THE DEPARTMENT *of* MATERIALS SCIENCE AND ENGINEERING

A. JAMES CLARK SCHOOL OF ENGINEERING

MSE3

Plasma Functionalization for Improved EPDM–HTPB Interfacial Bonding

***Team Rocket Ready**: Katrina Chou, Alessandra Contreras, Alessandra Crippa, Isabelle LaManna, and Alyssa Taylor*

Problem Definition

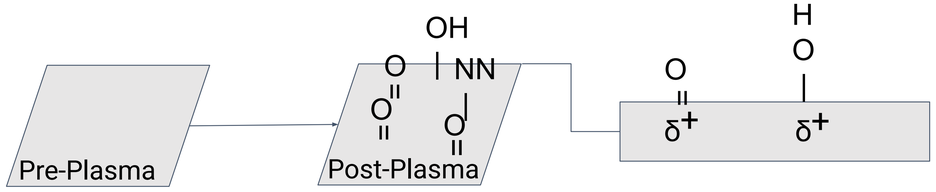
NORTHROP GRUMMAN

- Ethylene propylene diene monomer (EPDM) rubber is difficult to bond because its non-polar, hydrophobic nature creates a low-energy surface that resists adhesives.

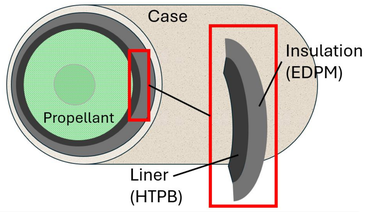
Goal → Improve EPDM bonding capabilities using plasma

- Plasma introduces free radicals that attach to the surface creating polar groups. Polar groups on the surface increase its hydrophilicity and surface energy making it more likely to bond with other surfaces.

Surface Chemistry of EPDM



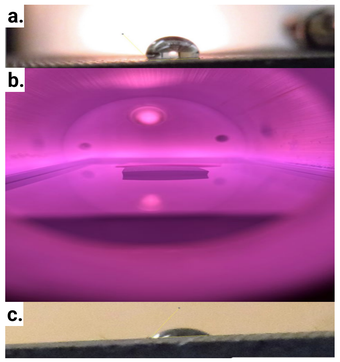
- Currently, industry standard insulation preparation for solid rocket motors is a mechanical abrasion process that leaves particles on the surface and variation, both can create problems for bonding.
- We hypothesize that using plasma will increase the bond strength of EPDM to the hydroxyl-terminated polybutadiene (HTPB) liner in the solid rocket motor system. This will create a scalable process for industry stakeholders.



Schematic of a solid rocket motor

Objective → Investigate plasma parameters that introduce polar groups on EPDM rubber surface to improve its bonding capabilities

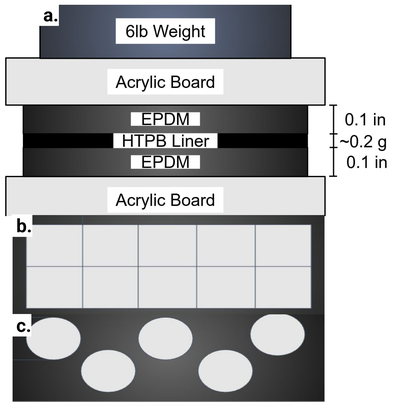
Final Design



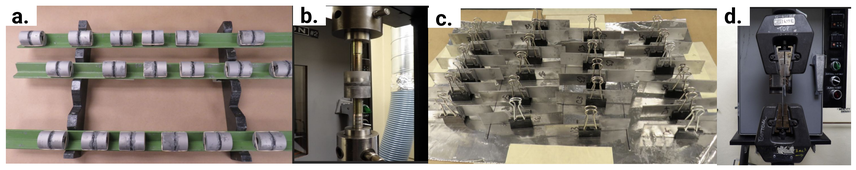
Proof of Concept: a. Water droplet before plasma treatment **b.** EPDM in plasma chamber **c.** After plasma

Final Plasma Parameter → 80 Watts, 10 sccm for 3 mins

Sample Preparation Conditions	
	1. Alconox detergent and dry
	2. Alconox detergent, dry, and plasma functionalize
	3. MEK, mechanical abrasion, and dry
	4. MEK, mechanical abrasion, dry, and plasma functionalize



