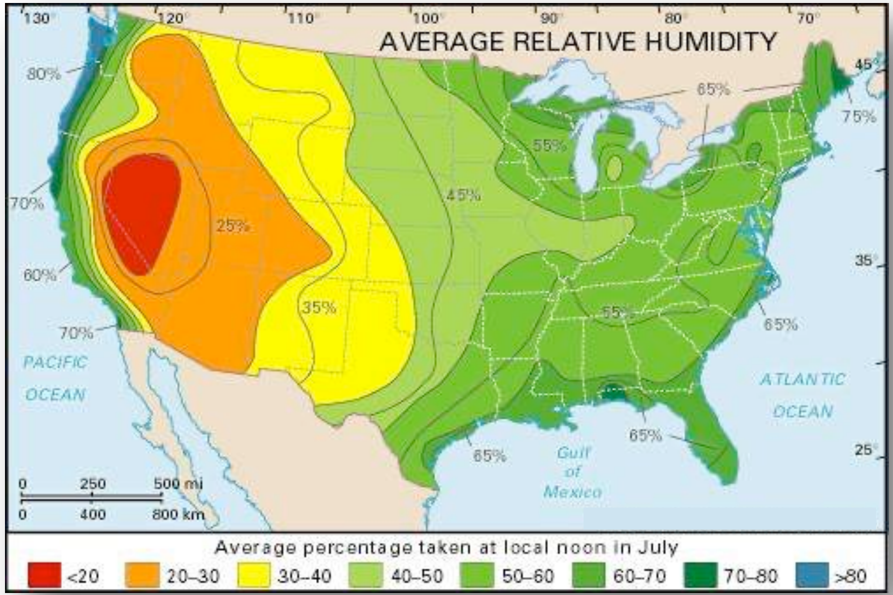
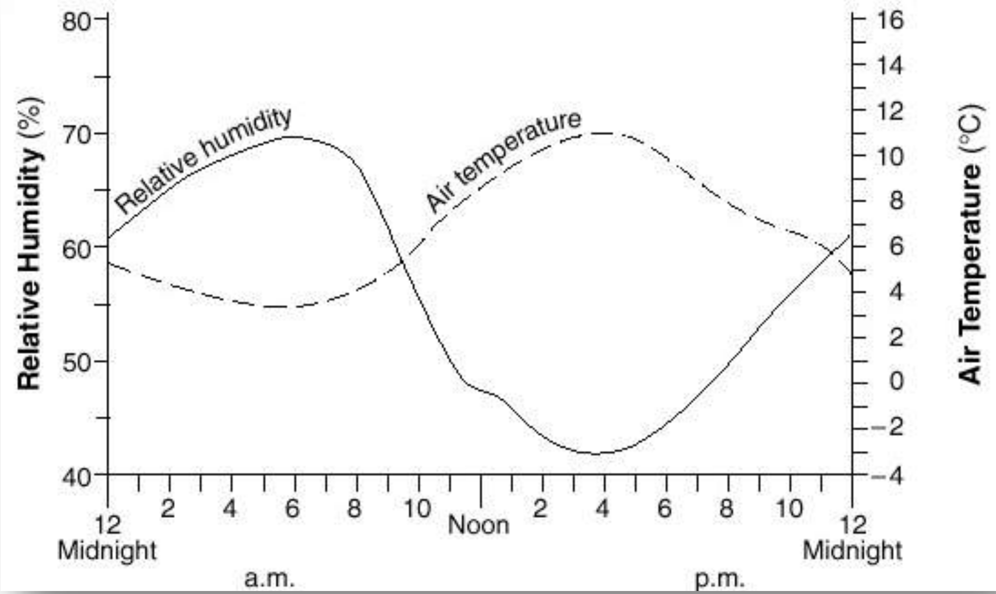
Time Variations in Temp and RH

Humidity and Temperature conditions vary widely based on:

