Contamination, Coatings, and Materials Workshop

NASA Goddard Space Flight Center, Greenbelt, MD
Code 546 Contamination and Coatings Engineering Branch

Development of the Molecular Adsorber Coating

for Spacecraft and Instrument Interiors

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OVERVIEW

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INTRODUCTION

THE PROBLEM

- On-orbit Molecular Contamination
  – Occurs when materials outgas and deposit onto very sensitive interior surfaces of the spacecraft and instruments

Sources of Outgassed Molecular Mass	Interior Surfaces Impacted by Outgassed Molecular Mass
• Potting compounds • Epoxies • Tapes • Lubricants • Other spacecraft materials	• Optical surfaces • Thermal control surfaces • Electronics boxes • Detectors

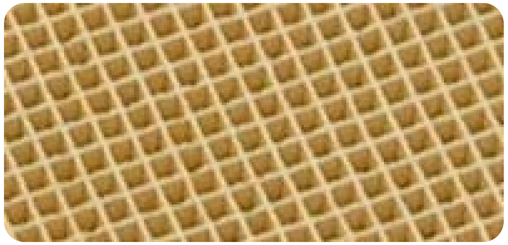
THE PROBLEM

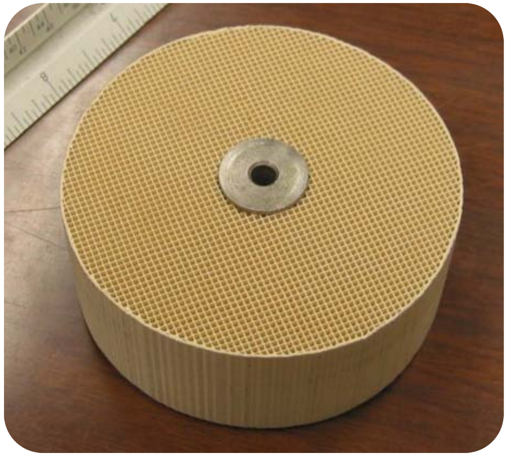
- On-orbit Molecular Contamination
  - If on-orbit molecular contamination is not properly adsorbed, vacuum baked, or vented, it can:
    - Degrade the performance of spaceflight hardware
    - Diminish the lifetime of the spacecraft
  - Impact on contamination sensitive surfaces:

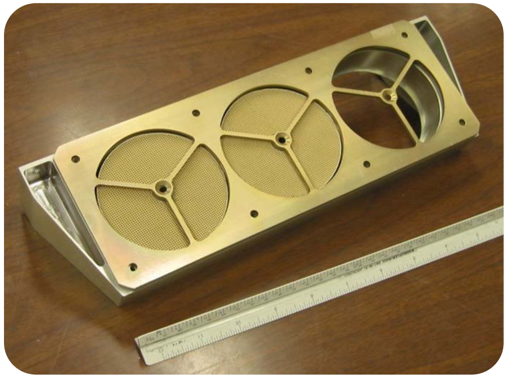
Optical Surfaces	• Results in cloudy imaging and incorrect sensing
Thermal Control Surfaces	• Changes thermal control characteristics and spacecraft temperatures

THE CURRENT SOLUTION

- **Molecular Adsorber Pucks**
  - Ceramic honeycomb patterned
  - Coated with zeolite adsorber slurry
  - Securely mounted on the interiors of the spacecraft and instruments
  - Collects, retains, and minimizes the transfer of outgassed molecular mass to contamination sensitive surfaces
  - Evaluated and proven successful with flight data from and ground simulation testing for NASA Goddard Space Flight Center (GSFC) missions:
    - *Hubble Space Telescope (HST)*
    - *Tropical Rainfall Measuring Mission (TRMM)*







THE CURRENT SOLUTION

- Disadvantages of Molecular Adsorber Pucks

Size	•Substantial amount of valuable space is required for additional hardware used to mount the pucks inside the spacecraft. These include support fixtures, screws, bolts, retaining hardware, and bonded inserts.
Weight	•Use of several pucks and mounting hardware impacts spacecraft mass allocations. For example, HST has over 60 puck-shaped 3.5 inch diameter adsorbers.
Cost	•Pucks are relatively inexpensive to fabricate. However, the fabrication of the mounting hardware is costly due to its unique design specifications.
Bake-Outs	•Impacts the integration and test schedule due to the extended subsystem hardware bake-outs that are necessary for the pucks and its additional support fixtures.

