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Particle Adhesion and Removal in Post-CMP Applications

George G. Adams
Northeastern University - Dept. of Mechanical and Industrial Engineering

Ahmed Busnaina
Northeastern University

Sinan Müftü
Northeastern University - Dept. of Electrical and Computer Engineering

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PARTICLE ADHESION AND REMOVAL IN POST-CMP APPLICATIONS

George Adams, Ahmed A. Busnaina and Sinan Muftu
the Microcontamination Research Laboratory
Mechanical, Industrial, and Manufacturing Eng. Department
Northeastern University, Boston, MA 02115-5000

OUTLINE

- Goals and Objectives
- Approach
- Preliminary Results
  - Particle Removal Mechanism
  - Double layer
  - Covalent bonds between for silica on thermal oxide films and glass particles on glass substrates
  - Adhesion induced deformation
- Key Preliminary Research Results

Surface Preparation Technology Requirements -- Long Term**

YEAR	1999	2000	2002	2005	2008	2011	2014
TECHNOLOGY NODE	180nm		130nm	100nm	70nm	50nm	35nm
FEOL Particle Size(nm)	90	82.5	60	50	35	25	18
FEOL Particles (#/cm^2)	0.064	0.06	0.064	0.051	0.052	0.052	0.052
BEOL Particle Size(nm)	180	165	130	100	70	50	36
BEOL Particles (#/cm^2)	0.064	0.06	0.064	0.051	0.052	0.052	0.052
Surface Roughness (nm)	0.15	0.14	0.12	0.1	0.08	0.08	0.08
Critical surface metals(*10^9)	9	7	4.4	2.5	--	--	--
Organics (*10^{13} atoms/cm^2)	7.3	6.6	5.3	4.1	--	--	--

** ---- The International Technology Roadmap for Semiconductors, 2000

Goals and Objectives

- To determine the adhesion force for different particles on different substrates in different solutions experimentally.
- To understand and determine the onset of large adhesion forces after polishing such as the development of covalent bonds.
- Study the removal and adhesion forces for alumina and silica slurry particles from silicon wafers (with different films, TOX, W, Cu, TaN, BPSG, etc.).
- Develop better cleaning guidelines and techniques to reduce surface defects after polishing.
- In addition, the effect of polishing pressure on the slurry particle adhesion force will be determined.

Approach

- Fundamental Approach
- Experimental and modeling approach to determine, understand and predict:
  - Particle Adhesion Force
  - Adhesion force increase due to:
    - Particle Deformation
    - Covalent Bonds
    - CMP
    - Slurry and Cleaning Solution Chemistry
    - Pad hardness, compressibility and tensile strength
    - Particle shape
    - Surface Roughness

Approach

- ***Fundamental Approach***
- **Key Particle Removal Parameters**
  - Particle shape
  - Polishing pressure
  - Particle size
  - Particle composition
  - Slurry and cleaning solution chemistry
  - Chemical reactions giving rise to covalent bonds
  - particle deformation
  - Double layer effect
  - Cleaning liquid surface tension
  - Surface and particle surface energy (hydrophilic or hydrophobic)

PARTICLE REMOVAL

- Nano-scale particles will be a challenge to current cleaning techniques.

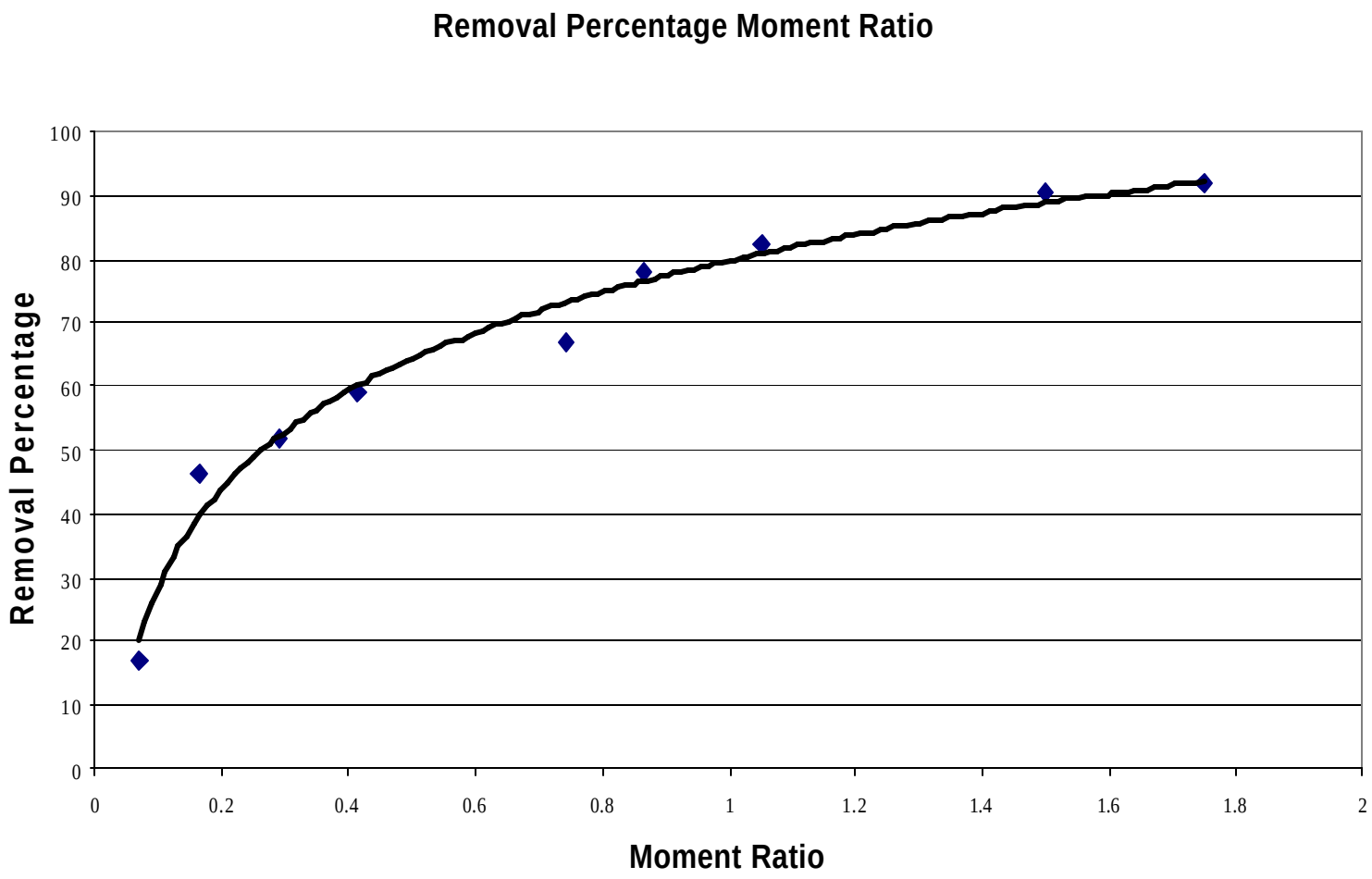
- The most widely used cleaning techniques:
  - ✓ non-contact method (megasonic cleaning)
  - ✓ contact cleaning method (brush scrubbers)