- Geography
- Time of Year
- Time of Day





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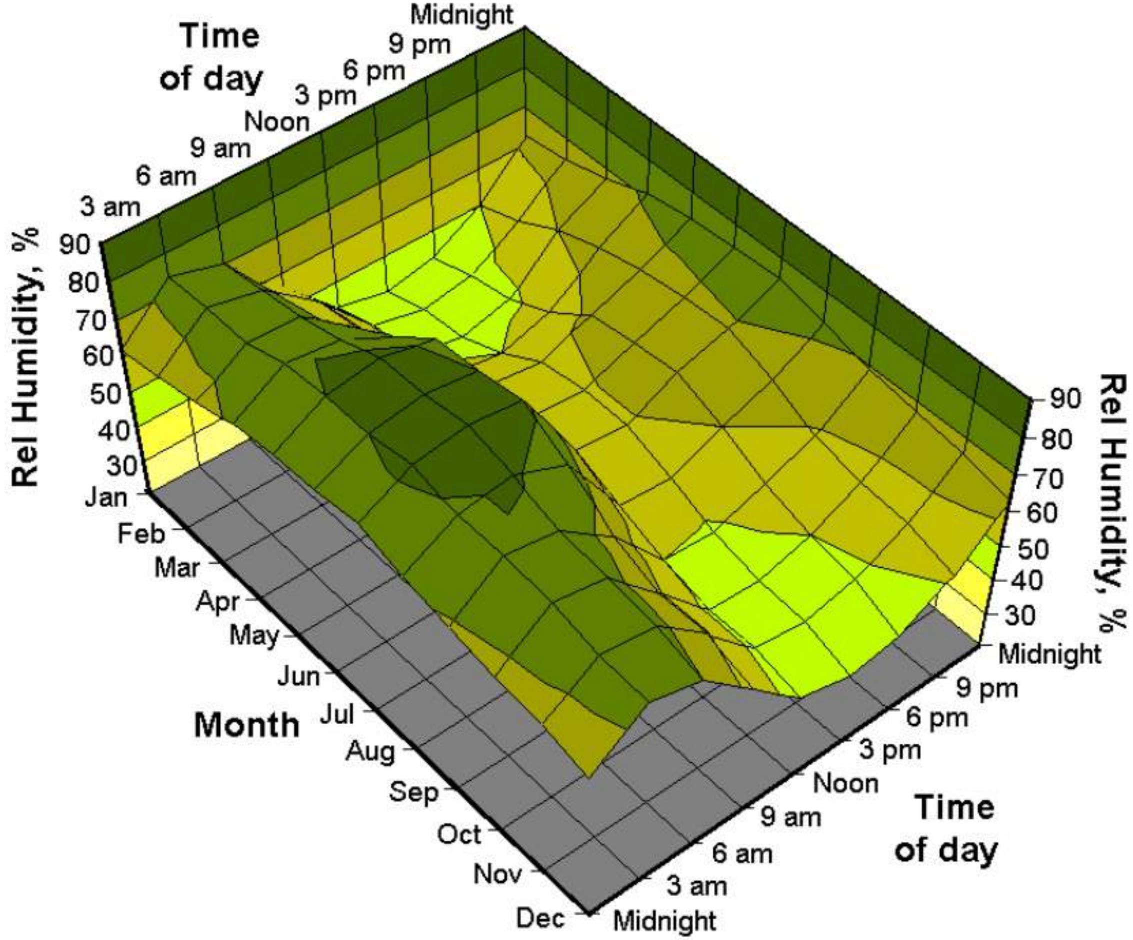
Time Variations in Temp and RH



Sydney Australia

Source: RA Francis, "Humidity and Dewpoint, Their Effect on Corrosion and Coatings"