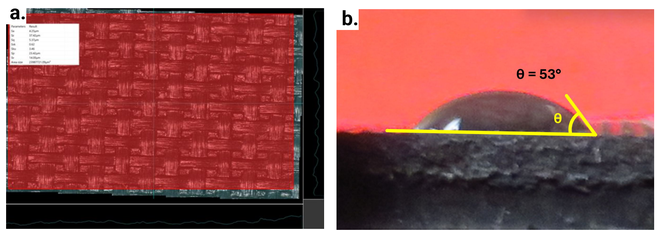
Schematic of Sample Preparation: a. Diagram of EPDM-HTPB bonded samples **b.** 1 in x 1 in cut out squares for lap shear **c.** 1.25 in diameter circles for flatwise tensile testing



Mechanical Testing: a. Prepared flatwise tensile samples **b.** Flatwise tensile testing in accordance with ASTM C 297 **c.** Prepared lap shear samples **d.** Lap shear testing following ASTM D 3164

Design Calculations & Analysis

Selection Goal → Plasma parameters that produce the lowest water contact angle with the lowest change in RMS roughness



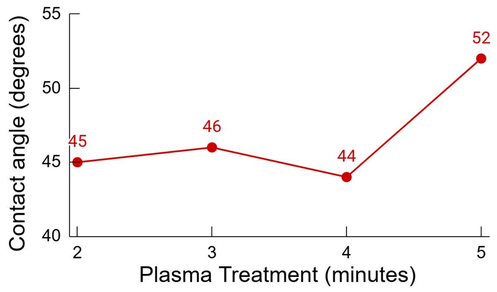
Parameter Measurements: a. RMS via digital microscopy surface roughness **b.** water contact angle measurement via ImageJ software

Maximum Theoretical Tensile Bond Strength

Governing failure point in adhesion → Hydrogen bonds

$$F_{bond} = \frac{E_{bond}}{l_{bond}} \qquad \rho_{areal}^{func.\ group} = \frac{o}{c} ratio \times \#C\ atoms/nm^3 \times l_{bond}$$

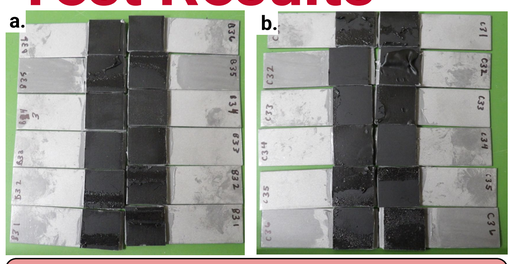
$$\sigma_{theory} = F_{bond} \times \rho_{areal}^{func.\ group} = \mathbf{6\ MPa}$$



Time [min]	Average ΔRMS [μm]	Water Contact Angle [°]
5	-0.32 ± 2.9	52 ± 7.3
4	1.1 ± 3.6	44 ± 13
3	1.1 ± 0.55	46 ± 12
2	-1.2 ± 1.8	45 ± 18

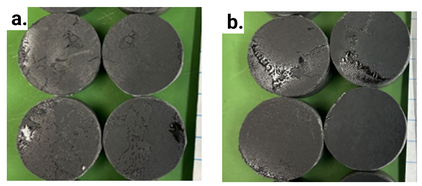
ΔRMS Value = (post-plasma) - (pre- plasma)
Positive Difference → Rougher surface
Negative Difference → Smoother surface

Test Results

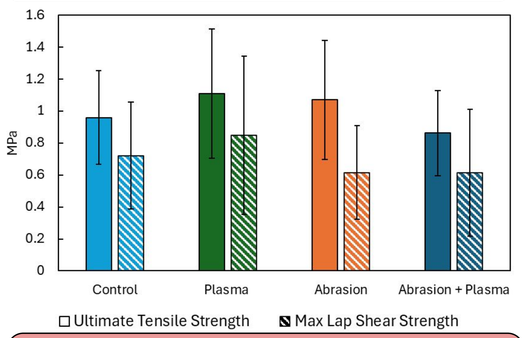


Lap Shear Samples Post-testing: a. Plasma treated **b.** Abraded

On average the plasma samples had more cohesive failures compared to the abraded samples which had more adhesive failures during lap shear and tensile testing



Flatwise Tensile Samples Post-testing: a. Plasma treated **b.** Abraded



Plasma treatment resulted in the greatest ultimate flatwise tensile strength and max lap shear strength

Major Findings

- Plasma surface treatment on EPDM resulted in an increase in adhesive strength with HTPB liner
- The fractured surfaces of the plasma treated samples from lap shear and flatwise tensile testing appear rougher indicating cohesive failure
- Cohesive failure of this interface is the desired failure mode of this joint system

Future Work

Time → Increasing time results in rougher surfaces and difficulties in measuring water contact angle
RF Power → Increasing RF power results in decreased water contact angle while increased RMS roughness
Gas Flow Rate → Increasing flow rate results in increased water contact angle and decreased surface roughness