- The two basic elements that need to be understood are :
  - ✓ Particle Adhesion
  - ✓ Particle Removal

Particle Adhesion

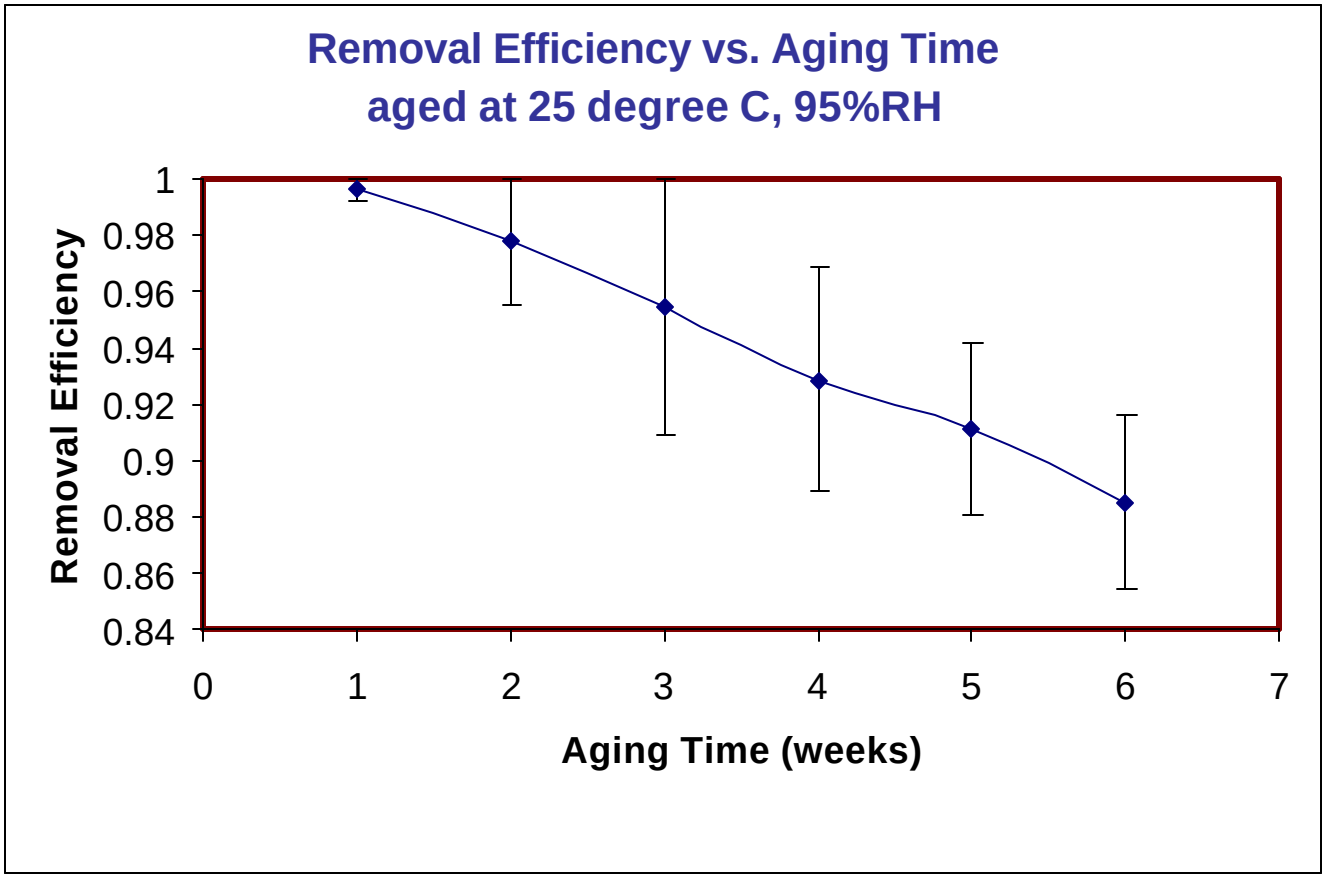
- **Adhesion between a contaminant particle and a wafer occurs in three basic steps:**
  - Long-range attraction forces draw the particle towards the surface
  - The contaminant particle touches the wafer at one point of contact
  - Short range van der Waals force dominates near the surface and the contact area increases.
  - Deformation may occur due to adhesion-induced deformation thereby increasing the adhesion force the deformation stops and the system is in equilibrium.