Substrate Interaction with Environment

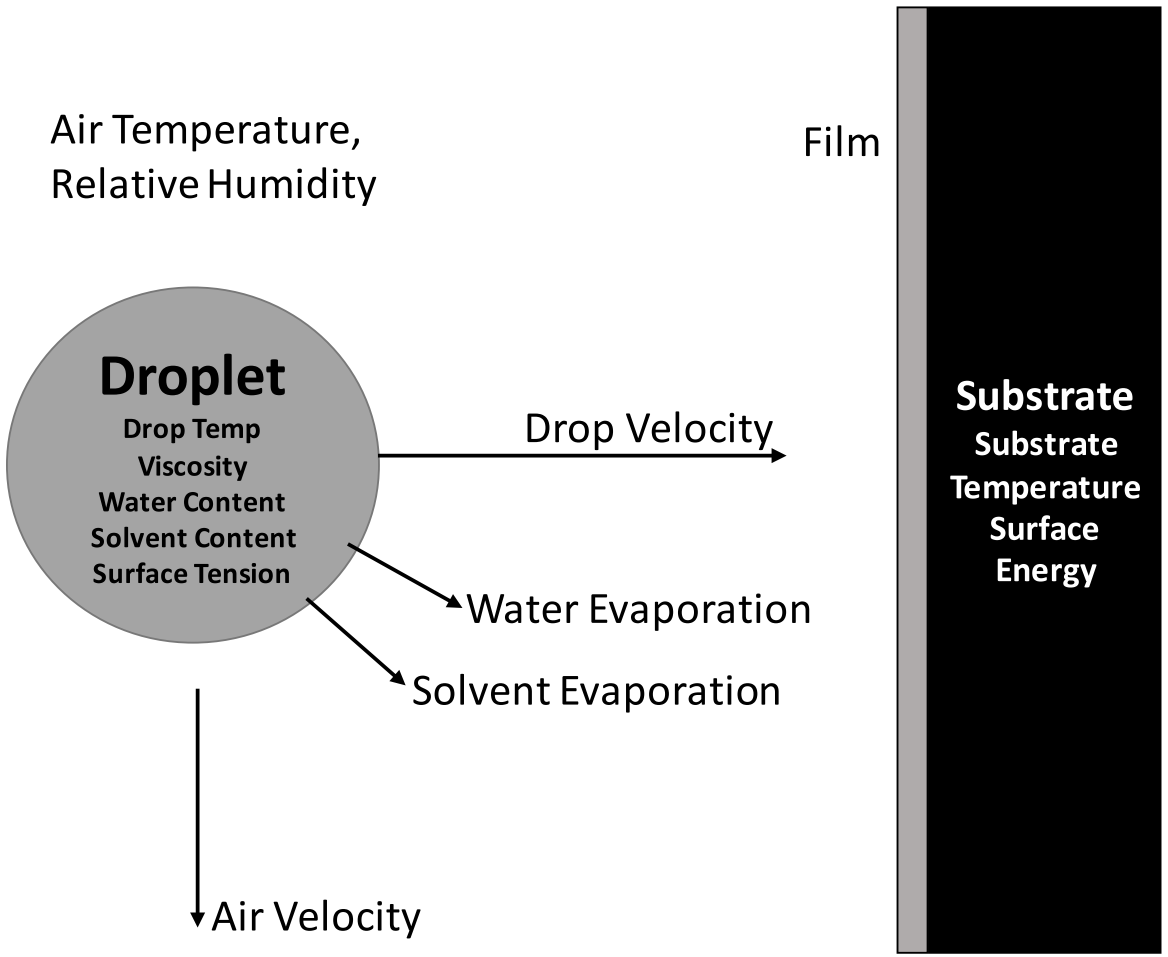
Substrate Dynamics

Moisture can lead to corrosion, film formation, and adhesion problems. If the temperature of the substrate is lower than the dew point of the surrounding air, water will condense onto the substrate. It's best practice to ensure that the temperature of the substrate is at least 3-5 degrees Fahrenheit above the dew point of the air. The presence of moisture on the surface can lead to significant problems, including:

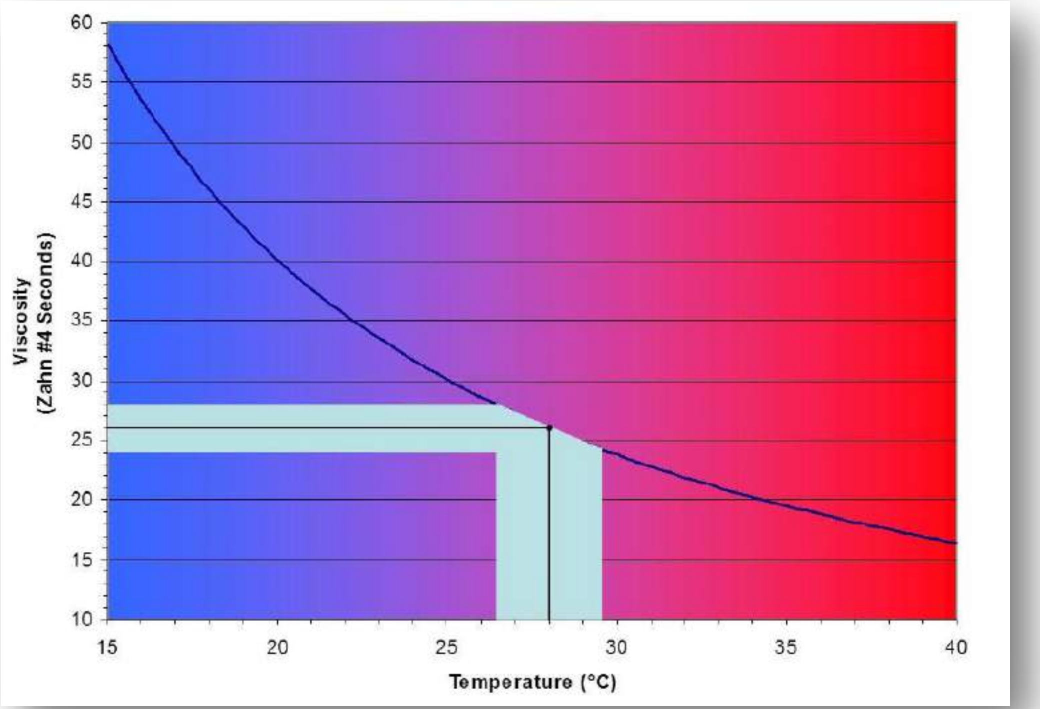
- Flash rusting and initiation of the corrosion process (Reduced corrosion resistance)
- Changes to free energy of the surface → changes to wettability, film formation, interfacial tension
- Evaporation of water during curing, which can lead to blistering
- Loss of adhesion
- Degraded chemical resistance