A NEW INNOVATIVE SOLUTION

- Molecular Adsorber Coating (MAC)
  - Code 546 is currently formulating, optimizing, and testing a ***sprayable alternative*** to molecular adsorber pucks
  - Zeolite-based coating with adsorbing properties that can be directly applied onto:

Internal instrument surfaces	Structural walls of spacecrafts	Inside and outside of electronics boxes

  - Benefits of using a sprayable coating alternative on future NASA's contamination sensitive flight projects
    - Eliminates the size, weight, and cost concerns associated with pucks and its additional mounting hardware
    - Reduces the time and/or need for subsystem hardware bake-outs during integration and testing

PROJECT DETAILS

PROJECT SUMMARY

- Objectives
  - Optimize the molecular adsorber coating formulation
    - To improve adhesion onto flight-like substrates
    - To increase its ability for molecular capacitance
  - Determine a successful spray application process
  - Perform laboratory testing and measurements under ground handling and on-orbit flight conditions
- Plan

Part I	Part II	Part III
• Formulation and Spray Application Study	• Adhesion Performance Study	• Molecular Capacitance Study

PART I: FORMULATION AND SPRAY APPLICATION STUDY

FORMULATION & SPRAY APPLICATION

- Goal of Study
  - Determine the best formulation and spray application process for the substrate configuration used in Code 546's research efforts
    - Substrate configuration is comprised of 3 layers:

Layer	
MAC Top Coat	FORMULATE AND SPRAY!!!
AZ-93 Base Coat	Ceramic white thermal control coating that is known to adhere very well to aluminum surfaces
Aluminum Substrate	Common surface coated for spaceflight hardware

FORMULATION & SPRAY APPLICATION

- MAC Formulation
  - **Key Components:**

ZEOLITE *"the pigment"*	LUDOX ® *"the binder"*
• Acts as the adsorbent material that captures and traps contaminants due to its porous structure	• Acts as the glue that holds the coating together and also provides adhesion to the AZ-93 and MAC layer interface

  - **Varying Parameters:**
    - Binder to Pigment Mass Ratios
    - Ludox ® Binder Grades
    - Water (for viscosity)

~ 17 MAC Formulations

FORMULATION & SPRAY APPLICATION

- Spray Application Process
  - **Varying Parameters:**
    - **Surface Treatment**
      - Rub priming
    - **Cure Conditions**
      - Durations
      - Temperatures
    - **Spray Gun Settings**
      - Air pressure
      - Fluid flow pressure
      - Atomizing pressure

