An Investigation into the Root Causes of O-Ring Adhesion

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Outline

Introduction

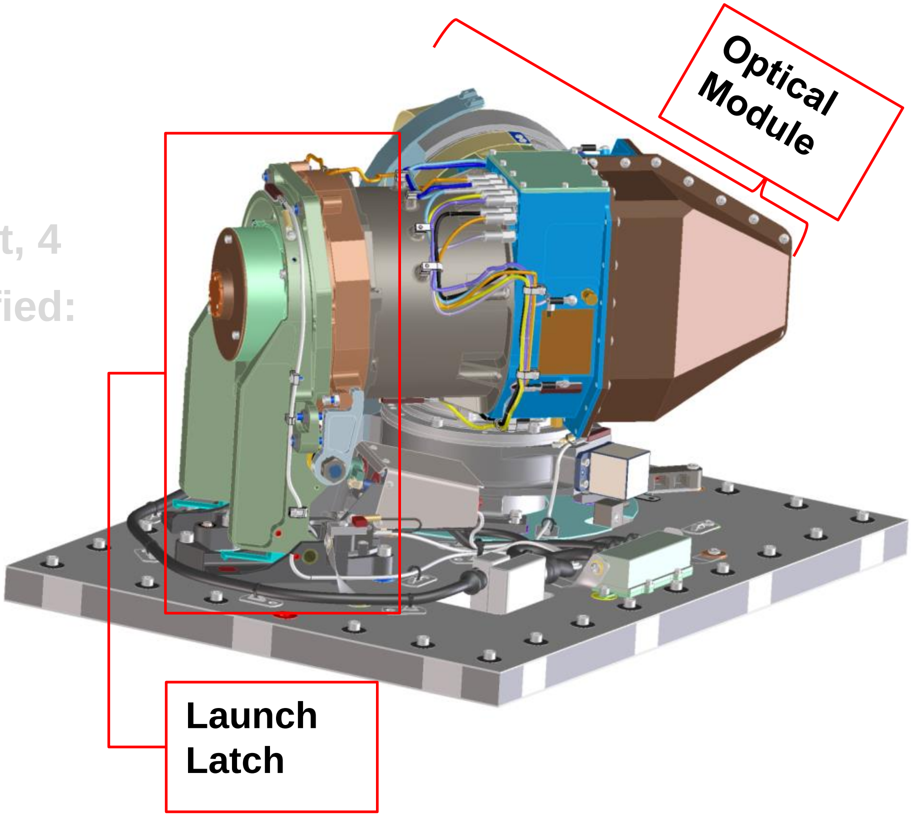
Test Results

Part Selection

Recommendations

The Space Terminal

- **The space terminal is a space-based high data rate laser communication system**
- **Launch Latch and interface**
  - Restrains telescope during launch
  - Contamination seal during ascent



- **To ensure the Launch Latch opens in orbit, 4 Launch Latch components must be specified:**
  - O-ring
  - Mating Interface
  - Lower Torsion Springs
  - Upper Vlier Spring Plunger
- **Launch Latch design criteria**
  - The load on the HOPAs and Pawl Arm do not yield or break during launch
  - Launch Latch opens once on orbit

Select components for Launch Latch design to ensure survival of hardware and successful opening

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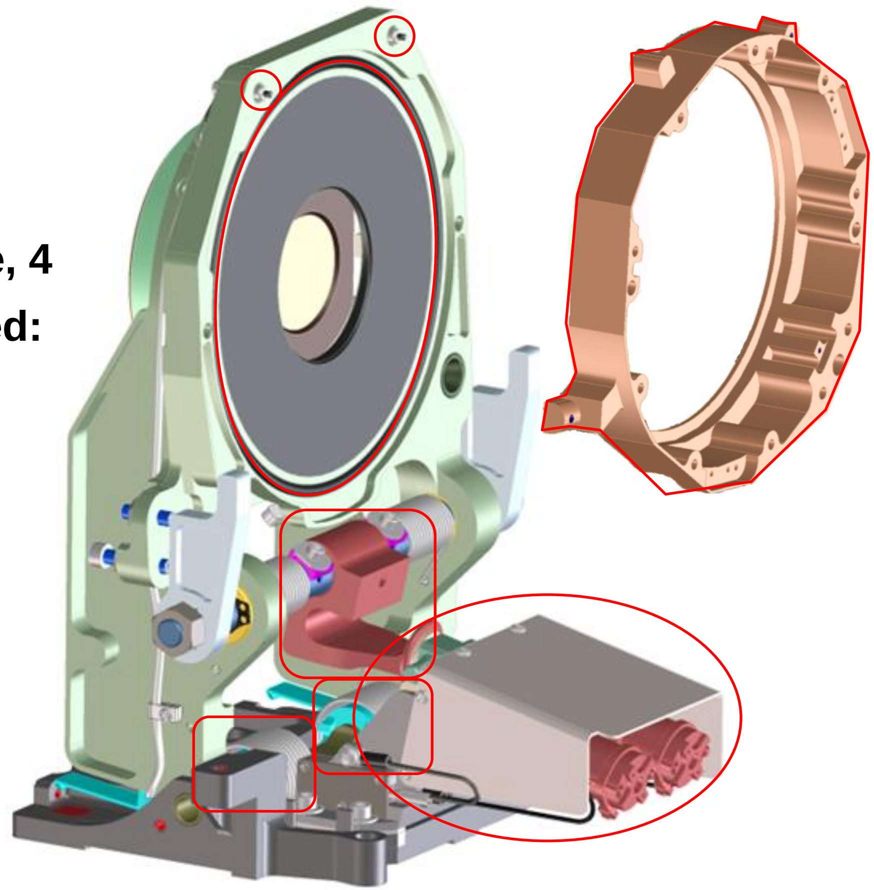

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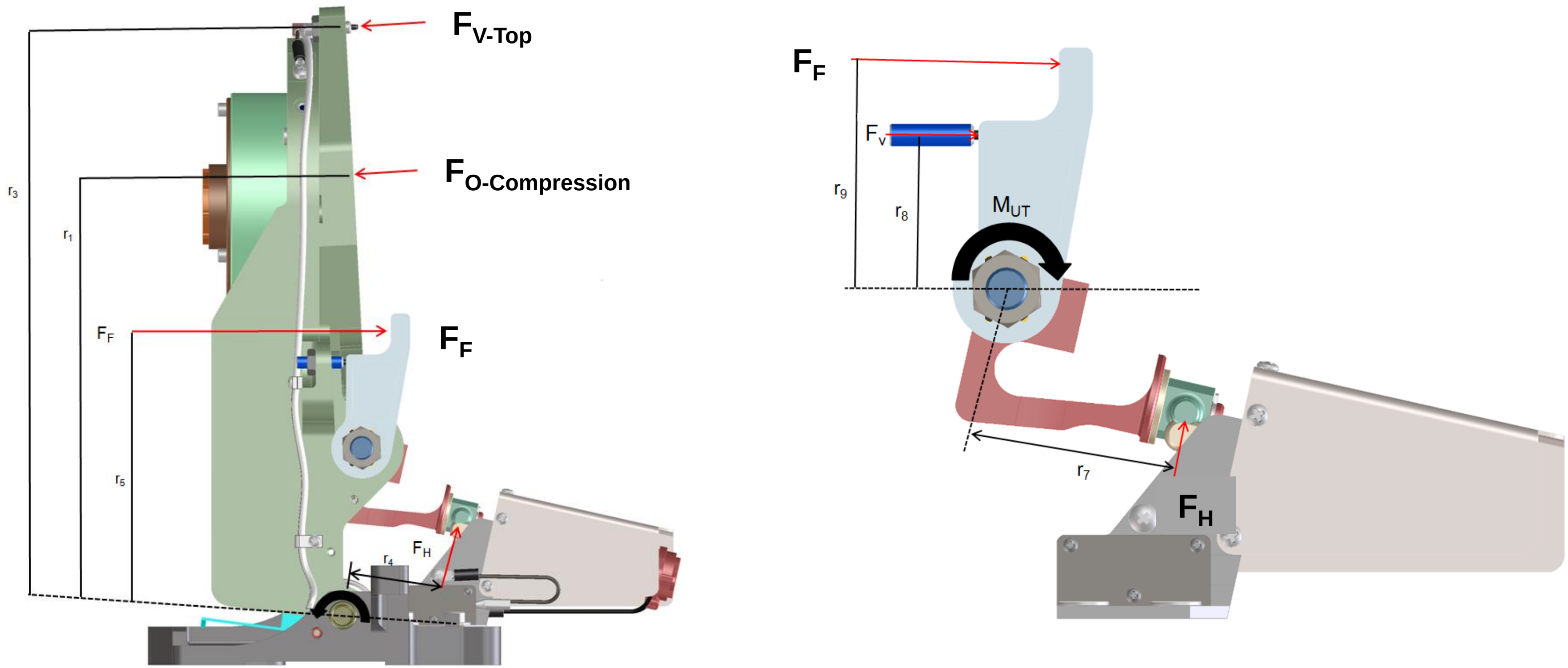
Problem: Ensure Latch Parts Survive

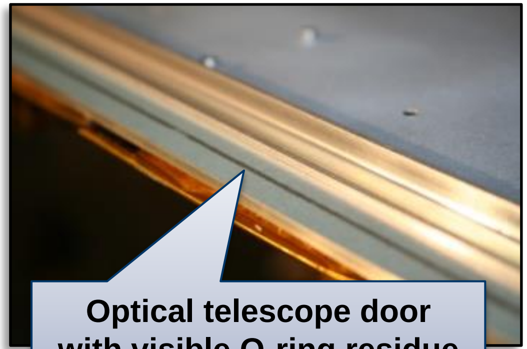


- Sum of the moments to find relations between F_F and F_H
- Selection of O-Ring, Vliers, and Lower Torsion Springs determine F_H
- $F_{Load} < F_{Vibration} + F_{Preload} + F_{HOPA}$

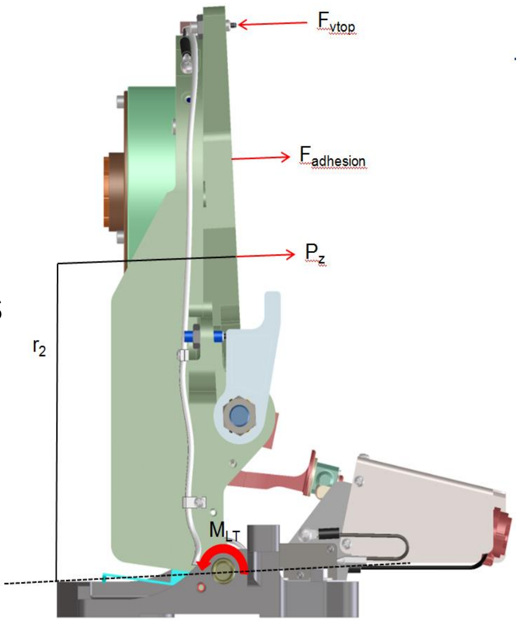
Select components for Launch Latch design to ensure survival of hardware during launch

Problem: Ensure Latch Opens

- **What can prevent opening?**
  - Parasitic latch pin force Pz (given)
    - Well understood and taken into account
  - O-ring adhesion
    - Fundamental mechanics not well understood
    - Time must be spent on this problem



- **Method to ensuring successful opening:**
  - Test O-ring adhesion
    - Quantify promising candidate O-rings and interfaces in search for a zero adhesion pairing
  - Select parts to overcome adhesion force
    - 1.25 safety factor applied to maximum adhesion force from testing



Testing of adhesion force and proper part selection will ensure successful latch opening