Application Dynamics with the Environment

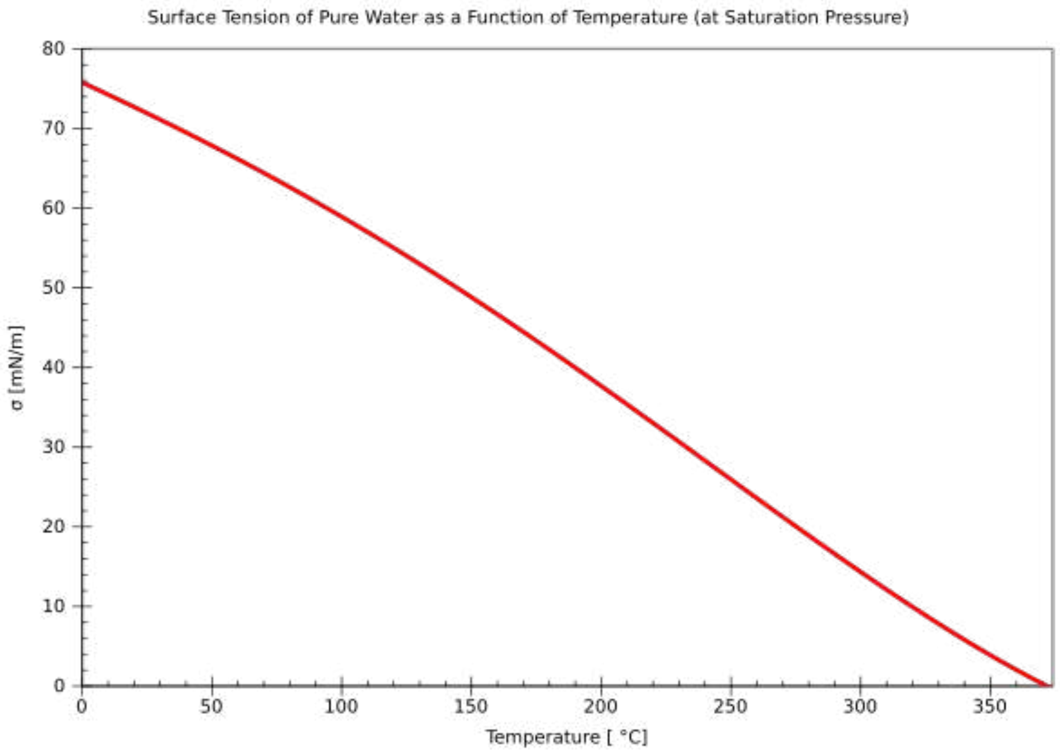
- RH and Temp influence
  - Rate of evaporation
  - Rheology
  - Surface Tension
  - Surface Energy



Application Dynamics with the Environment



- Viscosity Vs. Temp

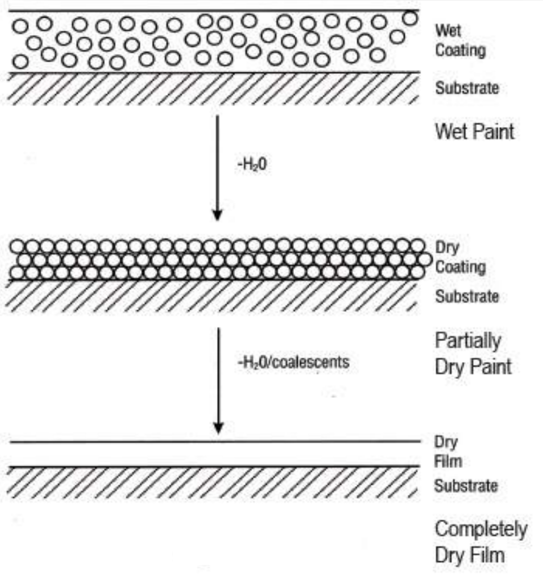


- Surface Tension Vs. Temp

Curing Dynamics with the Environment

Water based Systems (Latex)

- At high RH, water may not evaporate quickly enough and will fail to cure properly, leading to physical performance problems downstream.
- At low RH, the water may evaporate too quickly, not allowing sufficient time for coalescing and proper film formation. Rapid curing may also lead to cracking and skinning.



Moisture Cure Systems (polyurethanes, silicones, cyanoacrylates)

- Low Humidity can lead to extremely prolonged curing time or insufficient cure
- High humidity can cause rapid skinning (interior of coating doesn't cure properly) and limit workability window of the material

2K Systems

- Amines in 2K epoxy systems are water sensitive. (CO2 + H_20 + Amine = ammonium carbamate → blushing and reduced cure.