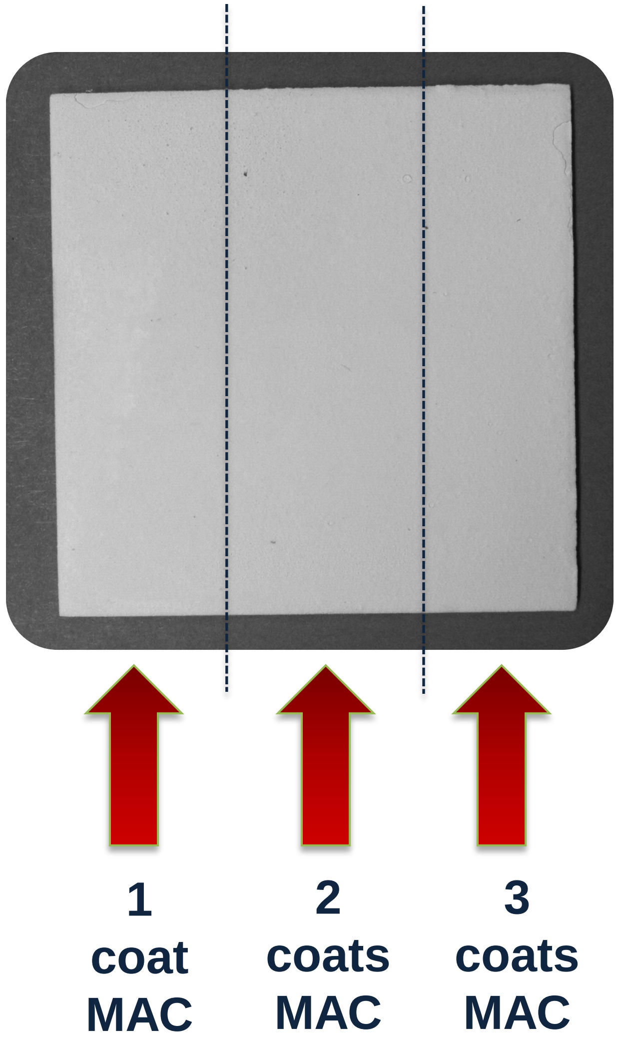
FORMULATION & SPRAY APPLICATION

- Sample Set-Up
  - 6” by 6” aluminum substrates
  - **Base Coat:**

AZ-93 Coats	Thickness
2	~ 2 – 4 mils

  - **Top Coat:**

MAC Coats	Thickness
1	~ 1 – 3 mils
2	~ 3 – 6 mils
3	~ 5 – 8 mils



FORMULATION & SPRAY APPLICATION

- Results
  - **Coating Failure**
    - Excessive cracking and peeling
    - Occurred on thicker regions of samples during the curing step in spray application process
      - *Between 2-3 coats*
    - Failure between MAC and AZ-93 only

  - **Coating Success**
    - Two formulations showed promising results using the appropriate technique during the spray process

Next Step:

Adhesion Performance Study

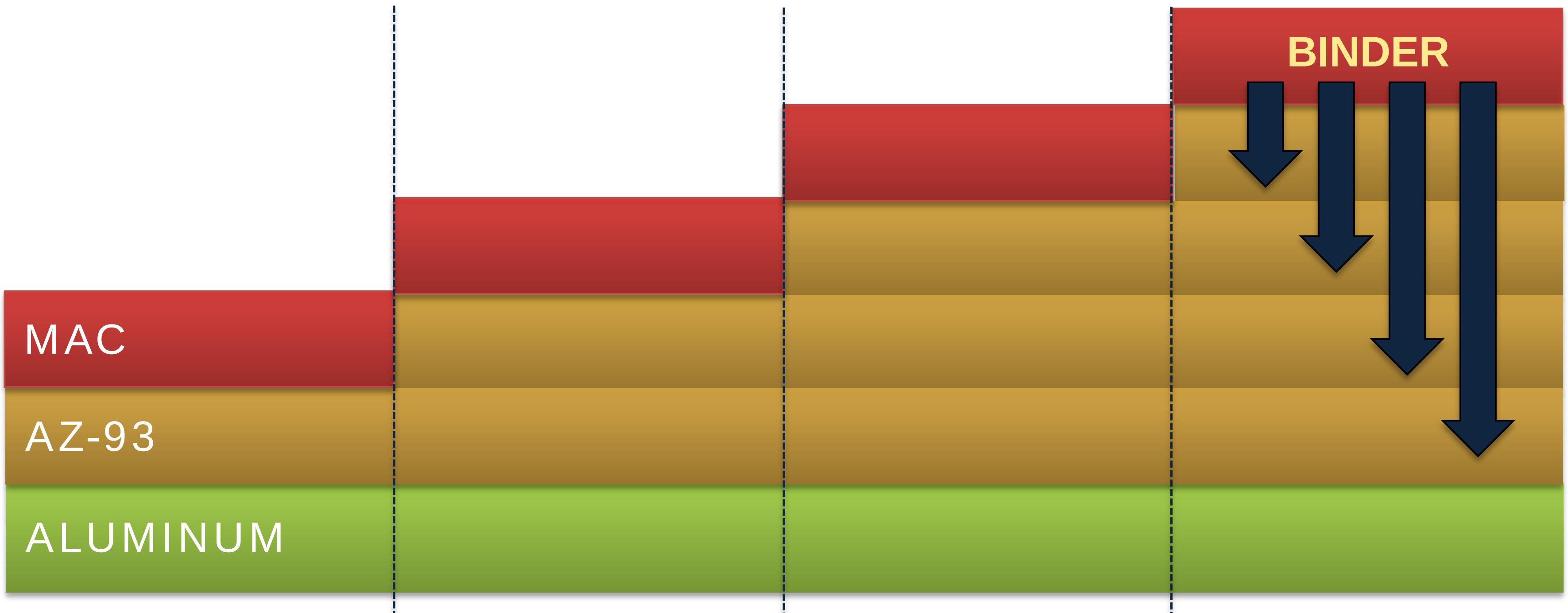
PART II: ADHESION PERFORMANCE STUDY

ADHESION PERFORMANCE

- Goals of Study
  - Evaluate the adhesion performance for the two formulations that showed the most progress in the previous study
    - *Which formulation of the two is better?*
  - Study the effect of the migration of binder between the coating layers and its correlation to adhesion performance
    - *Does enough binder migrate from the top coating into the base coating to provide strong adhesion?*
  - Determine the optimal number of coats at which adhesion issues are at its minimal
    - *How thick do the top MAC layers and base AZ-93 layers need to be in order to avoid adhesion problems?*

ADHESION PERFORMANCE

- Sample Set-Up
  - Eight 2” by 12” aluminum substrates
  - Vary thickness of base coat while keeping top coat constant
    - *Is there a correlation between the migration of binder and coating thickness to adhesion performance?*



ADHESION PERFORMANCE

Summary of Sample Set-Up

Formulation	Sample ID	MAC Coats	AZ-93 Coats	Ludox ® Grade
A	MA 214-1	2	1-4	Type 1
	MA 214-2	3		
	MA 214-3	4		
	MA 214-4	5		
B	MA 214-5	2	1-4	Type 2
	MA 214-6	3		
	MA 214-7	4		
	MA 214-8	5		

ADHESION PERFORMANCE

- ## Coating Adherence Testing
  - **ASTM* D 3359-02: X-Cut Tape Test (Method A)**
    - Standard Test Methods for Measuring Adhesion by Tape Test
      - *Due to the "extreme" or "vigorous" nature of testing adherence using this ASTM standard, results may or may not indicate adhesion failure*
  - **Pre-Thermal Cycle X-Cut Tape Tests**
    - 4 x-cuts per sample for each section
      - 16 total x-cuts for Formulation A
      - 16 total x-cuts for Formulation B
  - **Post-Thermal Cycle X-Cut Tape Tests**
    - 4 x-cuts per sample for each section
      - 16 total x-cuts for Formulation A
      - 16 total x-cuts for Formulation B