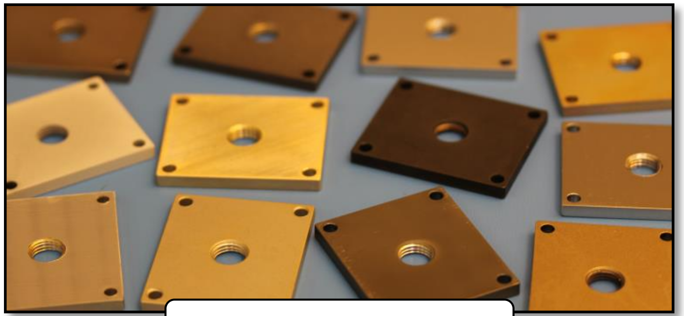
O-Rings and Interfaces

O-Ring	Type	Manufacturer
V0986	Fluorocarbon	Parker
S0899	Silicone Rubber	Parker
C0267	Polychloroprene	Parker
E1100	Ethylene Propylene Rubber	Parker
LM151	Fluorosilicone	Parker
S0469	Silicone Rubber	Parker
S0820	Silicone Rubber	Parker
CV2289*	RTV	MIT LL
RTV566*	RTV	MIT LL
SCV2585*	RTV	MIT LL
JaBar	Silicone Rubber	Ja-Bar
S7440	Silicone 0.05” Inner Diameter (ID)	Parker
S7440 FEP*	Silicone 0.05” ID FEP Encapsulated	MIT LL
Creavey 030	Silicone 0.03” ID FEP Encapsulated	Creavey
Creavey 050	Silicone 0.05” ID FEP Encapsulated	Creavey

*** Custom**

Interface	Type	Manufacturer
Chem Film **(CFM)**	AL Finish	n/a
Chem Film, Polished **(CFP)**	AL Finish	n/a
Chem Film, Bead Blasted **(CFB)**	AL Finish	n/a
Silver Teflon Tape **(TAPE)**	AL Coating	n/a
Nedox NH1 **(NH1)**	AL Coating	General Magnaplate
Sanford Hardlube **(SANF)**	AL Coating	General Magnaplate
Dicronite **(DICR)**	AL Coating	Dicronite
Tufram HTR **(HTR)**	AL Coating	General Magnaplate
Invar, none **(INV)**	Invar Finish	n/a
Invar, Bead Blasted **(INB)**	Invar Finish	n/a
Nedox 615 **(N615)**	Invar Coating	General Magnaplate
Nedox SF-2 **(SF2)**	Invar Coating	General Magnaplate

A few O-Rings We Tested

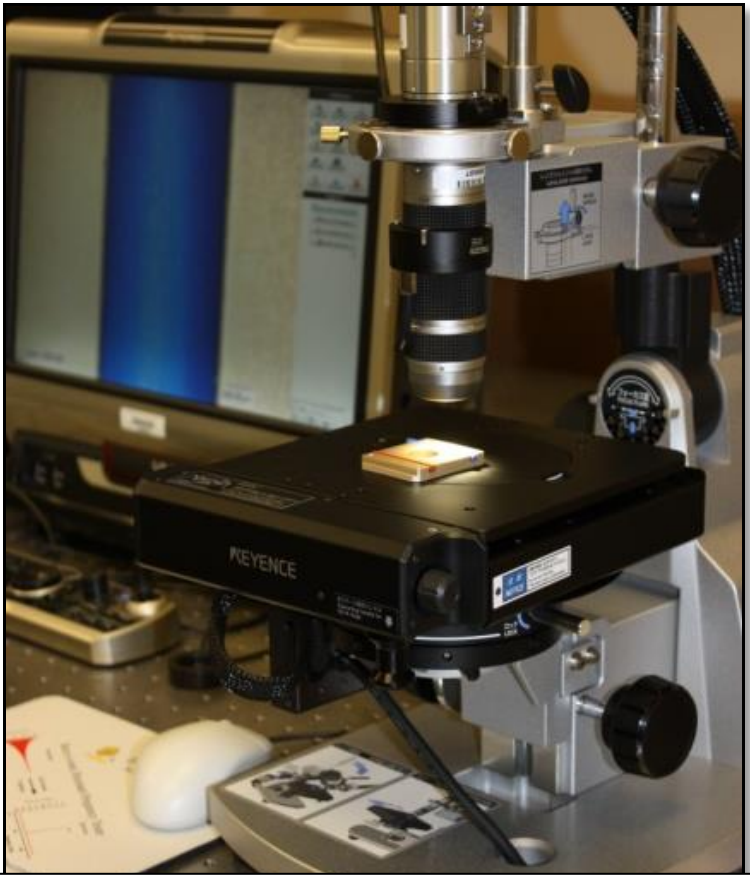


Interfaces Tested

Methodology: O-Ring and Interface Testing

Downselection process of O-rings through rigorous testing

- **Thermal Survival Testing**
  - Compress and Test samples at -75°C
- **Low Outgassing Testing**
  - Per ASTM standards (Outsourced)
  - To protect the Optical Sensor
- **Adhesion Testing**
  - Using a Dynamic Mechanical Analyzer (DMA)
  - Constants:
    - Base-plate, compression, rate of applied force
  - Variables:
    - Interface plate, O-ring, coatings, treatments
  - Thermal Testing (-50°C, +50°C)
    - For promising pairs
- **Stiffness Testing**
  - To discover force necessary to compress O-ring
- **Surface Roughness Testing**
  - Correlation between interface and adhesion



Keyence microscope to analyze thermal survival samples

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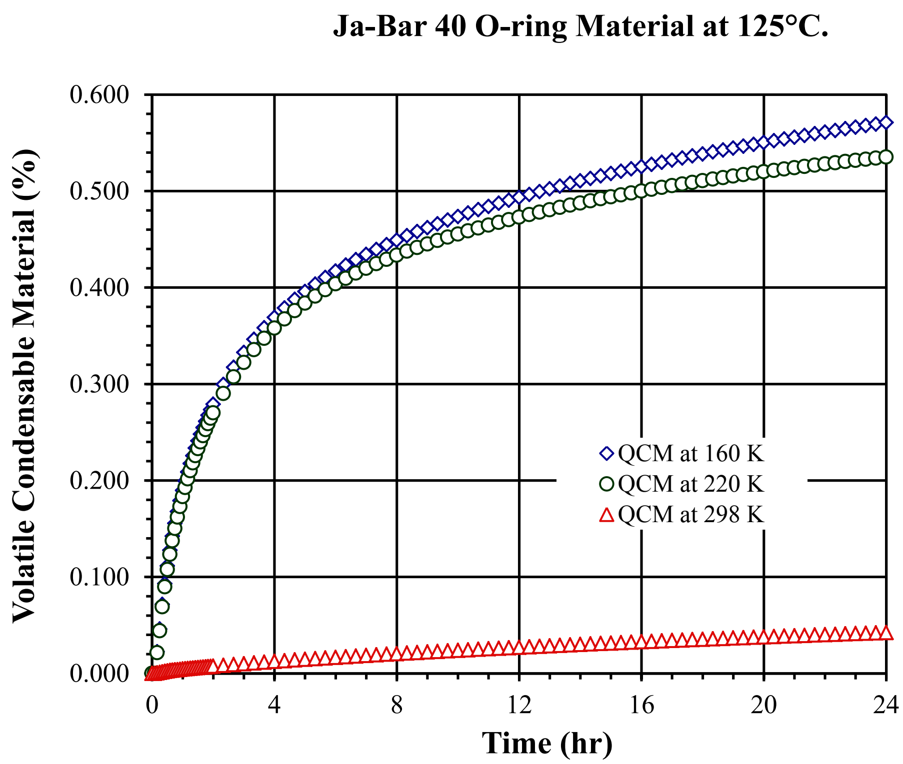

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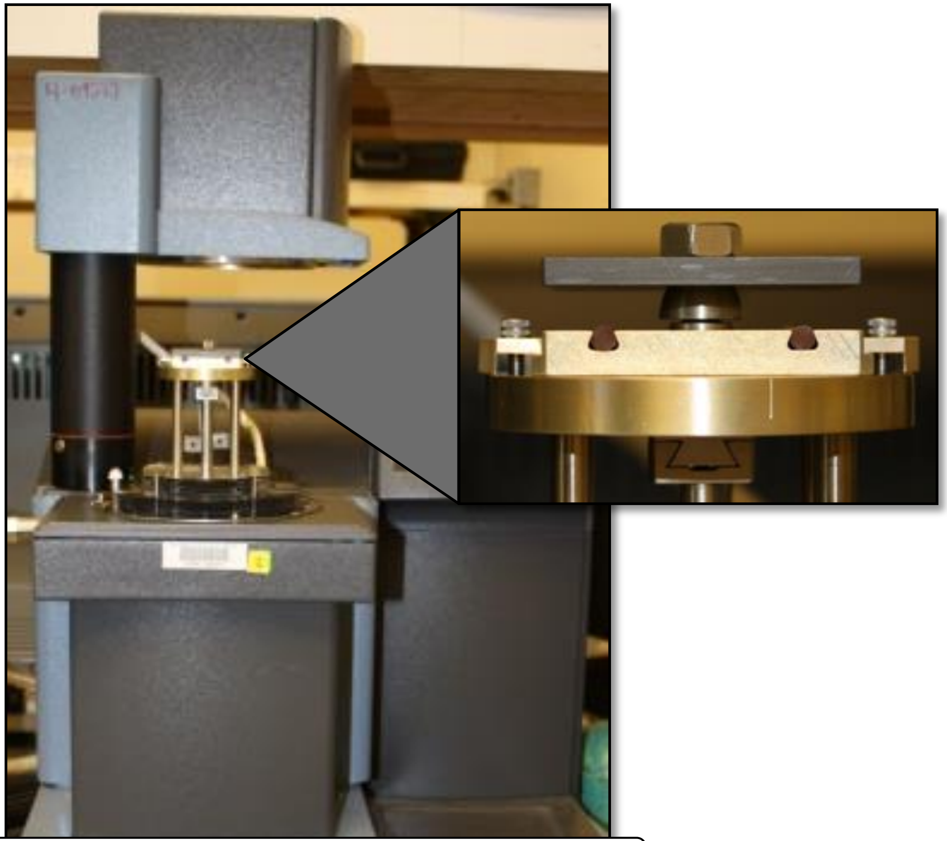

Testing of O-Ring using the DMA

Methodology: O-Ring and Interface Testing

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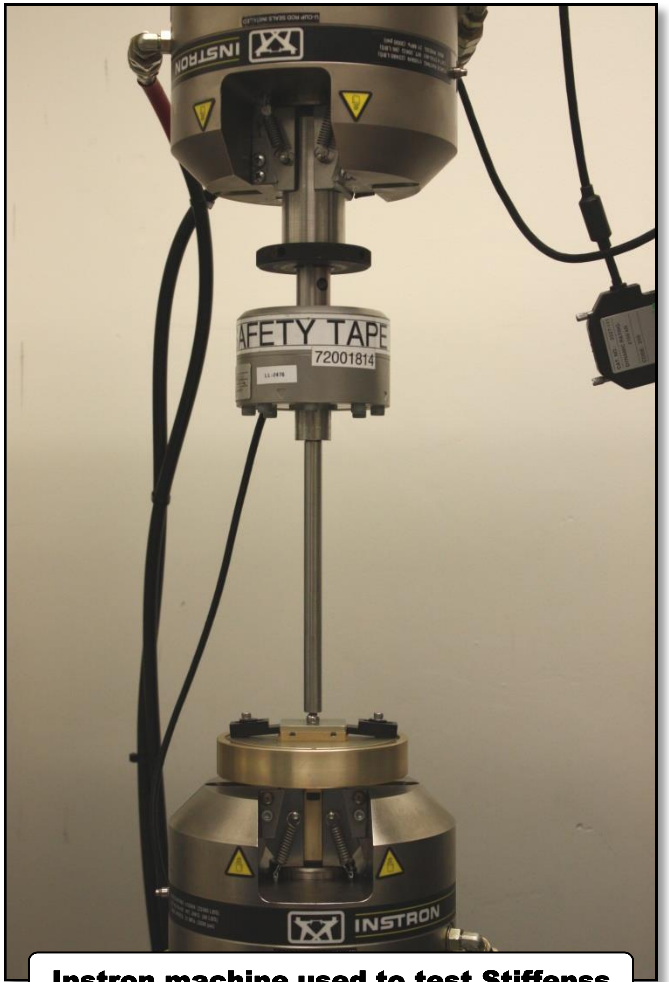