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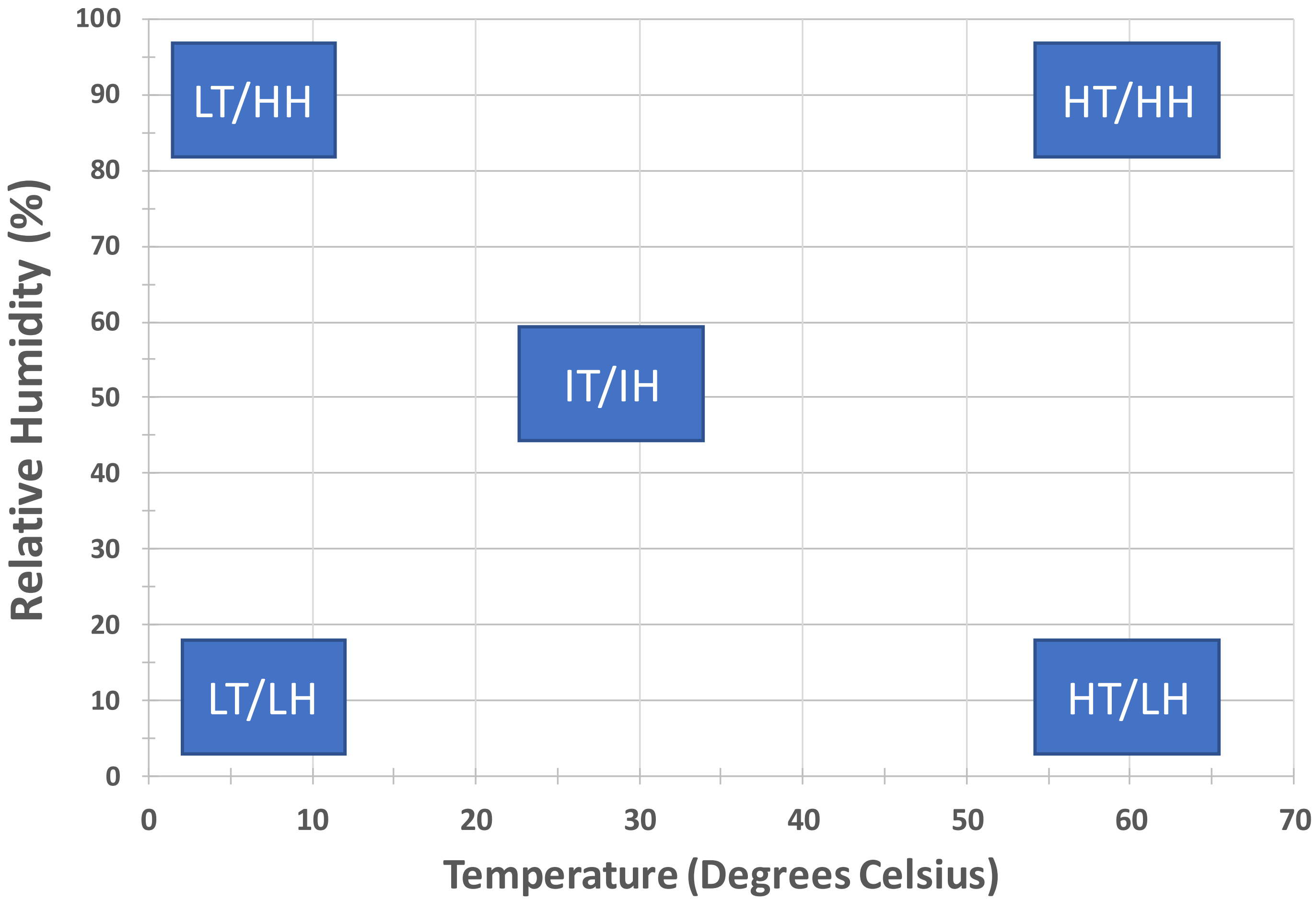
Psychrometrics

- Important to test spray application performance and curing dynamics at diverse points in the psychometric space (RH, T)



