Materials for Noise and Vibration Control: What Causes Product Variation?

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This presentation and the published paper that it's based on, are about developing Failure Modes & Effects Analyses (FMEA) on materials for noise and vibration control.

By identifying potential causes of failures and the necessary steps to eliminate them, variations in product performance can be reduced, if not eliminated.

This presentation focuses on developing Process FMEA.

I'll identify two quality factors that are the basic sources for performance variations.

A generalized Process FMEA was created as part of the paper, and it should be useful to those who use these materials, as well as those who develop and produce them.

MATERIALS FOR NOISE AND VIBRATION CONTROL

A SPECIAL TYPE IS BASED ON VISCO-ELASTIC (V-E) MATERIALS

Polymers exhibit elastic flow and viscous flow.

Compositions based on polymer glass transition temperature.

Coatings are complex mixes of polymers and special additives.

Properties can be “tuned” to application requirements.

Dampers are layered polymer-based coatings & substrates.

This presentation focuses on materials for brake shims.

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As you may know, there are a number of methods available for attenuating unwanted noises and vibrations found in aerospace, electronic, commercial, and automotive components.

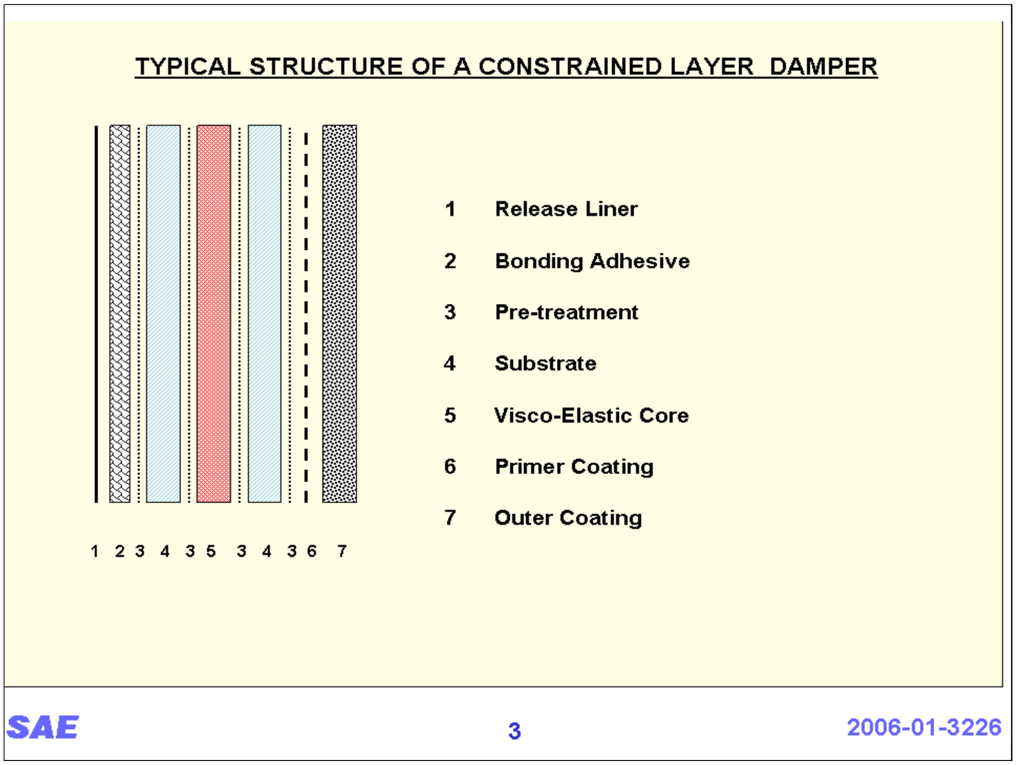
A special type of damping material involves polymer-based coatings that exhibit both *elastic flow* and *viscous flow*, depending on their temperatures.

These are commonly referred to as *visco-elastic* materials.

In engineering applications, the visco-elastic damping product is basically made of different materials assembled in layers.

In the simplest case, an assembly might be composed of a visco-elastic coating and a single supporting substrate such as steel.