Instron machine used to test Stiffenss

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Zygo microscope used to measure surface roughness

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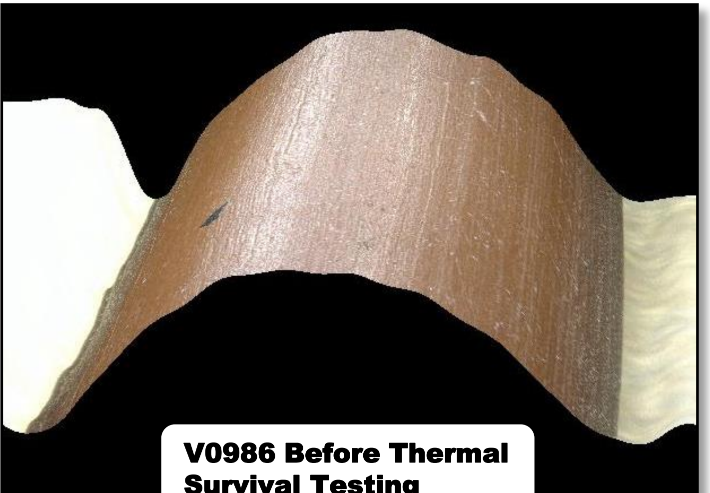
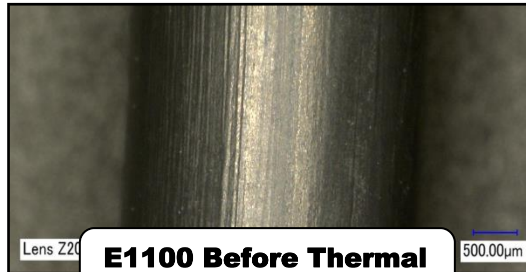
Thermal Adhesion Testing (Design Related)

Thermal Survival Testing

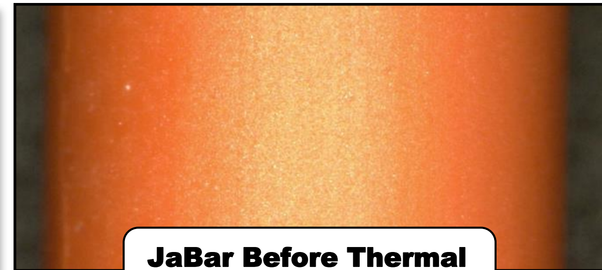


V0986 Before Thermal Survival Testing

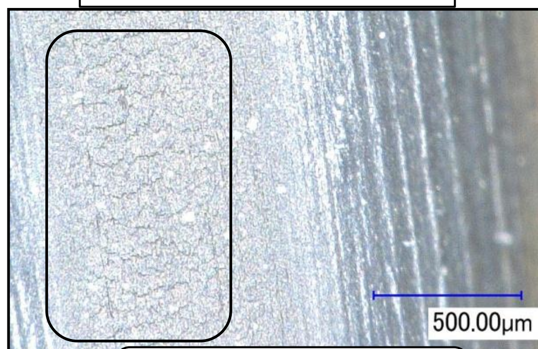
V0986 After Thermal Survival Testing



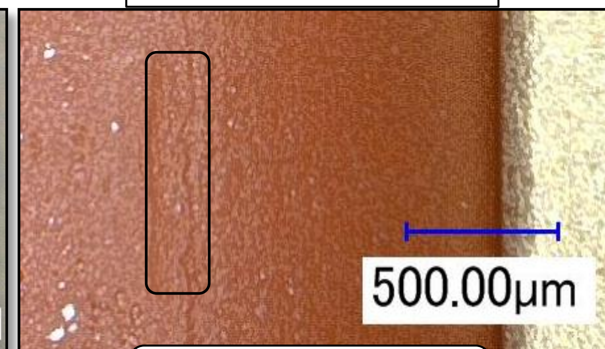
E1100 Before Thermal Survival Testing



JaBar Before Thermal Survival Testing



E1100 After Thermal Survival Testing



JaBar After Thermal Survival Testing

- Soaked at -75°C for 240 hours while under compression
- Keyence Microscope used for evaluation of cracks, pits, voids…etc.
  - Noticeable deformation in some O-rings
  - Noticeable cracks and pits were seen in E1100 and JaBar

If the O-ring does not pass the thermal survival test, it will not be considered for space flight payloads

Down Selection After Thermal Survival

O-Ring	Thermal Survival	Low Outgassing	Stiffness (lbf/in^2)	Adhesion (lbf/in)	Interface	Manufacturer
V0986	Pass					Parker
S0899 B2	Pass					Parker
S0899 B1	Pass					Parker
C0267	Pass					Parker
E1100	**Fail**					Parker
LM151	Pass					Parker
S0469	Pass					Parker
S0820	Pass					Parker
CV2289	Pass					MIT LL
RTV566	Pass					MIT LL
SCV2585	Pass					MIT LL
JaBar	**Fail**					Ja-Bar
S7440	Pass					Parker
S7440 FEP	Pass					MIT LL
Creavey 030	Pass					Creavey
Creavey 050	Pass					Creavey

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Low Outgassing Analysis

- **Total Mass Loss (TML)**
  - < 1% Pass
  - > 1% Fail
- **Collected Volatile Condensable Materials (CVCM)**
  - < 0.1% Pass
  - > 0.1% Fail

O-Ring	Total Mass Loss	Collected Volatile Condensable Material
V0986	0.22%	0.02%
S0899	0.10%	0.02%
C0267	8.33%	3.35%
E1100	8.82%	4.34%
LM151	1.70%	0.40%
S0469	1.66%	0.44%
S0820	0.06%	0.01%
CV2289*	0.44%	0.04%
RTV566*	0.10%	0.01%
SCV2585*	0.08%	0.01%
JaBar	0.62%	0.04%
S7440	0.31%	0.11%
S7440 FEP*		
Creavey 030		
Creavey 050		

*** Custom**

- C0267 and E1100 Fail
- LM151, S0469, S7440 initially fail but may pass after vacuum baking
- No results for S7440 FEP and Creavey

If the O-ring does not pass the outgassing test, it will not be considered for space flight payloads

Down Selection After Outgassing Testing

O-Ring	Thermal Survival	Low Outgassing	Stiffness (lbf/in^2)	Adhesion (lbf/in)	Interface	Manufacturer
V0986	Pass	Pass				Parker
S0899 B2	Pass	Pass				Parker
S0899 B1	Pass	Pass				Parker
C0267	Pass	**Fail**				Parker
E1100	**Fail**	**Fail**				Parker
LM151	Pass	**Fail**				Parker
S0469	Pass	**Fail**				Parker
S0820	Pass	Pass				Parker
CV2289	Pass	Pass				MIT LL
RTV566	Pass	Pass				MIT LL
SCV2585	Pass	Pass				MIT LL
JaBar	**Fail**	Pass				Ja-Bar
S7440	Pass	**Fail**				Parker
S7440 FEP	Pass	n/a				MIT LL
Creavey 030	Pass	n/a				Creavey
Creavey 050	Pass	n/a				Creavey

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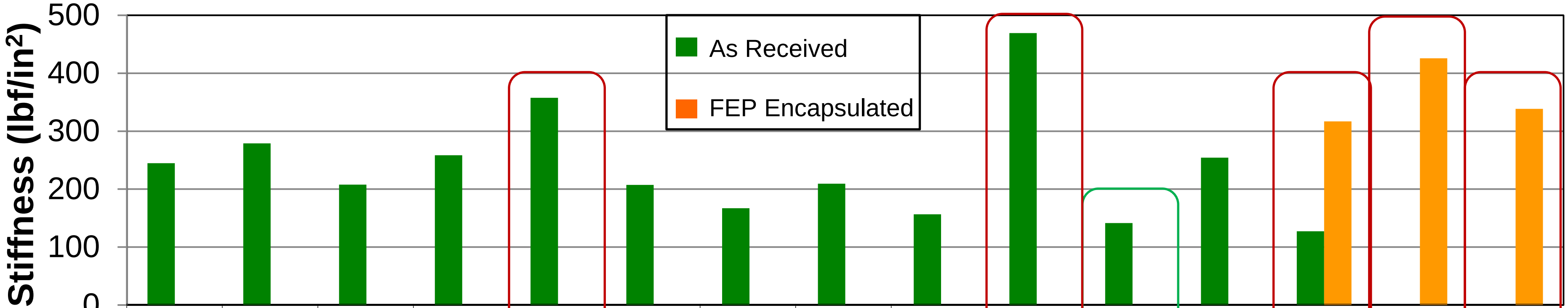
Instron Analysis for Stifness



	V0986	S0899 B2	S0899 B1	C0267	E1100	LM151	S0469	S0820	CV2289	RTV566	SCV 2585	JaBar40	S7440 050	Creavey 030	Creavey 050
As Received	245	279	208	258	358	207	167	209	157	469	142	254	127	---	---
FEP	---	---	---	---	---	---	---	---	---	---	---	---	317	426	338

- Samples placed into system and the top plate was pressed down by Instron
- Force used to compress the sample and inches of deflection were recorded simultaneously
- Plots were developed for the Force (lbf) vs. the Deflection (inches)
- Linear fits were given to the plots and the slope of these plots divided by 3 inches (length of O-rings in the sample) is the Stiffness in lbf/in^2

Selecting a "soft" O-ring may be necessary in many payload applications, including ours

Down Selection After Stiffness Testing

O-Ring	Thermal Survival	Low Outgassing	Stiffness (lbf/in^2)	Adhesion (lbf/in)	Interface	Manufacturer
V0986	Pass	Pass	245			Parker
S0899 B2	Pass	Pass	279			Parker
S0899 B1	Pass	Pass	208			Parker
C0267	Pass	**Fail**	258			Parker
E1100	**Fail**	**Fail**	**358**			Parker
LM151	Pass	**Fail**	207			Parker
S0469	Pass	**Fail**	167			Parker
S0820	Pass	Pass	209			Parker
CV2289	Pass	Pass	157			MIT LL
RTV566	Pass	Pass	**469**			MIT LL
SCV2585	Pass	Pass	142			MIT LL
JaBar	**Fail**	Pass	254			Ja-Bar
S7440	Pass	**Fail**	127			Parker
S7440 FEP	Pass	n/a	**317**			MIT LL
Creavey 030	Pass	n/a	**426**			Creavey
Creavey 050	Pass	n/a	**338**			Creavey