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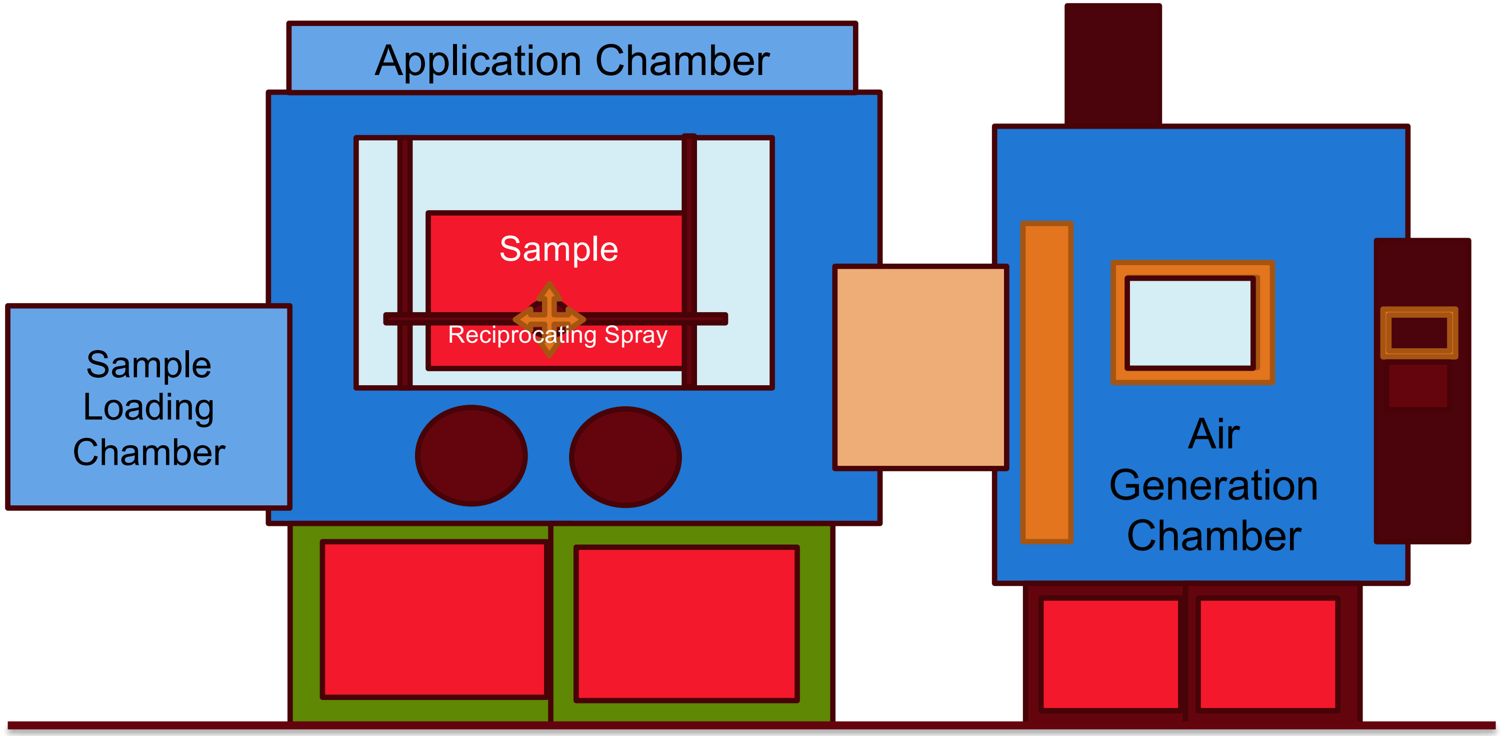
Environmental Chamber for Application and Curing Performance

- Temperature Range: 5° C – 65° C
- Relative Humidity Range: 10%RH – 95%RH
- Temperature and Humidity Independently Controlled: low temp and low RH, as well as high temp and high RH.
- Air Flow: Variable over the range 0.0 linear feet per minute, up to 50 linear feet per minute.
- Coating Chemistries: Water, Solvent, 100% Solid.
- Substrates: All types. 1' x 2' x 6" deep maximum dimension.