Other configurations can involve layers of more that one kind of coating and more than one type of substrate.



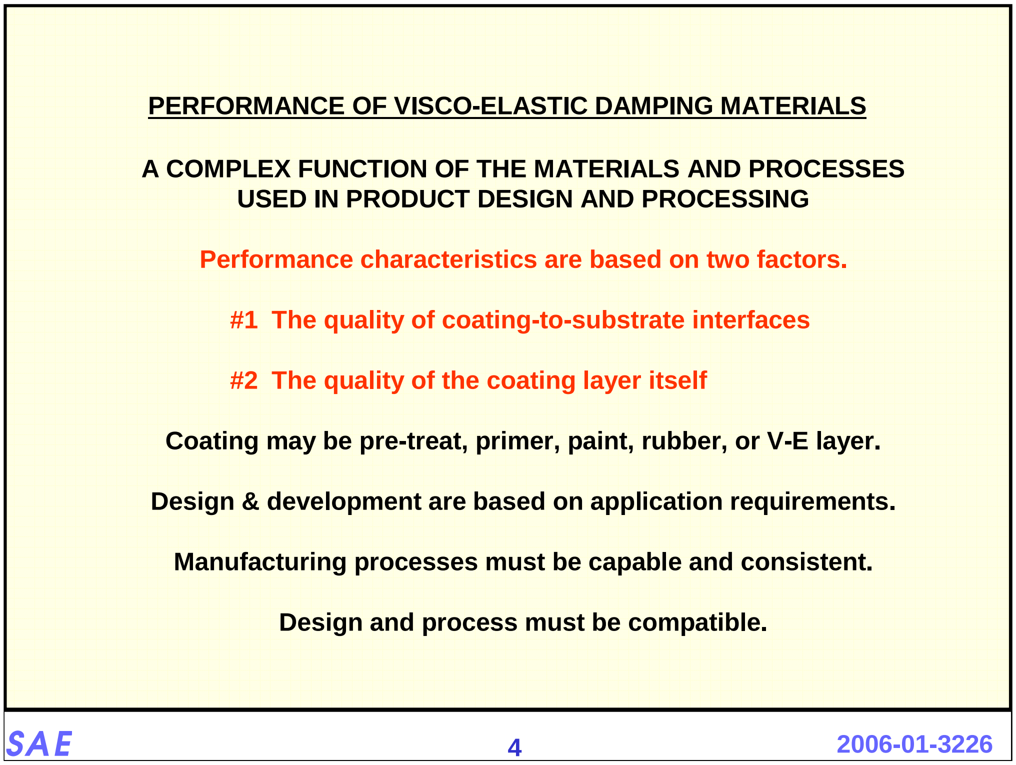
Slide #3 illustrates one type of multi-layered damper .

On the right in black is an outer coating that might be a simple black paint, or it could be a thick, rubber-based coating that may contribute to damping.

In blue are two layers of steel substrate that constrain the visco-elastic core represented in red.

On the left-hand side is a layer of adhesive used to bond the brake shim to a backing plate. The adhesive is protected by some type of release liner.

Also present are layers of metal surface treatments and a primer used to enhance adhesion of the outer coating.



-- No matter what their applications is, the expected performance for these layered assemblies is based on two factors: (1) the quality of the coating-to-substrate interface; and (2) the quality of the visco-elastic coating itself. <u>This is the simplest case.</u>

-- Complex damping materials such as the one illustrated in the previous slide have ten interfaces, seven coating layers, and two substrate layers.

-- It is the qualities and consistencies of each interface and coating layer that determine variability. This is the basis for developing a FMEA.

-- Thus, performance is a complex function of individual materials and processes used in fabricating the finished product.

-- Product design and development are based on a clear understanding of application-specific requirements such as damping, thermal environment, mechanical properties such as shear and peel strengths, and methods of attachment.

-- The manufacturing processes used to fabricate the damping material must be capable and consistent.

POTENTIAL FAILURE MODES

INADEQUATE DAMPING

COATING FAILURES

POOR ATTACHMENT

SHORT STORAGE LIVES

COATING COMPOSITION NOT "TUNED"

POOR SUBSTRATE PREPARATION

PREPARATION OF COATING MIXES INCORRECT

INCORRECT PROCESSING OF COATING

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Achieving consistent performance is dependent on many variables including, but not limited to, substrate cleaning, primers, proper curing, and thicknesses.