Removal Percentage vs. Moment Ratio (Silica Removal Experiment)



RESULTS

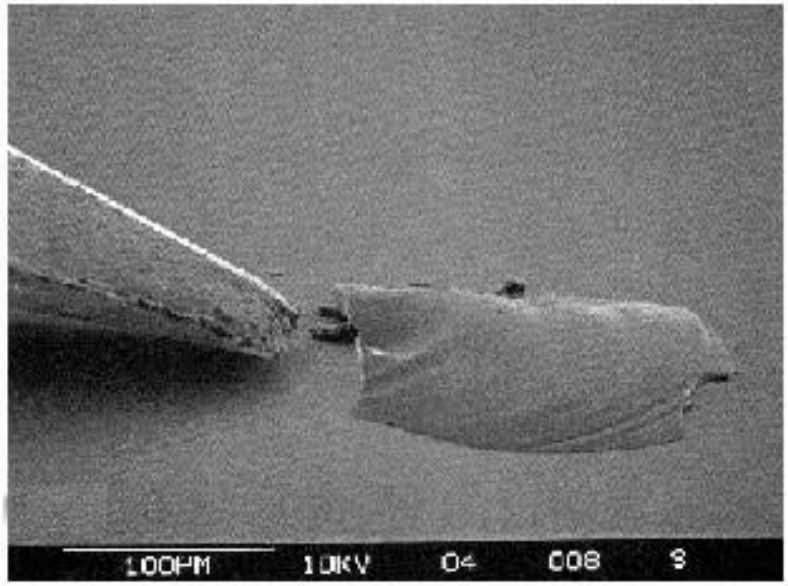
Aging Effect on Glass Particle Removal from FPD

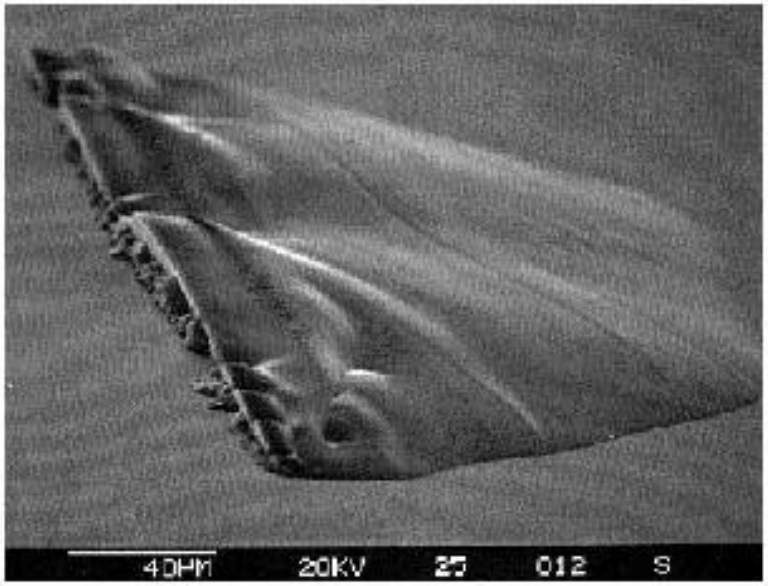


RESULTS

Imprints on the glass surface (megasonic cleaned after aging)