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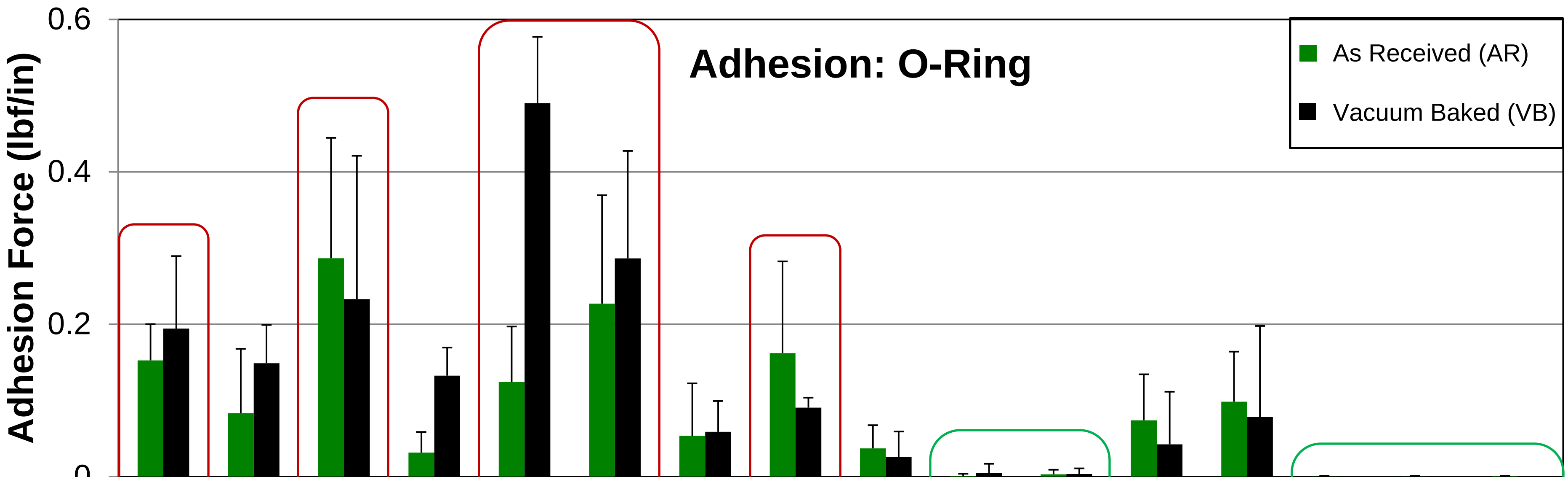
Adhesion Testing



	V0986	S0899 B2	S0899 B1	C0267	E1100	LM151	S0469	S0820	CV 2289	RTV566	SCV 2585	JABAR 40	S7440 050	S7440 050 FEP	FEP + SIL HC 030	FEP + SIL HC 050
Average AR	0.1526	0.0832	0.2867	0.0316	0.1243	0.2272	0.0538	0.1621	0.037	0.0009	0.003	0.0739	0.0984	0.0002	0.0003	0.0006
95% AR	0.2003	0.1678	0.4447	0.0587	0.1970	0.3694	0.1224	0.2825	0.0676	0.0038	0.0090	0.1344	0.1641	0.0011	0.0011	0.0010
Average VB	0.1944	0.1489	0.233	0.1325	0.4901	0.2865	0.0589	0.0905	0.0258	0.0051	0.0035	0.0424	0.0781			
95% VB	0.2895	0.1991	0.4211	0.1694	0.5771	0.4274	0.0992	0.1036	0.0593	0.0168	0.0108	0.1114	0.1978			

- 5-25 samples tested for each O-ring (depending on availability, previous tests, time…etc.)
- Bar represents 95% confidence level
- FEP Encapsulated O-rings resulted in practically 0 adhesion

Some O-rings show adhesion values very close to 0 on our "typical" interface

Down Selection After Adhesion Testing

O-Ring	Thermal Survival	Low Outgassing	Stiffness (lbf/in^2)	Adhesion (lbf/in)	Interface	Manufacturer
V0986	Pass	Pass	245	**0.2895**		Parker
S0899 B2	Pass	Pass	279	0.1991		Parker
S0899 B1	Pass	Pass	208	**0.4211**		Parker
C0267	Pass	**Fail**	258	0.1694		Parker
E1100	**Fail**	**Fail**	**358**	**0.5771**		Parker
LM151	Pass	**Fail**	207	**0.4274**		Parker
S0469	Pass	**Fail**	167	0.0992		Parker
S0820	Pass	Pass	209	0.1036		Parker
CV2289	Pass	Pass	157	0.0593		MIT LL
RTV566	Pass	Pass	**469**	0.0168		MIT LL
SCV2585	Pass	Pass	142	0.0108		MIT LL
JaBar	**Fail**	Pass	254	0.1114		Ja-Bar
S7440	Pass	**Fail**	127	0.1978		Parker
S7440 FEP	Pass	n/a	**317**	0.0011		MIT LL
Creavey 030	Pass	n/a	**426**	0.0011		Creavey
Creavey 050	Pass	n/a	**338**	0.0010		Creavey

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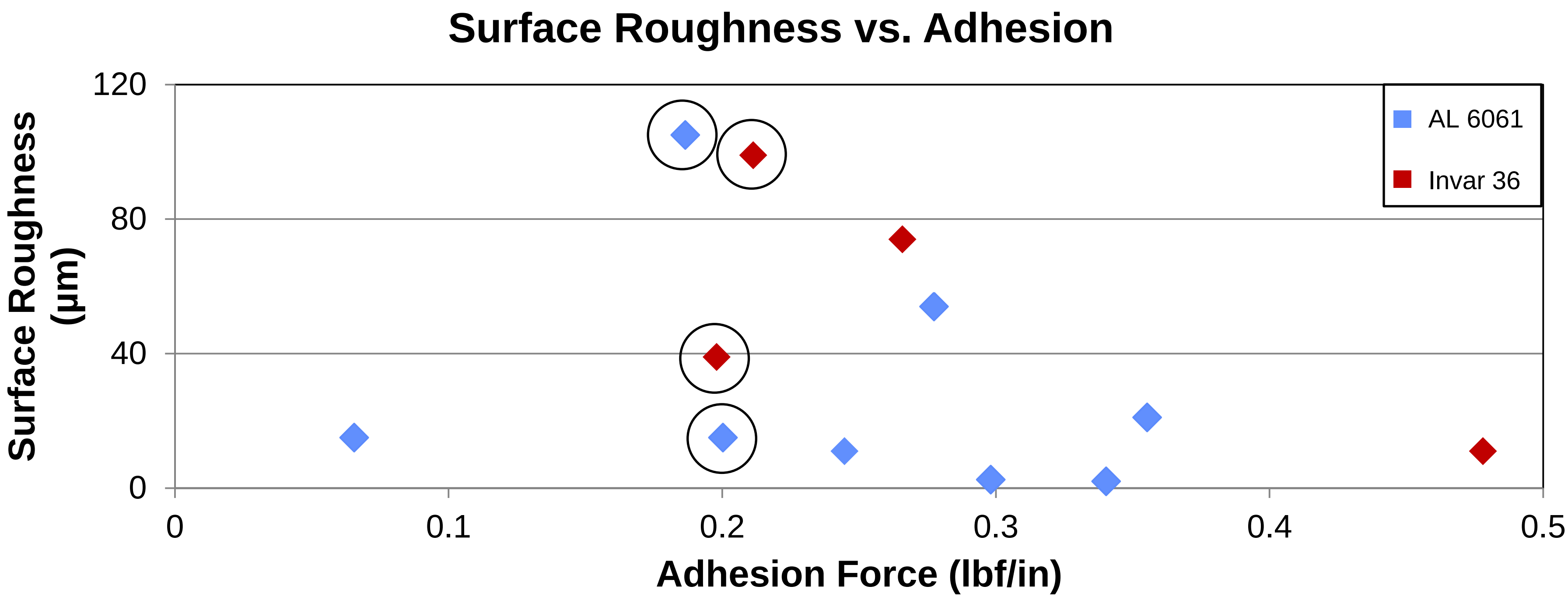
Interface's Effect on Adhesion



- Zero adhesion not strictly possible from these interfaces
- CFM, CFB, N615, and SF2 all performed around 0.2 lbf/in
- Coatings are logistically complicated so a simple finish may be best

There is no correlation between any surface roughness parameters and adhesion

Down Selection to Thermal Testing Pairs

O-Ring	Thermal Survival	Low Outgassing	Stiffness (lbf/in^2)	Adhesion (lbf/in)	Interface	Manufacturer
V0986	Pass	Pass	245	**0.2895**	CFM	Parker
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C0267	Pass	**Fail**	258	0.1694	CFM	Parker
E1100	**Fail**	**Fail**	**358**	**0.5771**	CFM	Parker
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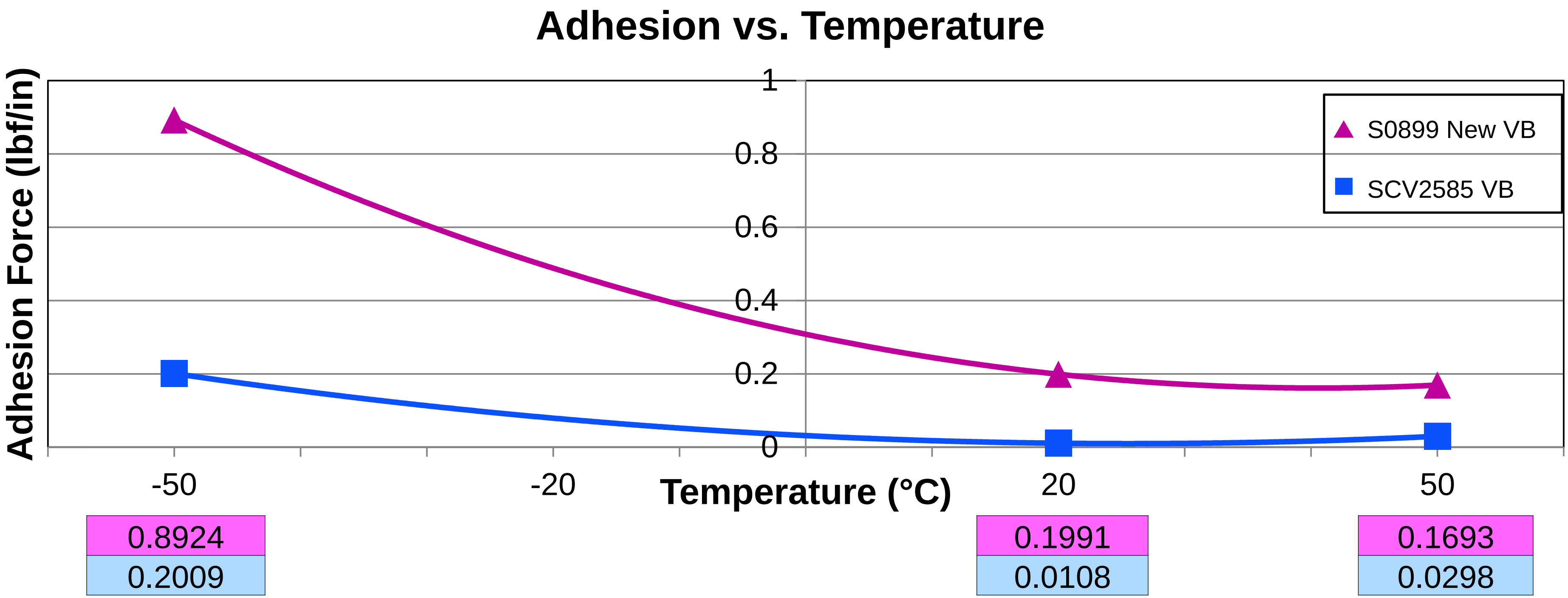
Adhesion at Temperature



- Only 5 samples were tested at -50°C and +50°C
- Adhesion force increased as temperature decreased
- We project that it will increase as temperature increases as well