In my introductory comments, I said that a generalized FMEA was created as part of my presentation and paper.

Slide #5 lists eight Potential Failure Modes that may alter the performances of materials for noise and vibration control.

This is not intended to be an exhaustive list. It's only a list to be used as a starter.

General Failure Modes and Effects Analyses for Variations in Materials for Noise and Vibration Control

Potential Failure Mode	Potential Effect on Performance	Potential Causes of Performance Variation
Inadequate damping	NVH problem persists	Material selection error Coating composition not “tuned” to requirements Incorrect preparation of coating mixes Defective coating-to-substrate interface Substrate not cleaned properly Pre-treatment Incorrect processing of coating Solvent retention Degree of coating cure
Coating failures	Loss of damping capability Loss of adhesive bonding Delamination	Application requirements/testing too severe Material selection error Incorrect processing of coating Heat degradation
Poor attachments	Assembly downtime Bond failure Failure to adhere Improper adhesive cure Low mechanical properties Loss of attachment	Electrical resistance of coating too great Welding equipment problem Incorrect processing of coating Heat bonding equipment limitations Incorrect heat bonding parameters
Short storage lives	Adhesive bonds poorly Parts stick together Adhesive oozes	Adhesive cure advanced with aging/heat Moisture absorbed in adhesive (humidity) Incorrect processing of coating Inappropriate storage conditions
	Release liner sticks	Adhesive-to-release coating incompatibility Inappropriate storage conditions

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Don’t try to read this slide nor the one that follows.

I simply want show that the generic chart in the published paper contains three kinds of useful concepts to support creating a Process FMEA.

The concepts are categorized in three columns:

- **Potential Failure Modes (previous slide)**
- **Their Potential Effects on Performance**
- **Potential Causes of Performance Variation.**

This is too much material to cover today. So, I’ll focus on two examples.

Potential Failure Mode	Potential Effect on Performance	Potential Causes of Performance Variation
Coating composition not “tuned” to requirements	Inadequate damping Coating failures Poor attachments	Application requirements uncertain Material selection error
Poor substrate preparation	Defective coating-to-substrate interface Low mechanical properties Delamination	Substrate not cleaned properly Alkaline versus acid cleaners Maintenance of cleaning process Badly contaminated substrate Application of surface pre-treatment Too much or too little
Preparation of coating mixes incorrect	Varied performance characteristics Damping capability Adhesive bonding Mechanical properties Electrical conductivity Shelf life	Coating composition is incorrect Non-homogeneous coating mixture Shelf life of ingredients Changes in ingredients
Incorrect processing of coating	Varied performance characteristics Damping capability Adhesive bonding Mechanical properties Adhesive oozing Sticky coating Poor attachment	Ineffective removal of solvents Use of diluents versus true solvents Incorrect degree of coating cure Inappropriate coating thickness Incorrect or varying time-temperature profiles Equipment, training, procedural issues

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Slide #7 is the other half of the chart.

Next slide.

FIRST EXAMPLE OF PERFORMANCE VARIABILITY

CONVERTING V-E MIXTURES TO FINISHED PRODUCTS

POTENTIAL VARIABILITIES:

Damping capability

Adhesive bond strengths

Mechanical properties

Adhesive “leakage” or “oozing”