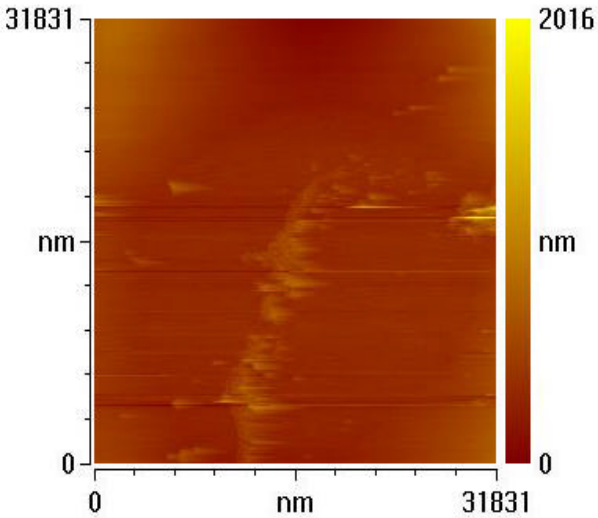
RESULTS



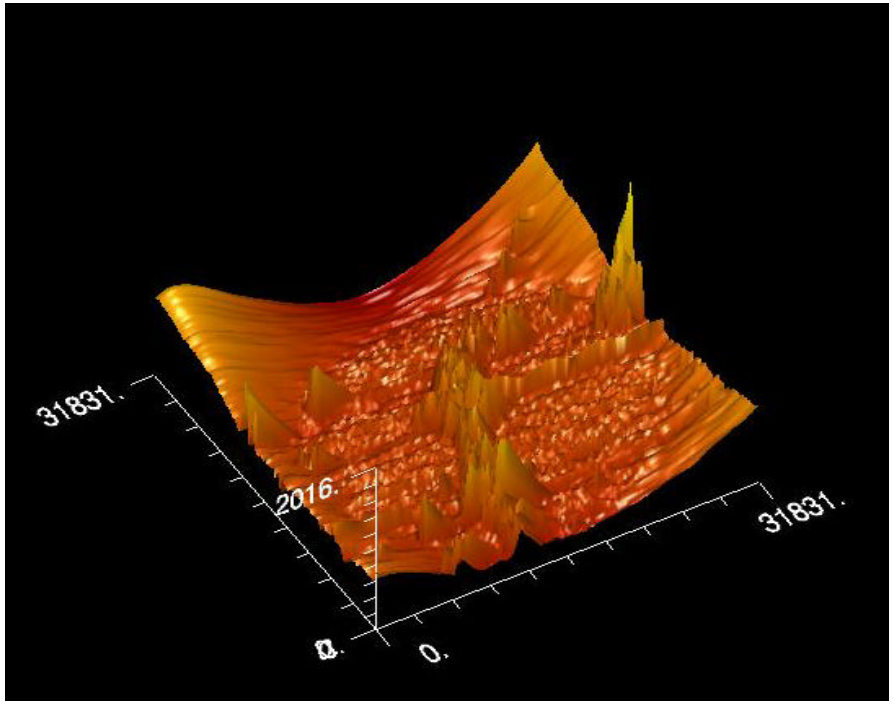


SEM image of glass chips(large bonding areas matched-flat surfaces in contact low profile)