Temperature has a large effect on the adhesion force of O-rings

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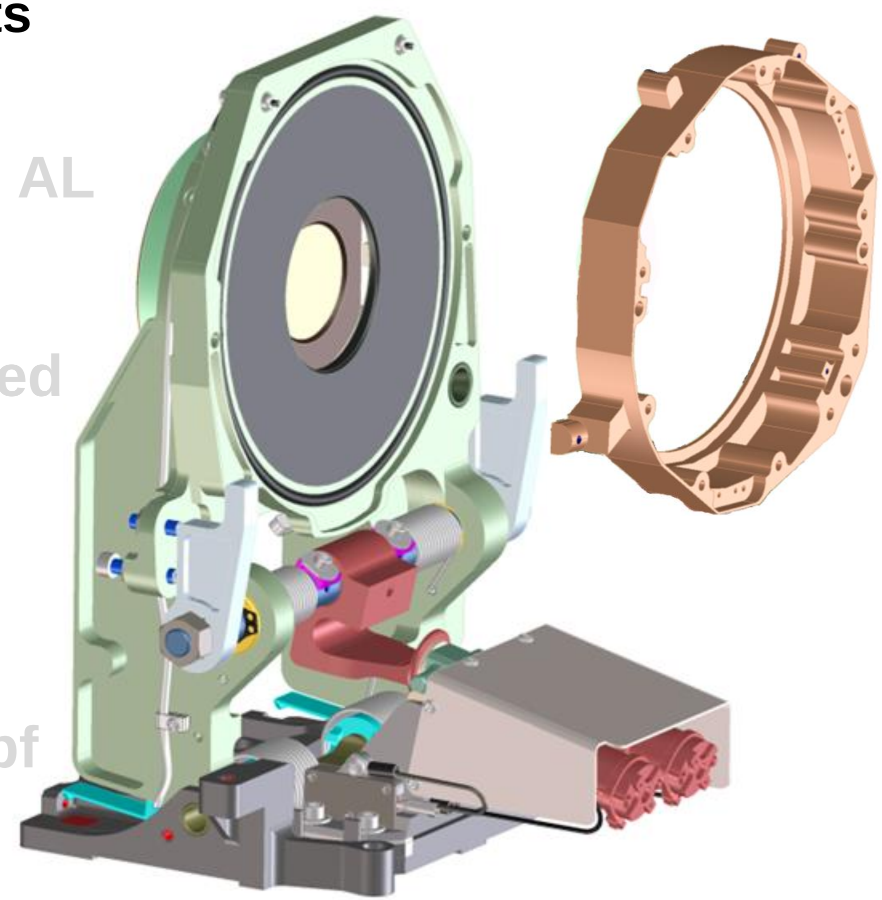

- Interface – **Chem Film Machined AL**
- O-Ring – **SCV2585 Vacuum Baked**
  - Adhesion Force = **3 lbf**
  - Compression Force = **27 lbf**
- Upper Vlier Spring Plungers = **4.5 lbf**
- Lower Torsion Springs = **5 lbf-inch**

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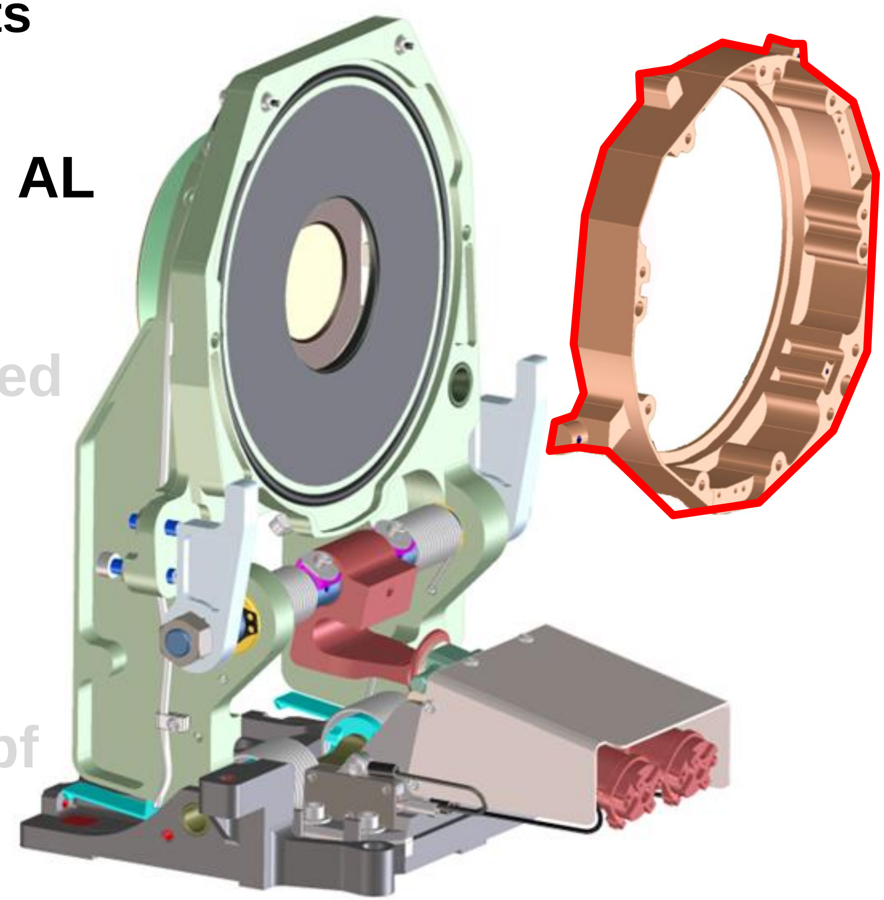
- O-Ring – **SCV2585 Vacuum Baked**
  - Adhesion Force = **3 lbf**
  - Compression Force = **27 lbf**
- Upper Vlier Spring Plungers = **4.5 lbf**
- Lower Torsion Springs = **5 lbf-inch**



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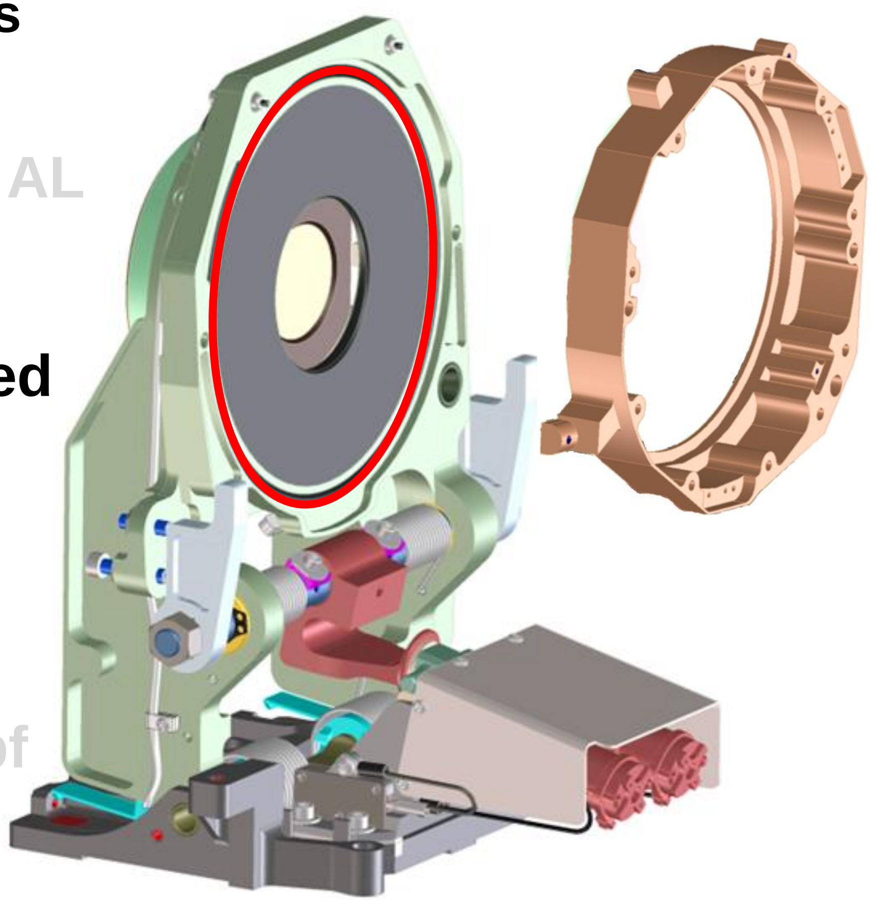

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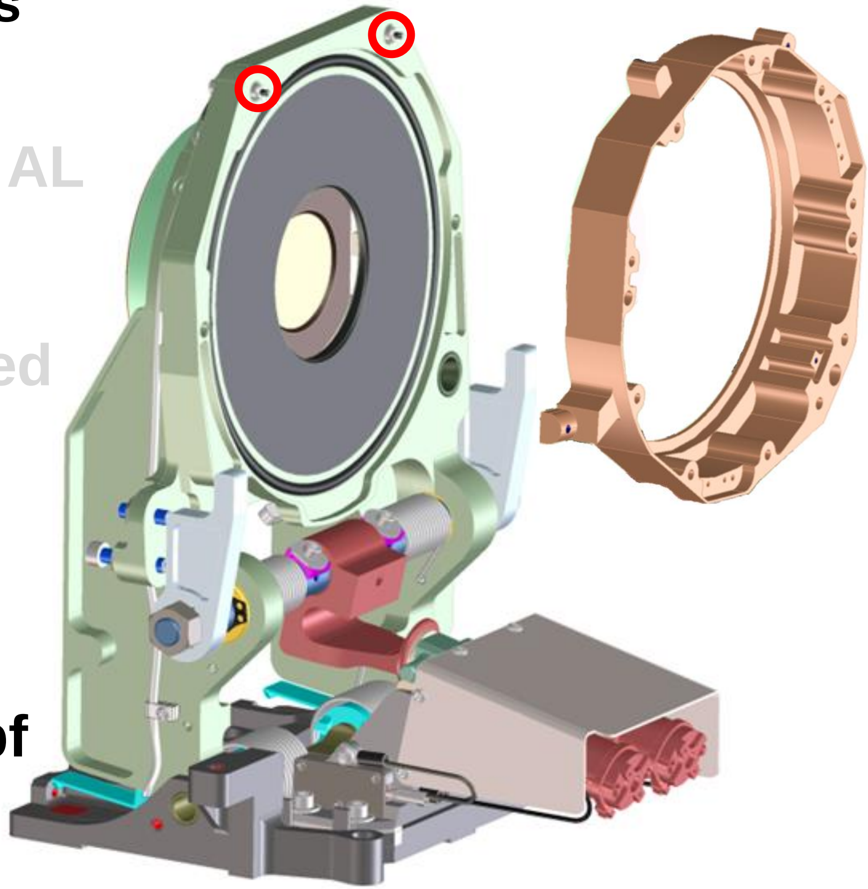