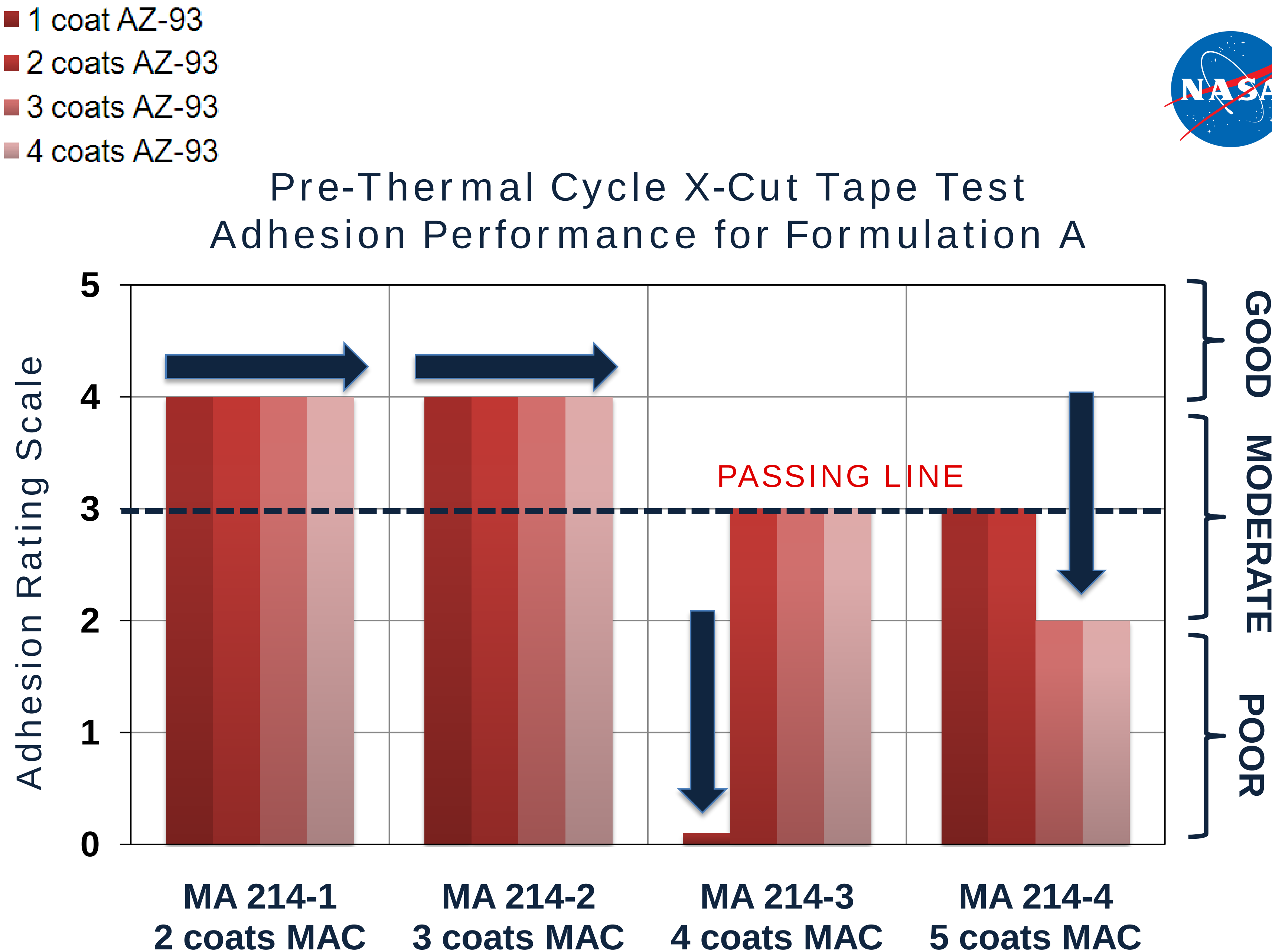
* American Society for Testing and Materials (ASTM)

ADHESION PERFORMANCE

Adhesion Rating Scale for X-cut Tape Test

ASTM Rating	Description of Peeling/Removal Conditions After Tape Test	Conclusion *GSFC Rules of Thumb*	
5A	No peeling or removal	Good Adhesion	**PASS!**
4A	Trace peeling or removal along incisions or at their intersection		
3A	Jagged removal along incisions up to 1.6 mm (1⁄16 in.) on either side	Moderate Adhesion	
2A	Jagged removal along most of incisions up to 3.2 mm (1⁄8 in.) on either side		**FAIL!**
1A	Removal from most of the area of the X under the tape	Poor Adhesion	
0A	Removal beyond the area of the X		