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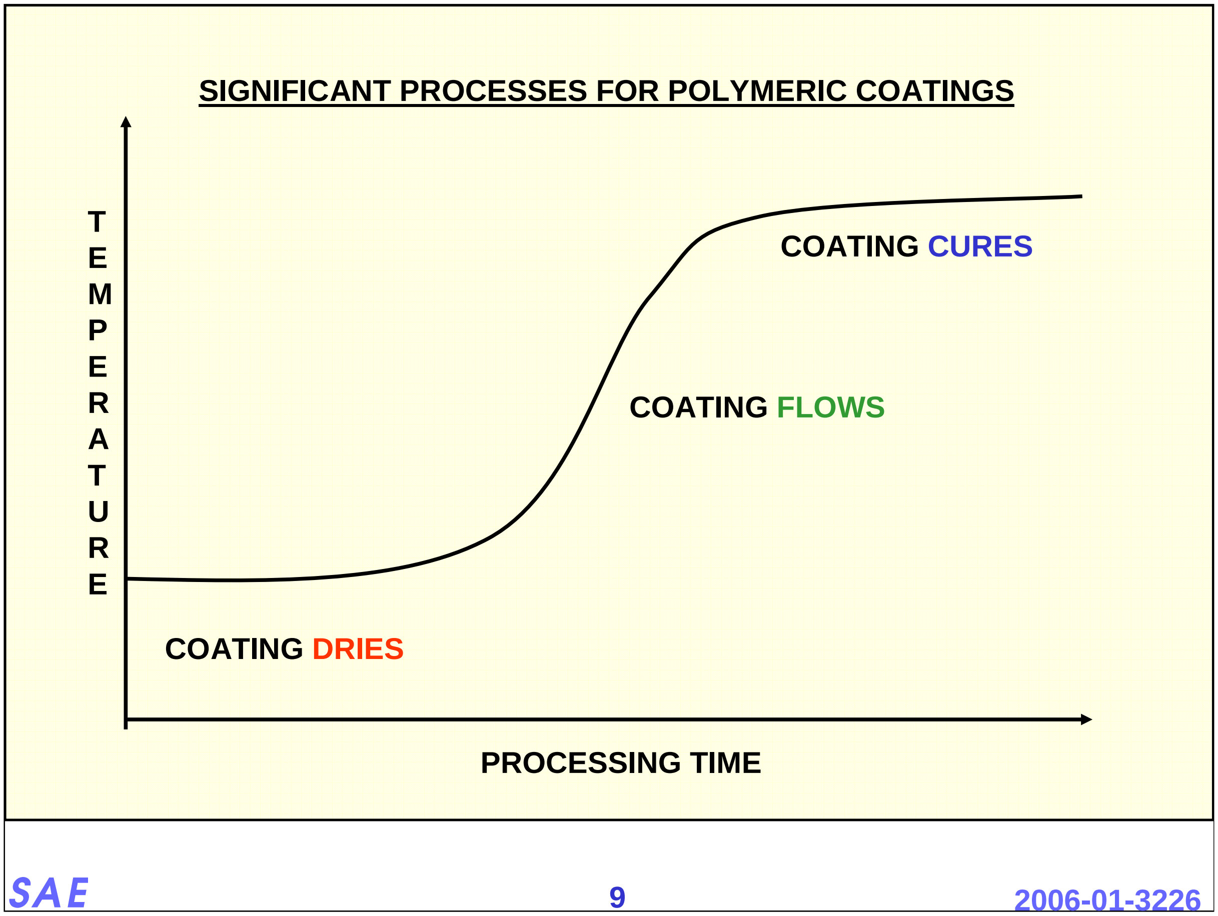
The first example considers converting V-E mixtures to finished products and some potential variations are listed in Slide #8.

In the manufacture of finished products, the coatings are generally solvent-borne mixtures formulated for the particular processing techniques being used.

These mixtures may contain numerous components such as polymers and additives to enhance adhesion, heat resistance, and other properties.

There are normal variations in the properties of each component. But, care must be taken during dispensing and mixing them.

Preparing a mixture for processing is the first opportunity to effect the quality of the finished coating, for better or worse.