RESULTS

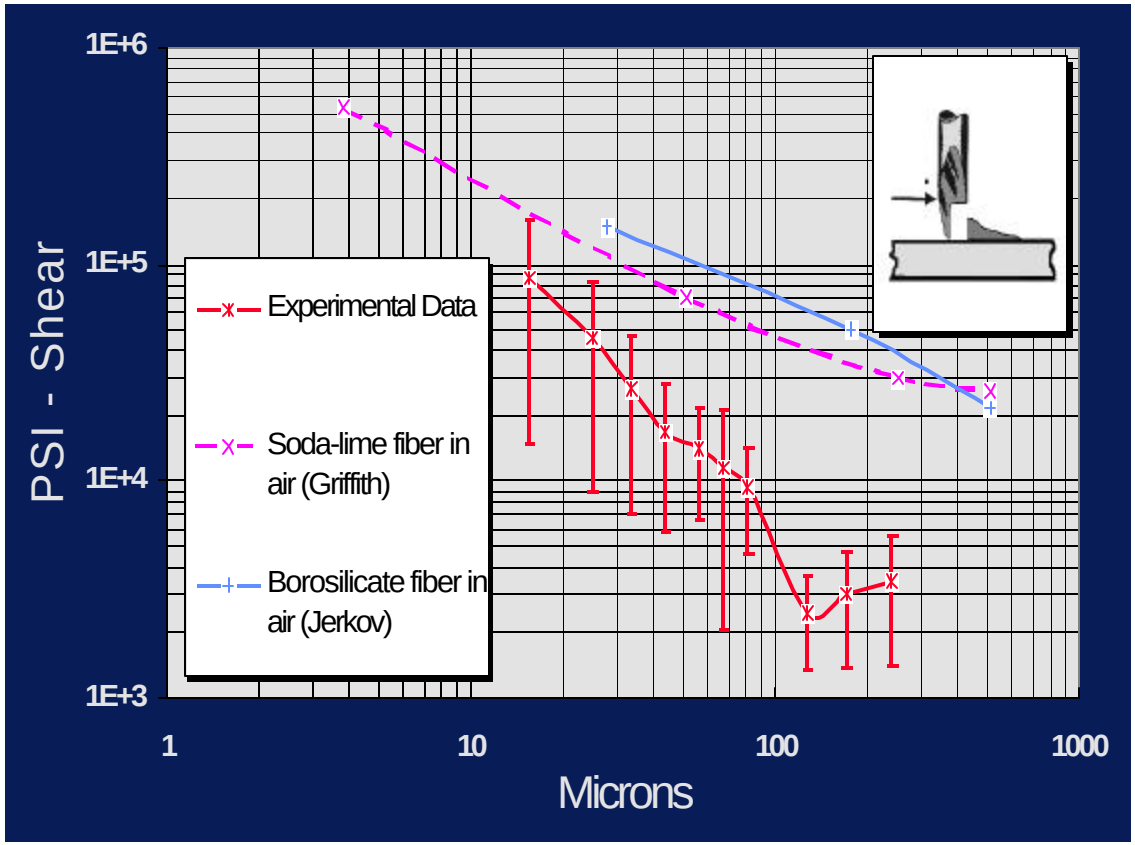


AFM micrograph of surface imprints



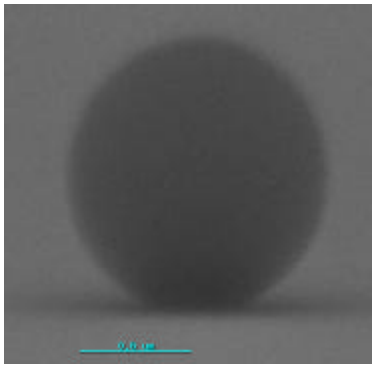
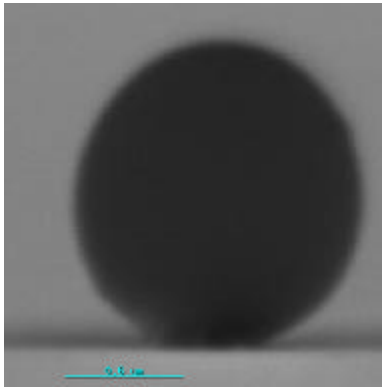
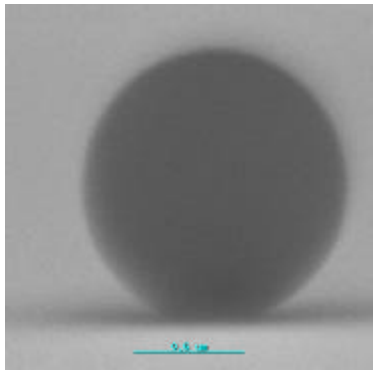
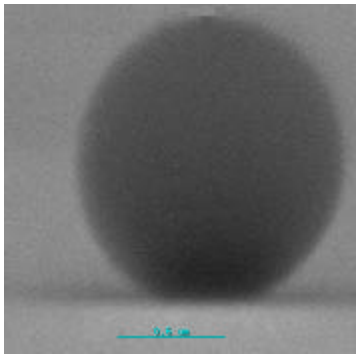
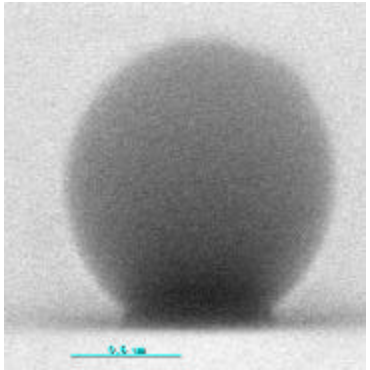
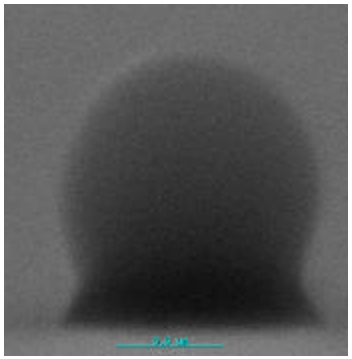
AFM three dimensional view of imprints

RESULTS



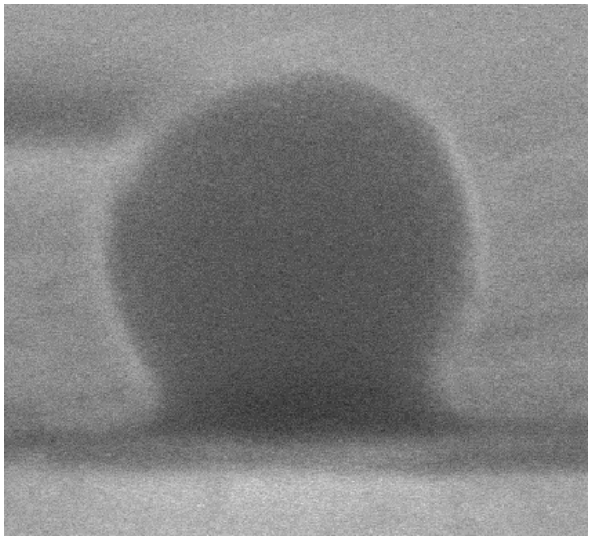
Bond strength vs. particle diameter (Experiment data compared with Griffth's tensile strength of glass fiber and with Jerkov's tensile strength of glass fiber)

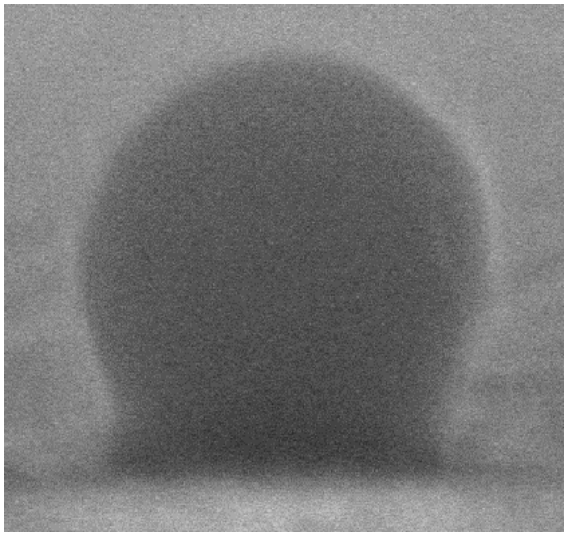
RESULTS

	Dry surface, 55%RH aging	Wet surface, 55%RH aging	Wet surface, 100%RH aging
One Week Aging			
Six weeks aging			