Pre-Thermal Cycle X-Cut Tape Test Adhesion Performance for Formulation A



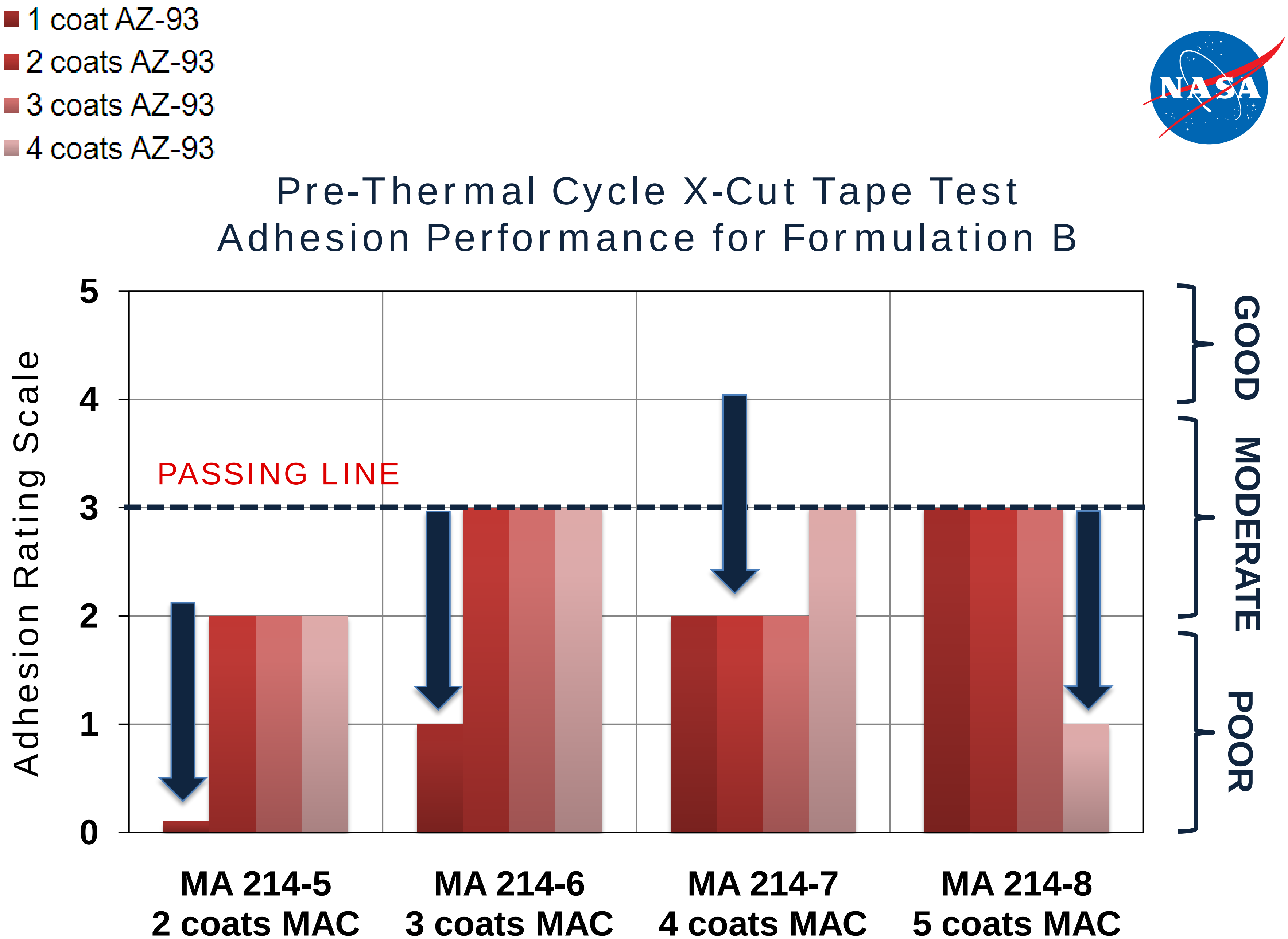
ADHESION PERFORMANCE

- Effect of MAC Thickness with Formulation A

Thinner MAC Coats	Thicker MAC Coats
• May improve adhesion • Example: MA 214-1 & 2	• May degrade adhesion • Example: MA 214-3 & 4

- Effect of AZ-93 Thickness with Formulation A
  - A general trend could not be adequately concluded due to conflicting discrepancies in x-cut tape test results
    - Adhesion performance decreased for:
      - *Thinner coats of AZ-93; i.e. MA 214-3*
      - *Thicker coats of AZ-93 ; i.e. MA 214-4*

Pre-Thermal Cycle X-Cut Tape Test Adhesion Performance for Formulation B



ADHESION PERFORMANCE

- Effect of MAC Thickness with Formulation B
  - A general trend could not be adequately concluded due to conflicting discrepancies in x-cut tape test results
    - *Samples with 3 and 5 MAC coats passed but 4 MAC coats did not pass*
  - Formulation B performed inferior in adhesion to Formulation A
- Effect of AZ-93 Thickness with Formulation B