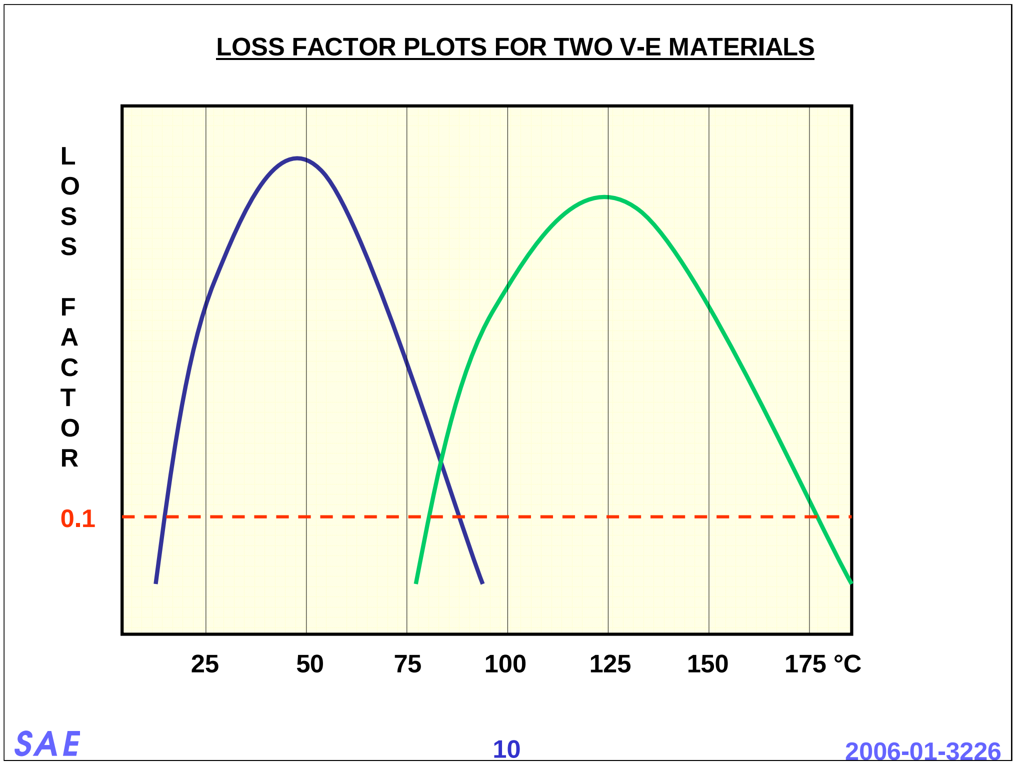


Converting a solvent-borne coating mixture to a finished coating involves sequential process steps as depicted in this slide.

The first step involves removal of solvents by controlled evaporation at a suitable low temperature and process speed. This is followed by a period of time where the temperature of the substrate and coating is increasing, and the solvent-free coating flows to yield a thin, uniform layer. Finally, the coating reaches the optimum temperature for completing the curing reaction.

The process of curing the coating involves chemically cross-linking the polymers for the correct amount of time and at the correct temperature.

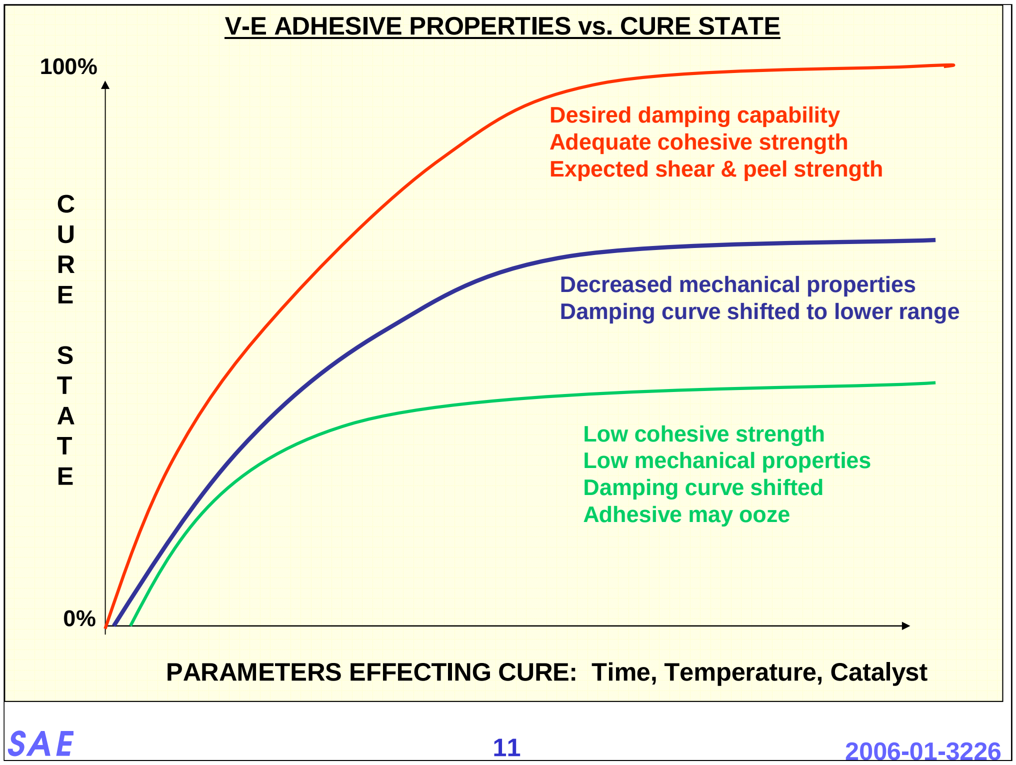
Done correctly, the damper would exhibit characteristic mechanical properties and a specific composite loss factor plot typified in the following slide.