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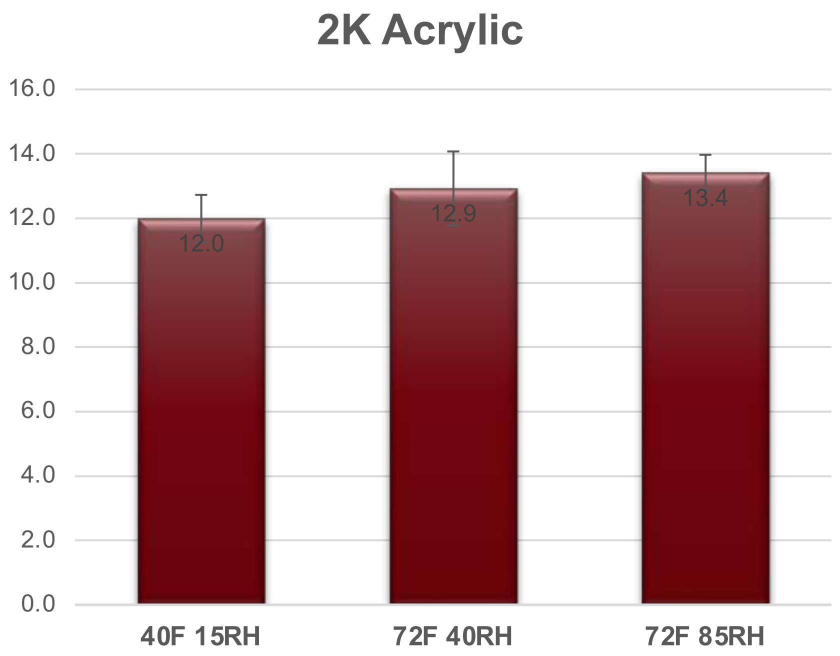
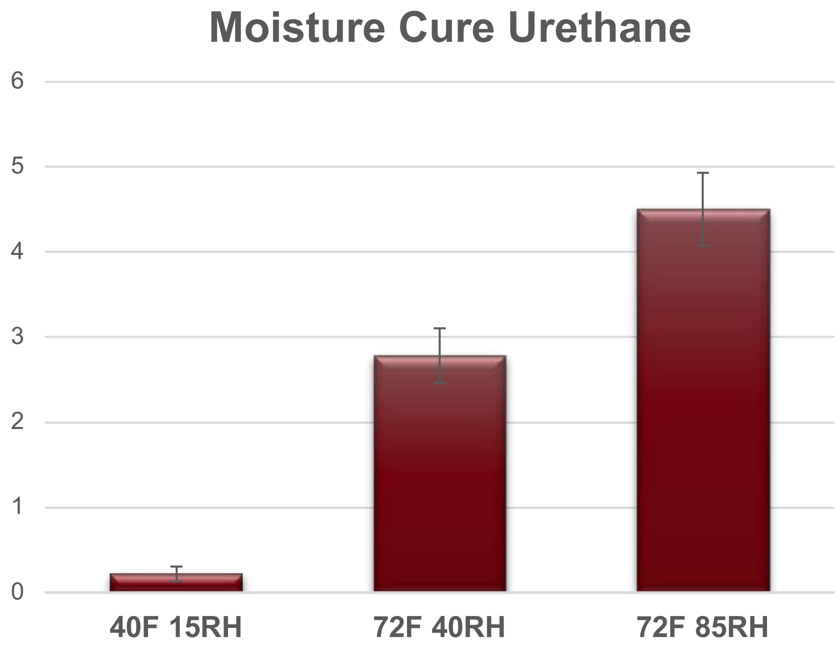
Environmental Chamber for Application and Curing Performance

Lap Shear Breaking Strength (MPa) on Cold Rolled Steel





Applied and Cured in System

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Summary

Benefits of Testing in a Manufacturing Environment

- Catch unforeseen/unpredictable problems before your customers do
- Optimize a raw material or a formula
- Unique advantage with customers
- Answers questions you didn't know to ask
- Provides knowledge beyond what is shown on typical TDS or Application Guideline

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