Thinner AZ-93 Coats	Thicker AZ-93 Coats
• May degrade adhesion • Example: MA 214-5,6 & 7	• May improve adhesion • Example: MA 214-5,6 & 7

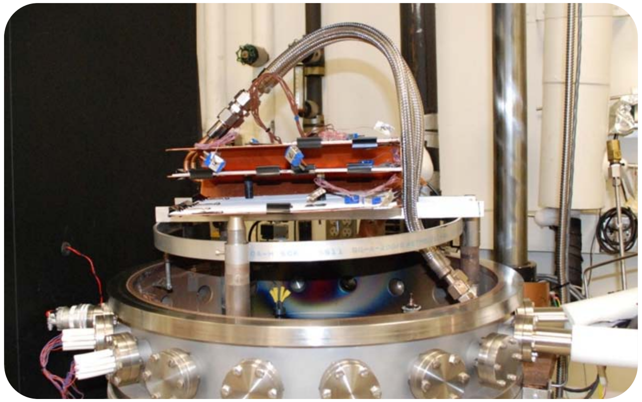
Note: *MA 214-8 does not follow this general trend*

ADHESION PERFORMANCE

- **Thermal Cycle Testing**
  - Performed in a vacuum chamber
  - Test conditions
    - -160 ºC to 150 º C for ~30 cycles
  - Molecular adsorber coating is intended for use at operating temperatures that are representative of electronics boxes
    - *Electronics boxes and other interior surfaces typically reach temperatures between -10 ºC to 40 ºC*
  - Perform tape tests again to verify the stability of coating after experiencing these spaceflight conditions

ADHESION PERFORMANCE

- Thermal Cycle Testing
  - **Test Set-Up**
    - Test stand constructed of copper for better conductivity and attached to liquid nitrogen (LN2) cold plate
    - Thermocouples and heaters securely attached to 8 samples and test stand to monitor temperatures
  - **Visual Inspection**
    - No signs of cracking or peeling
    - Noticed slight yellowing discoloration
      - *May indicate contamination or a sensitivity to temperature*



ADHESION PERFORMANCE

- Post Thermal Cycle X-Cut Tape Test Results
  - **Formulation A**
    - No major improvements or drastic failures to adhesion ratings
      - This provides confidence that Formulation A will remain stable
  - **Formulation B**
    - Adhesion ratings remained fairly consistent (for the most part)
      - Some samples within specific sections experienced 2 to 3 level improvements to adhesion ratings
      - These slight changes suggest that the level of confidence in coating stability for Formulation B may be questionable?

Sample ID:	MA 214-5 2 coats MAC		MA 214-6 3 coats MAC		MA 214-8 5 coats MAC	
Coats of AZ-93	*Pre TC*	*Post TC*	*Pre TC*	*Post TC*	*Pre TC*	*Post TC*
1 coat AZ-93	0A	**3A**	1A	**3A**	3A	3A
4 coats AZ-93	2A	3A	3A	3A	1A	**3A**

ADHESION PERFORMANCE

- Conclusions
  - Formulation A performed better than Formulation B in coating adhesion and thermal stability
    - This may be due to chemical composition of binder used
  - Migration of binder through the coating layers:

Formulation A	Formulation B
• Showed that thinner layers of MAC may improve adhesion	• Showed that thicker layers of AZ-93 may improve adhesion

If its too thick, binder may not be able to migrate to base coat to develop that adhesive bond at the base/top layer substrate interface

If its too thin, there may not be enough pores in the base coat for the binder to migrate through to create an adhesive bond at the base/top layer substrate interface

FUTURE PLANS

FUTURE PLANS

- Repeatability Study
  - Repeat to verify that results are replicable and conclusive
  - Continue to further optimize formulations and techniques for spray application process to achieve best adhesion performance
- Molecular Capacitance Study
  - Evaluate the molecular capacitance of successfully coated MAC formulations using an efficient test set-up system
    - *Which formulation is capable of adsorbing more contaminants?*
    - *Does thickness play a role in the amount that can be adsorbed?*
- Qualification Study
  - Complete full flight qualification of the MAC coating for application on future spaceflight missions

QUESTIONS?

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