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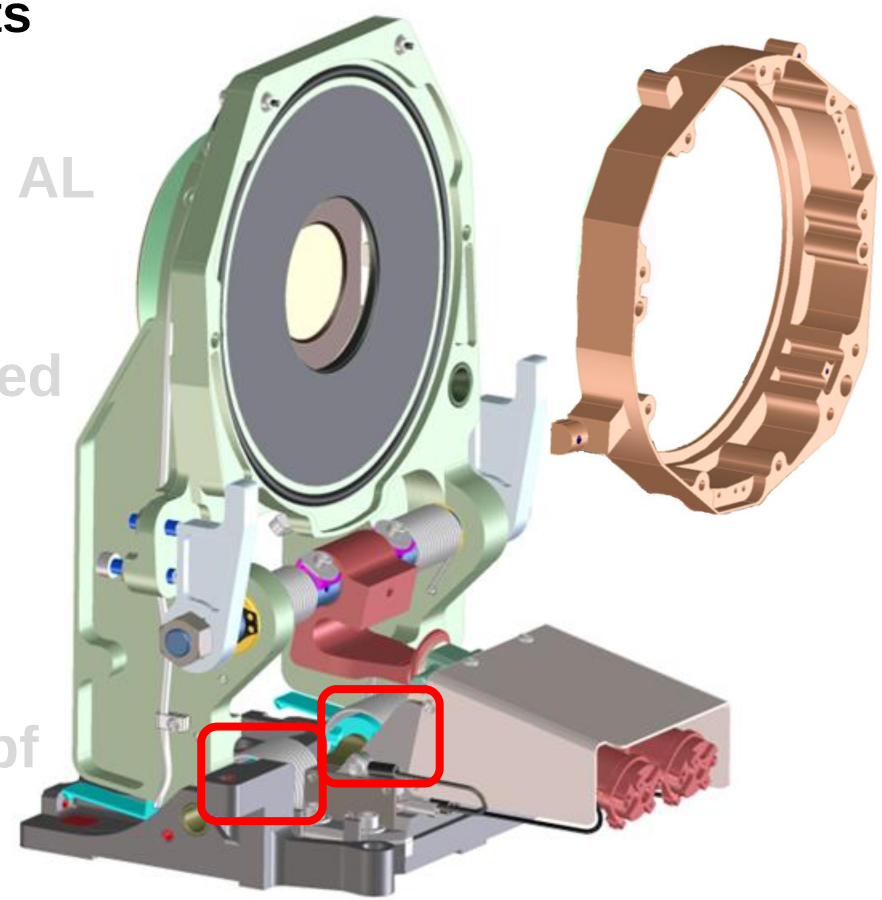
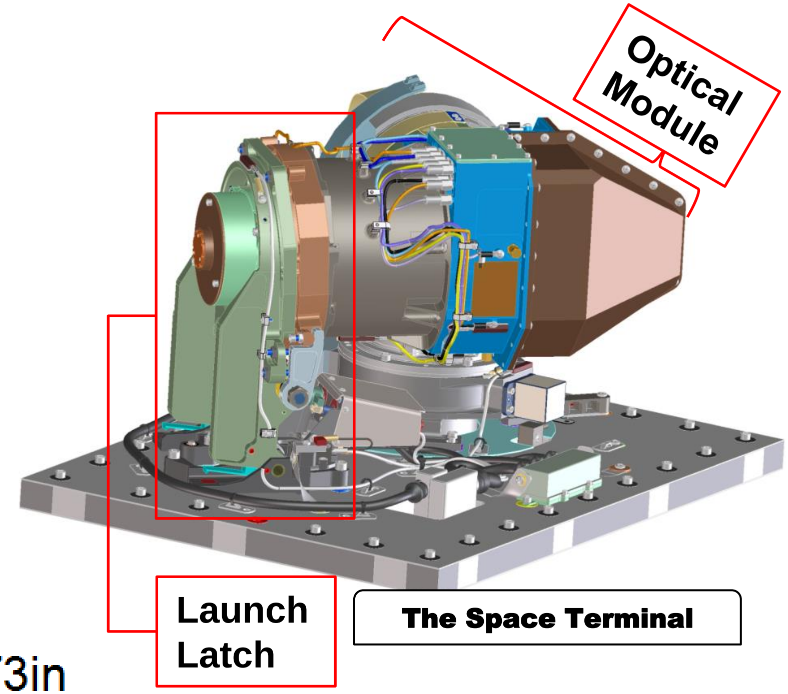


- Lower Torsion Springs = **5 lbf-inch**

Ensuring Latch Opens

- O-Ring adhesion force must be lower than the opening force
- After part selection all parameters are known



- $F_{Adhesion} * 1.25 < \frac{2M_{LT} + (2F_{Vlier} - P_z)r_3}{r_1}$
- $3lbf * 1.25 < \frac{2(5lbf*in) + (2(4.5lbf) - 5.6lbf)7.73in}{5.4in}$
- **3.75 lbf < 4.87 lbf**

Ensuring HOPAs and Pawl Arm Survive

- **HOPA Survival**
  - $F_{Load\text{-}MAX}$ = (260 lbf/1.25)*2 = 416lbf
  - $F_{Load\text{-}MAX} > F_{Vibration} + F_{Preload} + F_{HOPA}$
  - 416 lbf > 53 lbf + 256 lbf + 86 lbf
  - **416 lbf > 395 lbf**

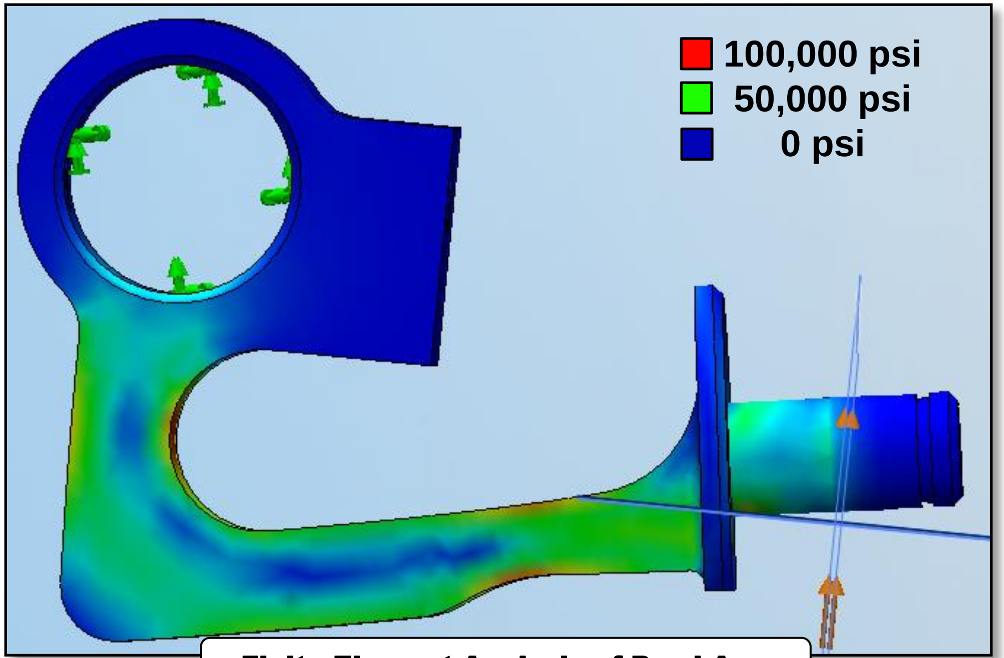
- **Pawl Arm Survival**
  - **Finite Element Analysis**
    - Max allowable stress = 150 ksi/1.25 = **120,000 psi**
    - Our system = **97,100 psi**

High Output Paraffin Actuator (HOPA)

Ensuring HOPAs and Pawl Arm Survive

- **HOPA Survival**
  - $F_{HOPA\text{-}MAX} = 520lbf/1.25 = 416lbf$
  - $F_{HOPA\text{-}MAX} > F_{Vibration} + F_{Preload} + F_{Close}$
  - 416 lbf > 53 lbf + 256 lbf + 86 lbf
  - **416 lbf > 395 lbf**

- **Pawl Arm Survival**
  - **Finite Element Analysis**
    - Max allowable stress = 150 ksi/1.25 = **120,000 psi**
    - Our system = **97,100 psi**



Finite Element Analysis of Pawl Arm

Outline

Introduction

Test Results

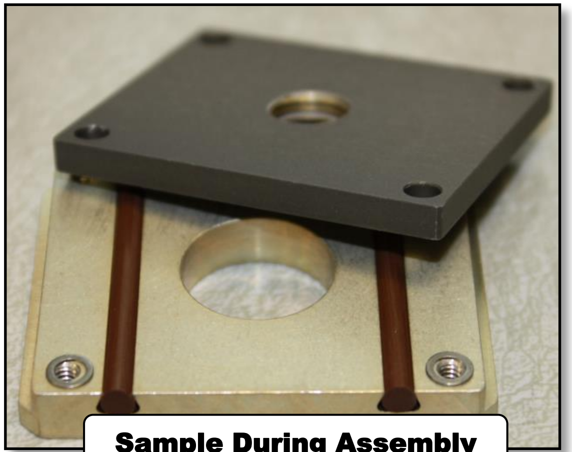
Part Selection

Recommendations

Recommendations for Future Work

- **Look into different treatments**
  - Interface - Thin layer of carbon
  - O-Ring - SiOx
- **Look into teflon coatings that are much softer**
  - Teflon gave us zero adhesion
  - Teflon coated samples tested so far too stiff
- **Test different O-rings on the interfaces**
  - V0986 resulted in uneven lifts
  - No clear trend with adhesion and coatings
- **Perform more thermal tests**
  - Be more confident in our adhesion results
  - Potentially find equation for adhesion in terms of temperature

Bin of Test Samples



Sample During Assembly

Acknowledgments

We would like to acknowledge and thank the following persons for all their help in making this project a success:

From Worcester Polytechnic Institute:

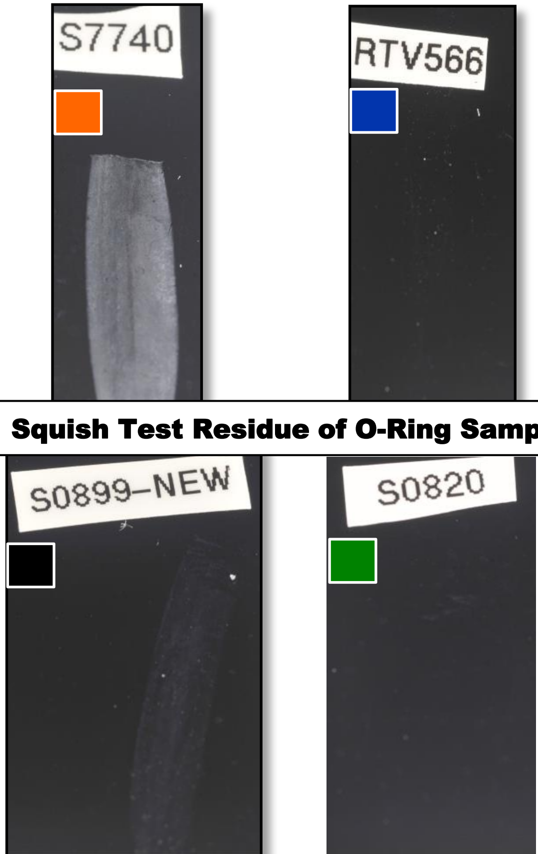
- **Professor Gatsonis** – Project Advisor
- **Professor Clancy** – Site Coordinator

From MIT Lincoln Laboratory:

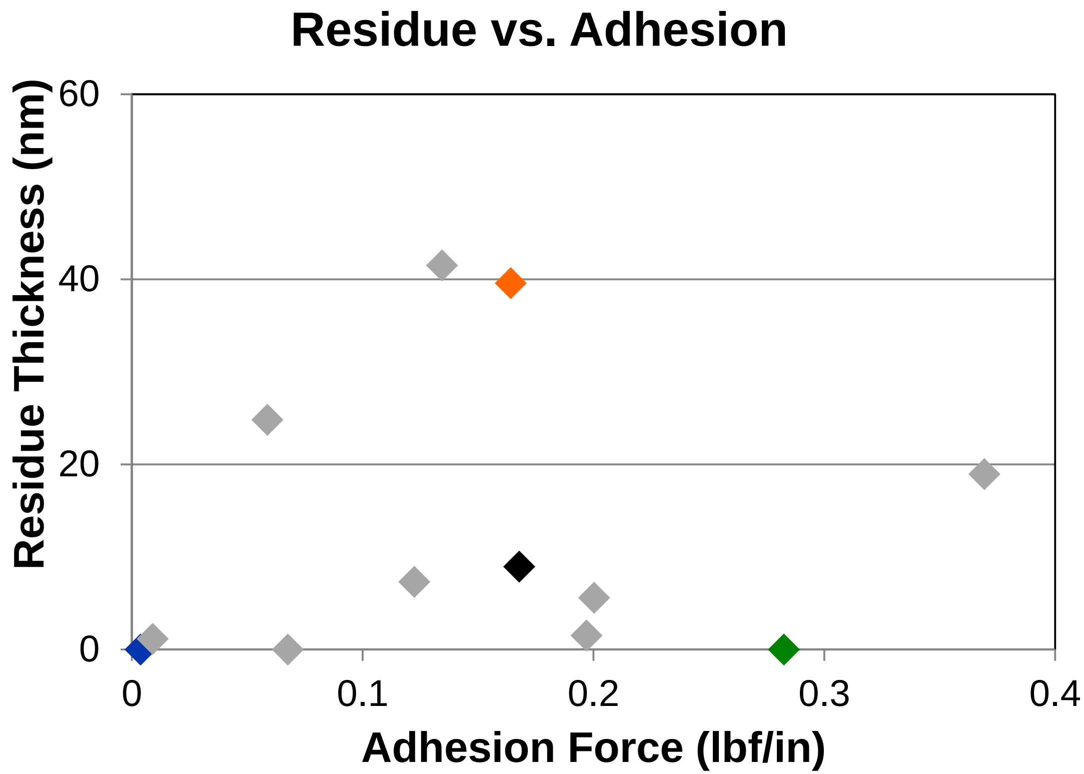
- **Carl Hart** – Supervisor, Group 71
- **Jesse Mills** – Supervisor, Group 75
- **Todd Mower** – Technical Staff, Group 75
- **Sharon Hardiman** – Secretary, Group 75
- **Carol Mullinax** – Secretary, Group 75
- **Peter Anderson** – Technician, Group 72
- **Russ Goodman** – Technician, Group 81
- **Scott Hillis** – Clean Room Technician, Group 72
- **Glenn Matot** – Clean Room Technician, Group 72
- **Tasha Naylor** – Clean Room Technician, Group 72

Questions?