1.58um Silica Particle on Thermal Oxide Wafer

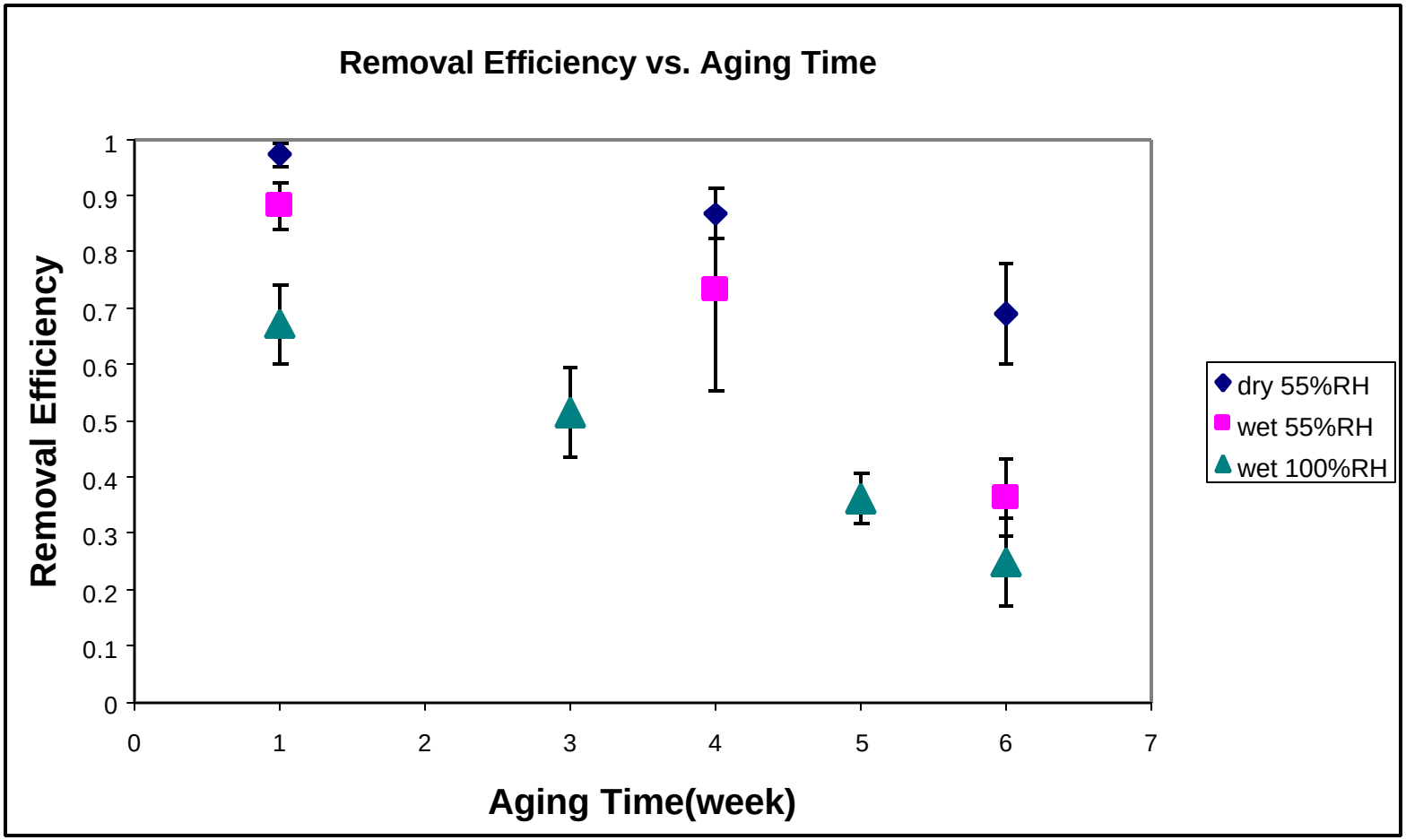
RESULTS



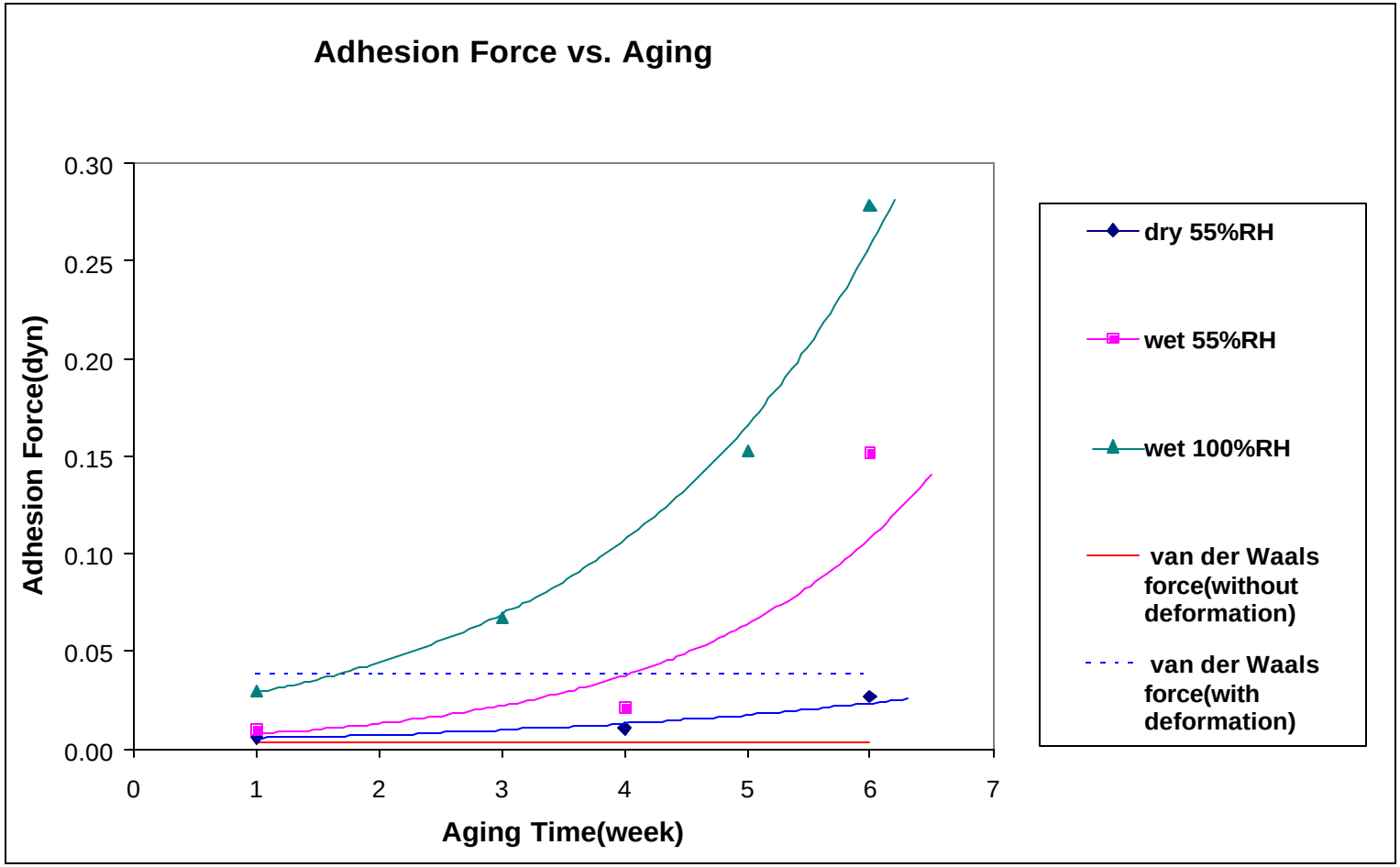


1.58μm silica particle on slurry wetted oxide surface within one hour

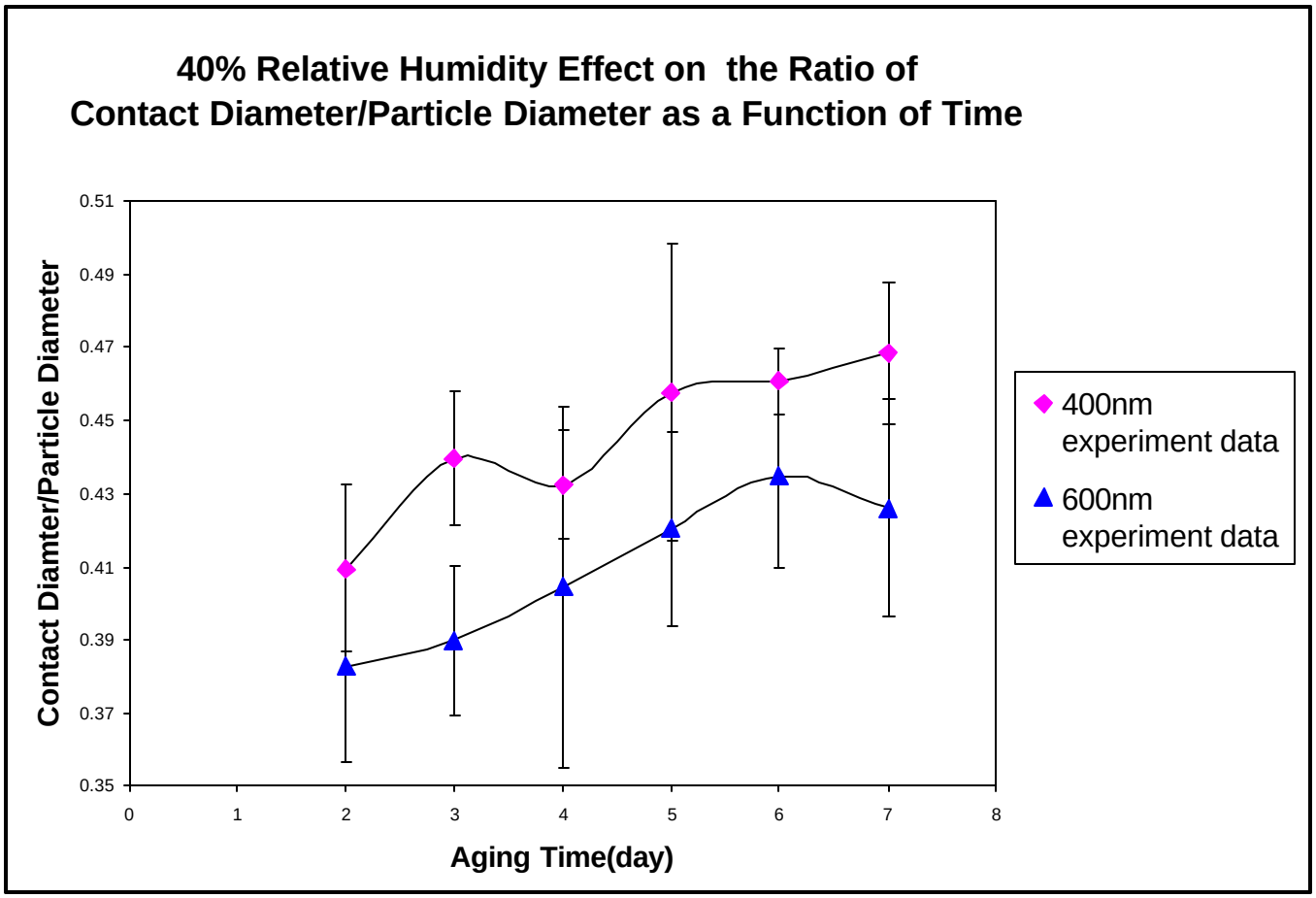