Slide 10 illustrates plots of CLF vs T for two materials formulated to damp over different temperatures.

The one on the left (in blue) exhibits "good" damping over a range of 15 to 85 °C.

The one on the right (in green) at at 80 to 175 °C.



But, if the level of cross-linking turns out to be different than desired, the damping performance and the *composite loss factor* may be different.

This may also affect mechanical properties such as shear strength – cohesive strength – of the coating. If the cohesive strength becomes too low, the coating may tend to flow and may ooze (leak) out the edges of the material causing a sticky mess.

Slide 11 illustrates some properties of a coating at three states of cure. This could represent any organic coating that undergoes cure.

It's very important that the required time/temperature profile be determined as part of scaling up the coating for production.

Also, it should be regularly verified as part of an on-going quality program.

SECOND EXAMPLE OF PERFORMANCE VARIABILITY

ADHESIVES FOR JOINING AND ATTACHMENT

POTENTIAL VARIABILITIES:

Assembly downtime

Bond failure

Failure to adhere

Release liner sticks

Equipment capability

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Methods for joining or attachment of materials for noise and vibration control include *adhesive bonding*, *resistance spot welding*, and *mechanical means* such as peens, clips, etc.

Adhesive bonding of brake shims can exhibit unwanted variability. Often, this comes in the form of difficulties in bonding.

Three types of adhesive are generally used, as described on the following slide.

PROBLEM: LOW BOND STRENGTHS IN SERVICE

Pressure Sensitive Adhesives (PSA)

Poor substrate preparation.
Paint contains a release agent.
Absorption of moisture.

Thermoplastic Adhesives (TPA)

Contaminated substrate.
Incorrect bonding parameters.
Paint contains a release agent.

Thermosetting Adhesives (TSA)

Incorrect bonding parameters.
Shelf life exceeded.
Storage conditions too warm/hot.
Contaminated substrate.