Residue's Effect on Adhesion



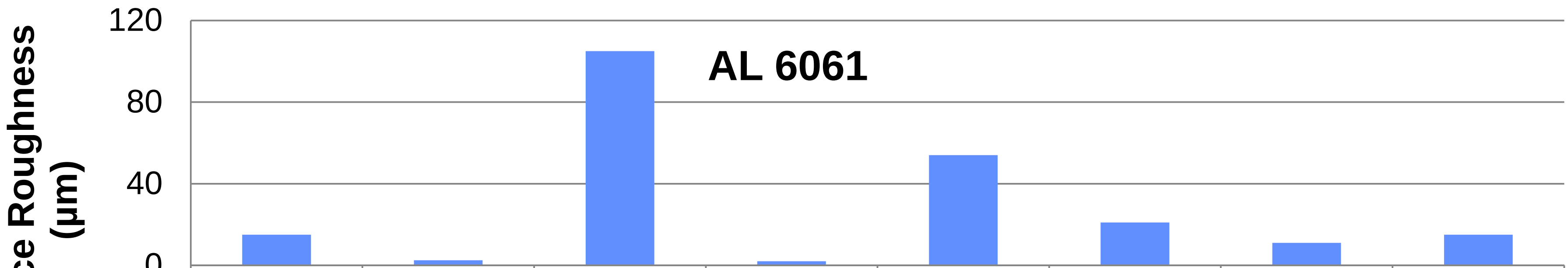
Squish Test Residue of O-Ring Samples



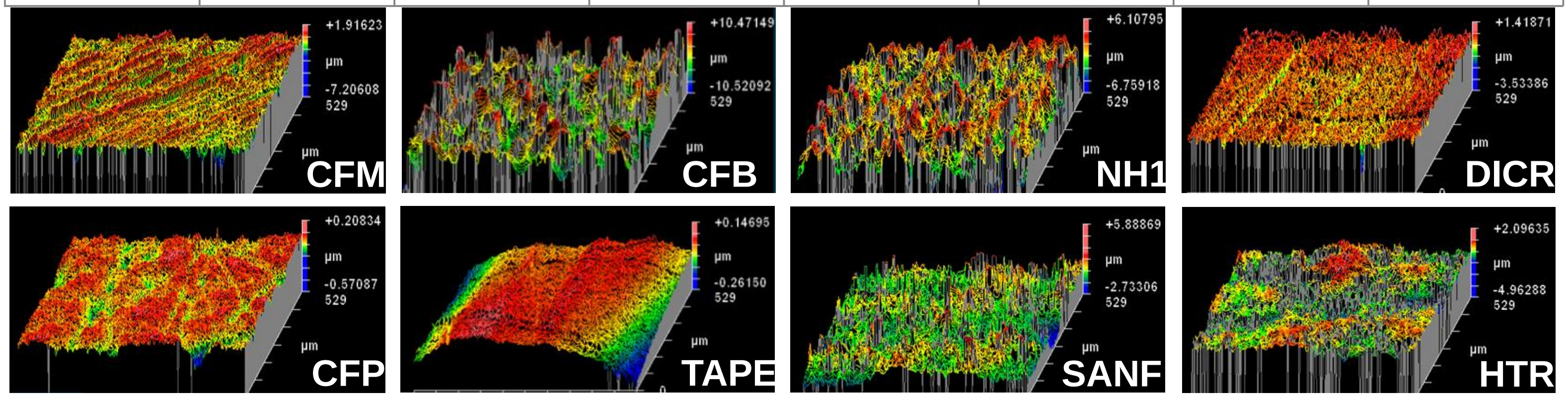
- S7740 and S0899-New (B2) have a similar adhesion force, but a large range in residue thickness
- RTV566 and S0820 have residue values of zero, but a large range in adhesion force

There does not appear to be any correlation between residue thickness and adhesion

Surface Roughness: AL 6061



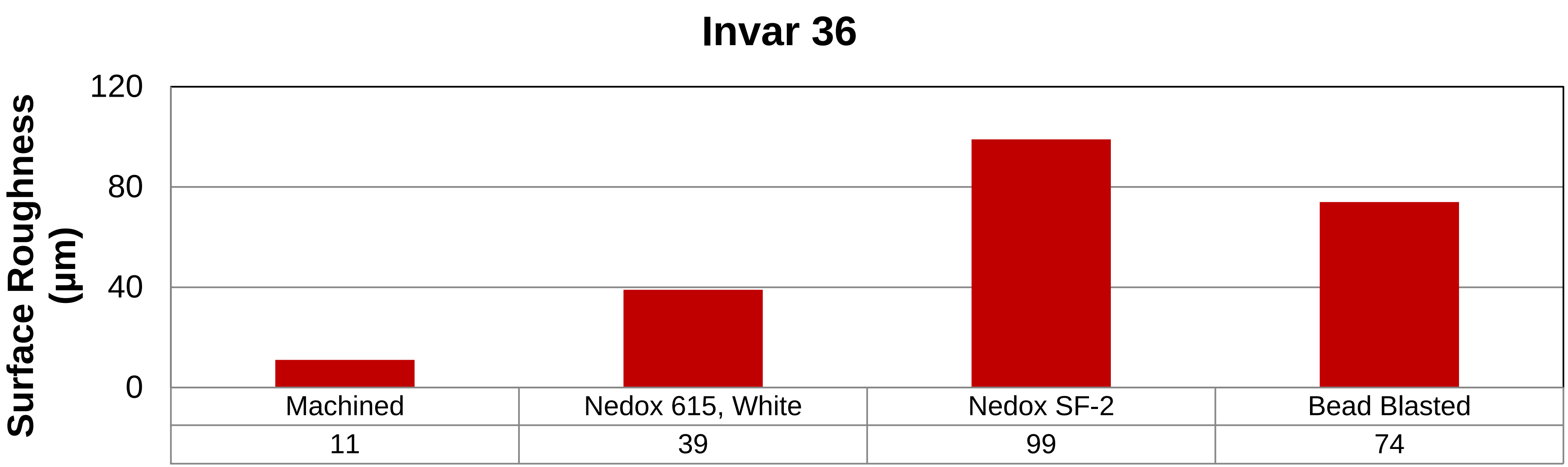
Chem Film (CFM), Typical Surface Roughness	Chem Film, Polished (CFP)	Chem Film, Bead Blasted (CFB)	Silver Teflon Tape (TAPE)	Nedox NH1 (NH1)	Sanford Hardlube (SANF)	Dicronite (DICR)	Tufram HTR (HTR)
15	3	105	2	54	21	11	15

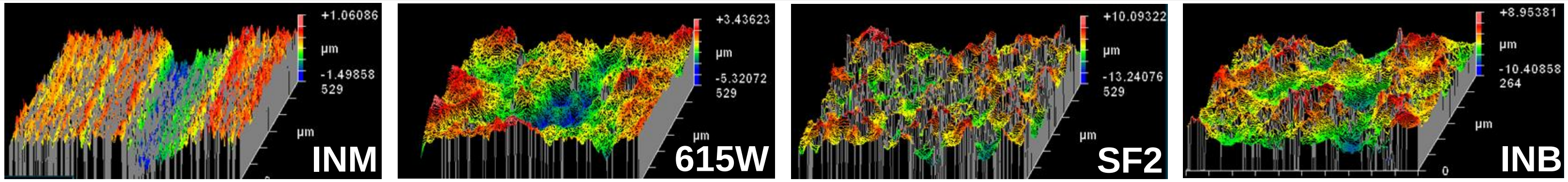


- Used Zygo to test for average surface roughness among other surface parameters
- Range from 2 µm (TAPE) to 105 µm (CFB)

The interface surface roughness of our interfaces may have an effect on the adhesion of the O-ring

Surface Roughness: Invar 36

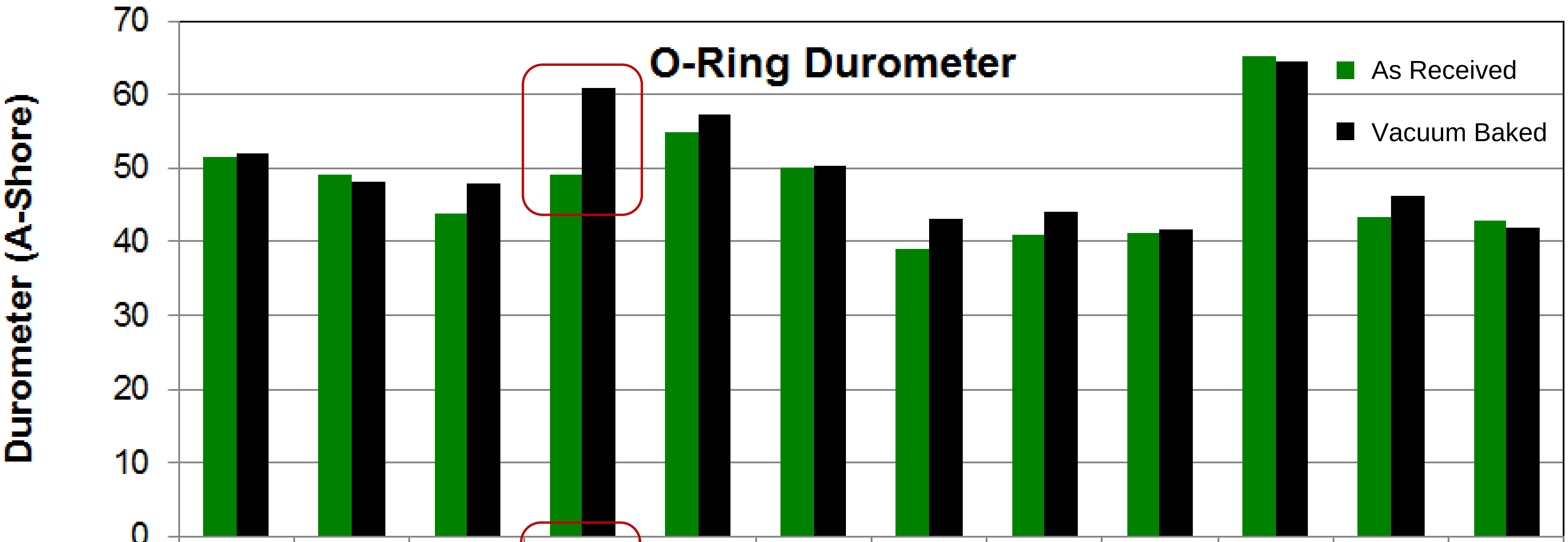




- Range from 11 µm (Machined) to 99 µm (SF2)
- Parameters of RMS, and Max Height show a similar order in increasing values for both Invar 36 and AL 6061

Other surface roughness parameters of our interfaces may have an effect on the O-ring adhesion

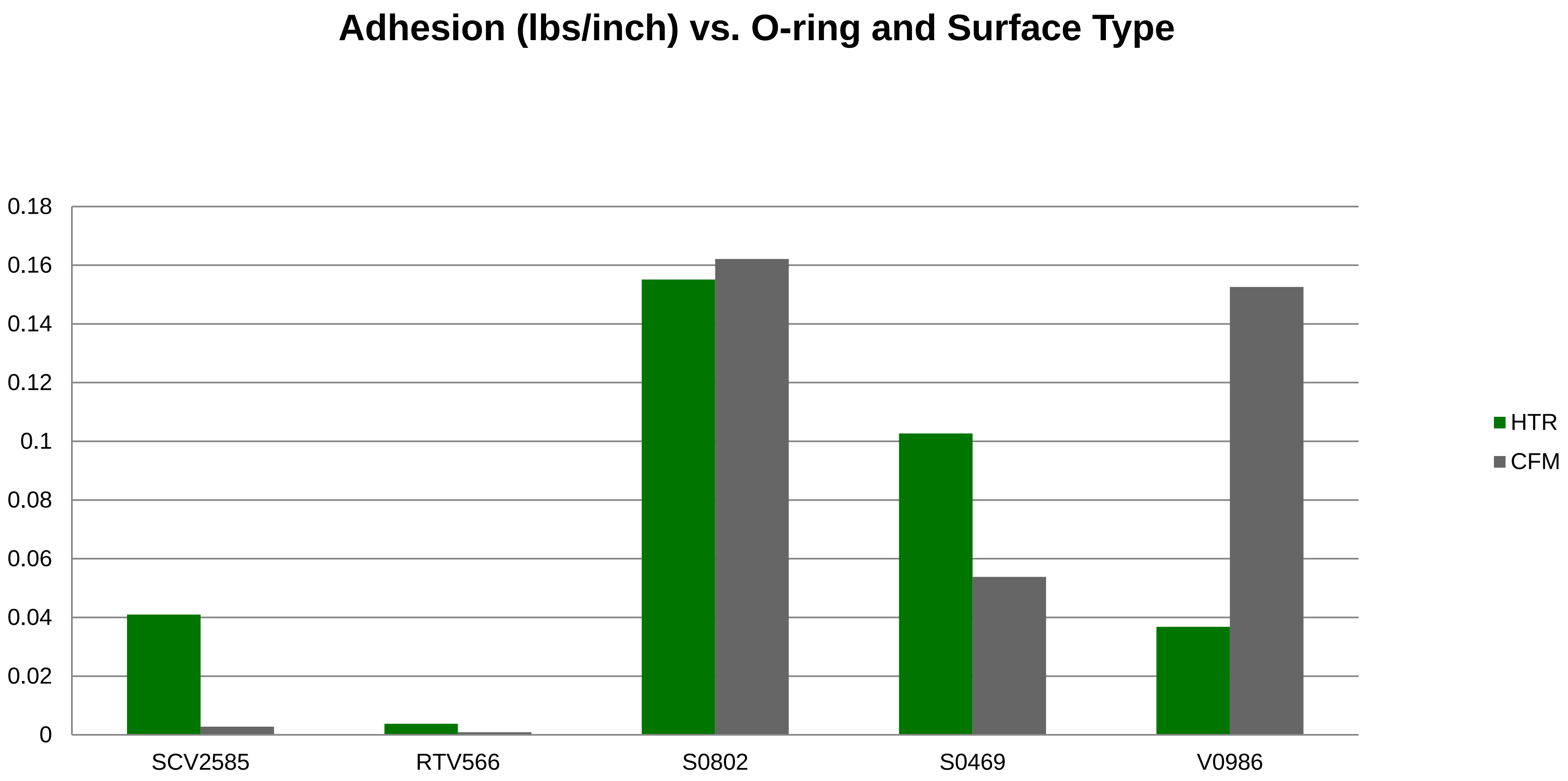
Durometer Testing



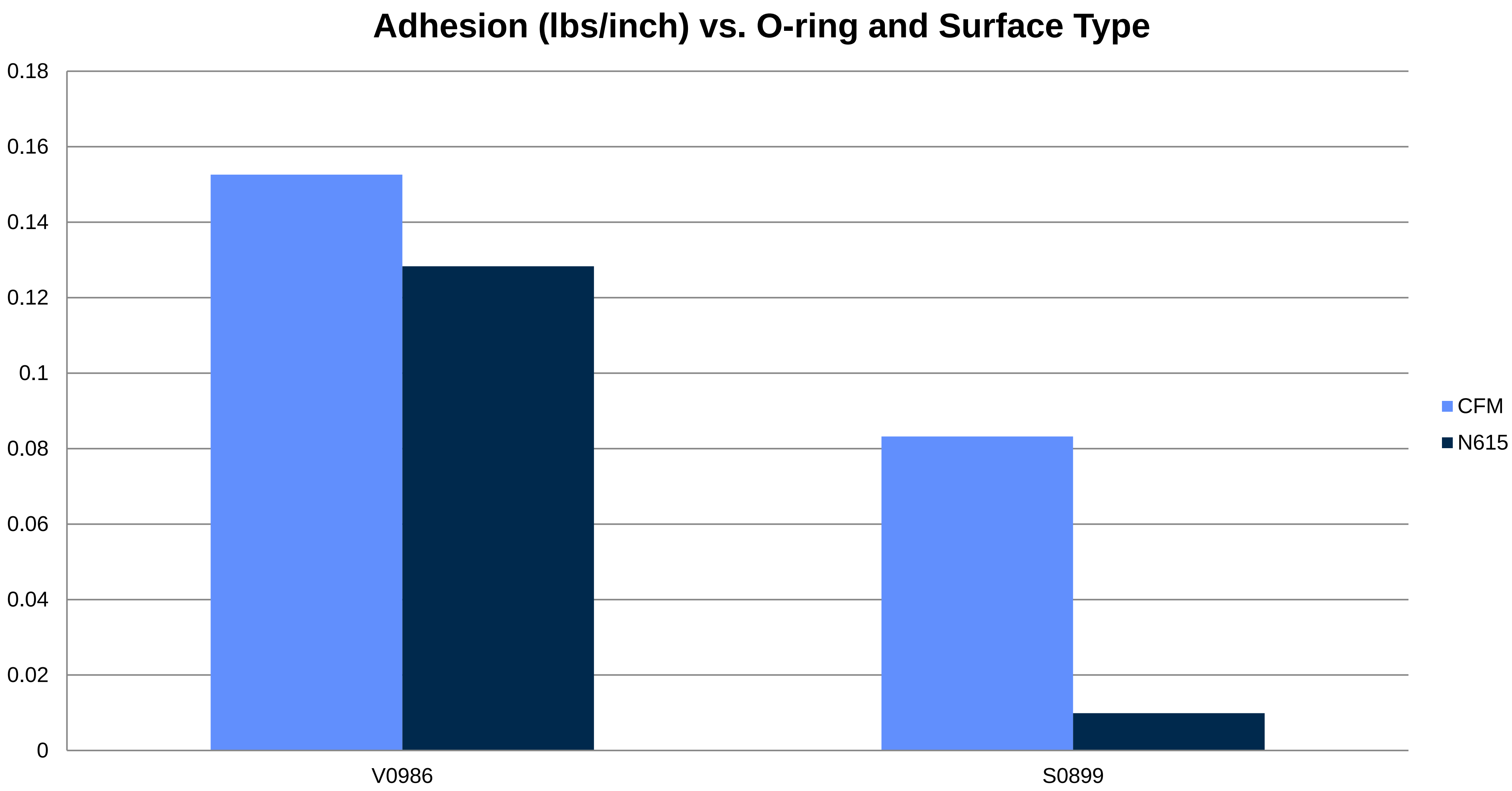
	V0986	S0899 New	S0899 B1	C0267	E1100	LM151	S0469	S0820	CV 22890	RTV 566	SCV 2585	S7440 050
As Received	52	49	44	49	55	50	39	41	41	65	43	43
Vacuum Baked	52	48	48	61	57	50	43	44	42	64	46	42

- Durometer taken before and after vacuum baking
- Most O-ring has slight increase in durometer
- C0267 increased by 12 while no others increased by more than 4
  - Equivalent of changing from the hardness of a rubber stamp to wiper blades

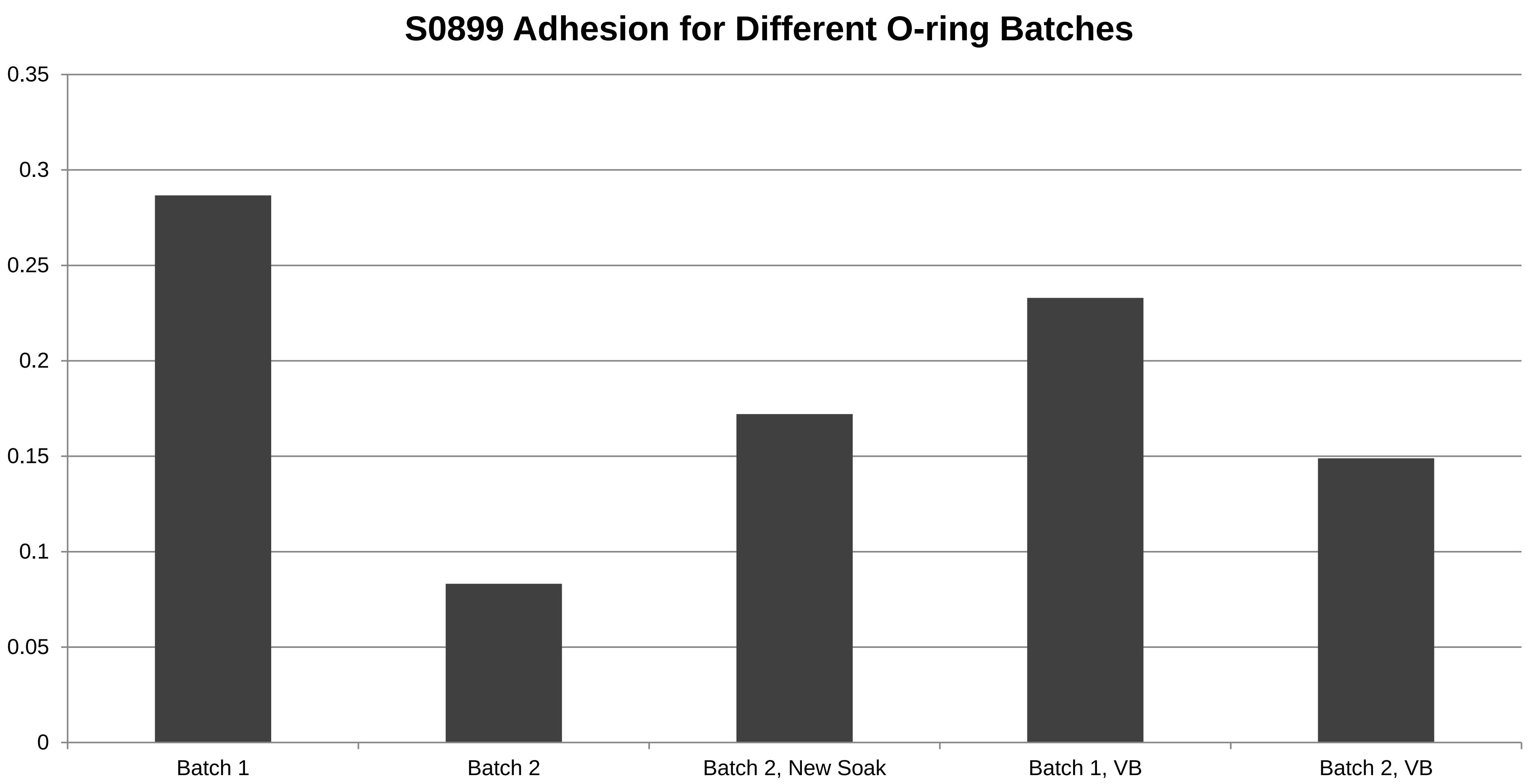
Adhesion on HTR and CFM



Adhesion of CFM and N615



S0899 Adhesion



Stiffness vs Durometer