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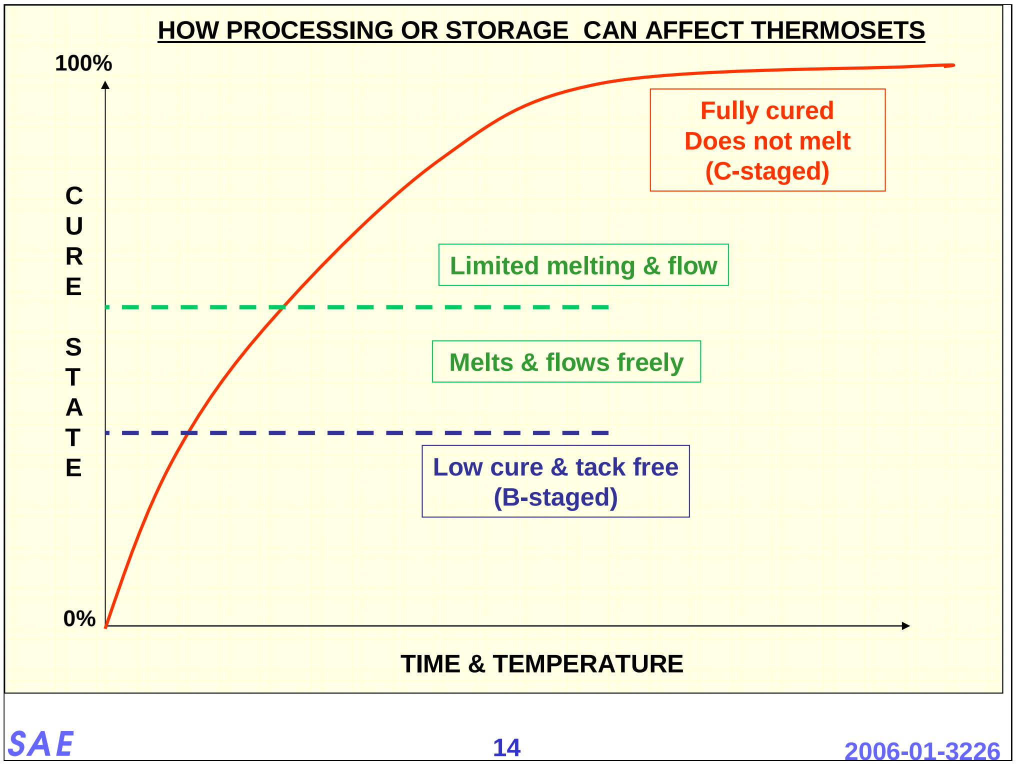
PSA are formulated to be tacky under ordinary ambient conditions and are attached to a substrate simply with pressure. Heat is not required, but is sometime used.

TPA are generally hard and tough. They require heat during bonding to soften them and develop enough tackiness and flow to wet the substrate. Upon cooling to ambient temperature, the TPA hardens. This is a reversible process, and parts can be re-bonded, if necessary.

TSA are sometimes hard, sometimes flexible, sometimes brittle. They require heat for melting to achieve good contact with the substrate and to initiate a curing reaction that results in a highly cross-linked material. After the bonding process is completed, application of heat does not soften the adhesive.



Solvent-free, uncured TSA are sometimes too tacky for easy handling. To reduce or eliminate the tackiness, it is common practice to "B-stage" or "pre-cure" the adhesive by controlled heating to slightly advance the level of cure. This must be done correctly to avoid over curing. A TSA that has been "B-staged" too far may be difficult to bond later.

TSA are inherently reactive and slowly cure at ordinary ambient temperatures. Performance can degrade if the product remains in inventory past its shelf life. Some are rapidly degraded when stored in hot or humid environments.

I'm a materials guy. To put a fine point on this, when a TSA is stored under such conditions, it's not a fault of the material that it degrades.

SUMMARY

Performance variability can be minimized.

Depends on qualities of interfaces and coatings.

Understanding the application requirements.

Appropriate selections of raw materials – chemicals, formulations, metals, etc.

Manufacturing processes must be capable of converting the raw materials into consistent products.

The paper and presentation provide a guide for creating a Process FMEA for materials for NVH control.

Later, Part II will consider design, materials, & validation issues.

In summary, the presentation, the paper, and the generic FMEA contained in it are intended to provide guides to developing Process FMEA. Hopefully, they will be useful to those to design, produce, and use the types of products discussed.

In the meantime, thank you for your time and interest.

CONTACT

The author is a professional chemist with 30+ years in academics, aerospace, and automotive-related industries. He received his PhD degree in chemistry from the University of Missouri at Rolla. While employed at LTV Aerospace & Defense Co. (Grand Prairie, TX), he was engineering laboratory manager working with specialty composites and coatings for very high temperature applications. At Materials Sciences Corporation (Elk Grove Village, IL), he was director of product development and focused on laminates and coatings for noise and vibration control. He was process engineering manager at EaglePicher – Wolverine Division (Blacksburg, VA), and was involved in optimizing production of materials for sealing applications and brake noise control. He has authored fourteen publications and twenty-six papers presented at technical conferences, including SAE International. As a professional consultant on various aspects of the chemistry of materials and their application, he works both independently and with a private firm. E-mail contact is RCDmatchem@msn.com.