RESULTS


Removal Efficiency vs. Aging Time
Removal Efficiency
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
7
Aging Time(week)
dry 55%RH
wet 55%RH
wet 100%RH

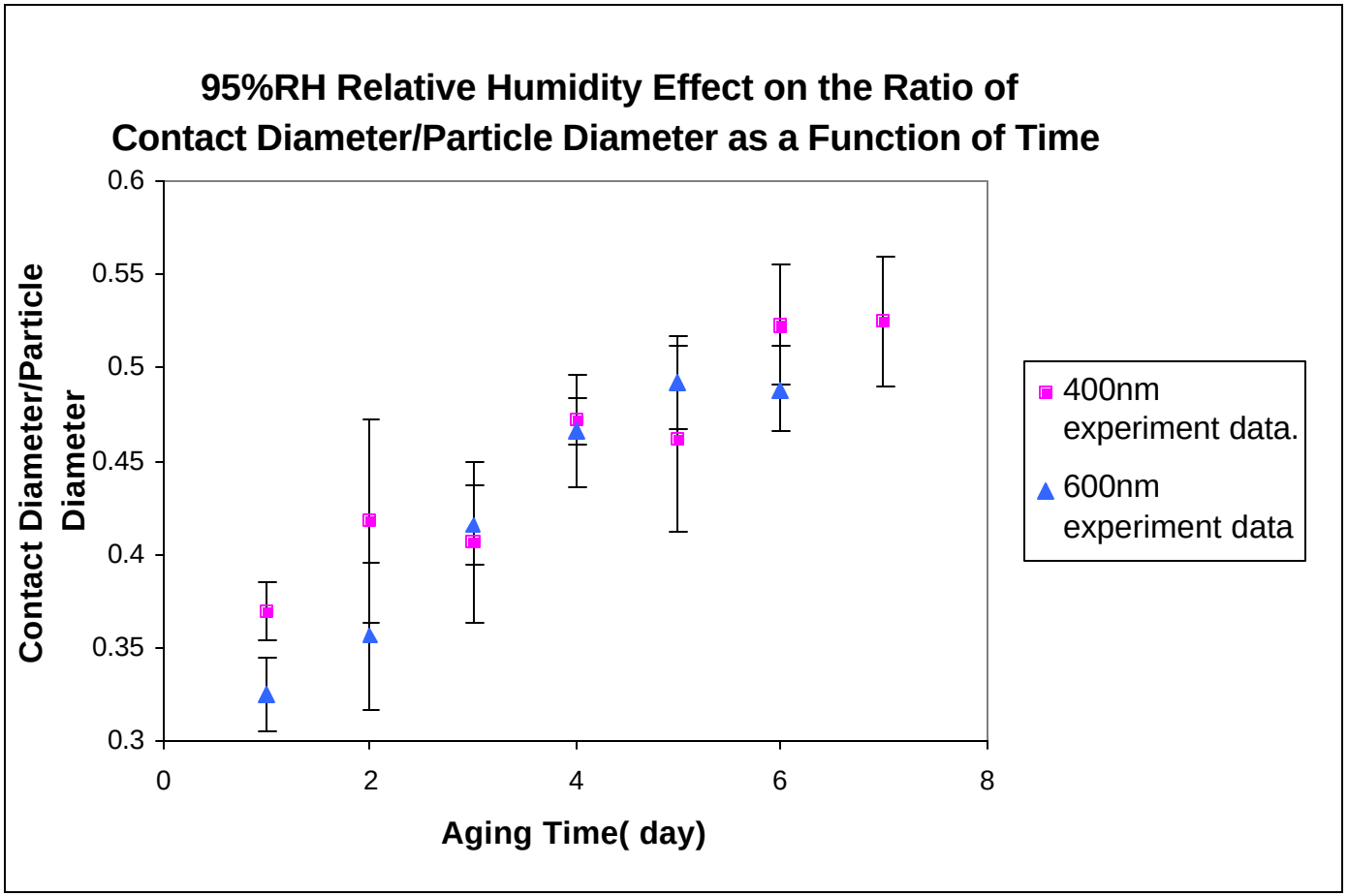
RESULTS


Adhesion Force vs. Aging
Adhesion Force(dyn)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
1
2
3
4
5
6
7
Aging Time(week)
dry 55%RH
wet 55%RH
wet 100%RH
van der Waals force(without deformation)
van der Waals force(with deformation)

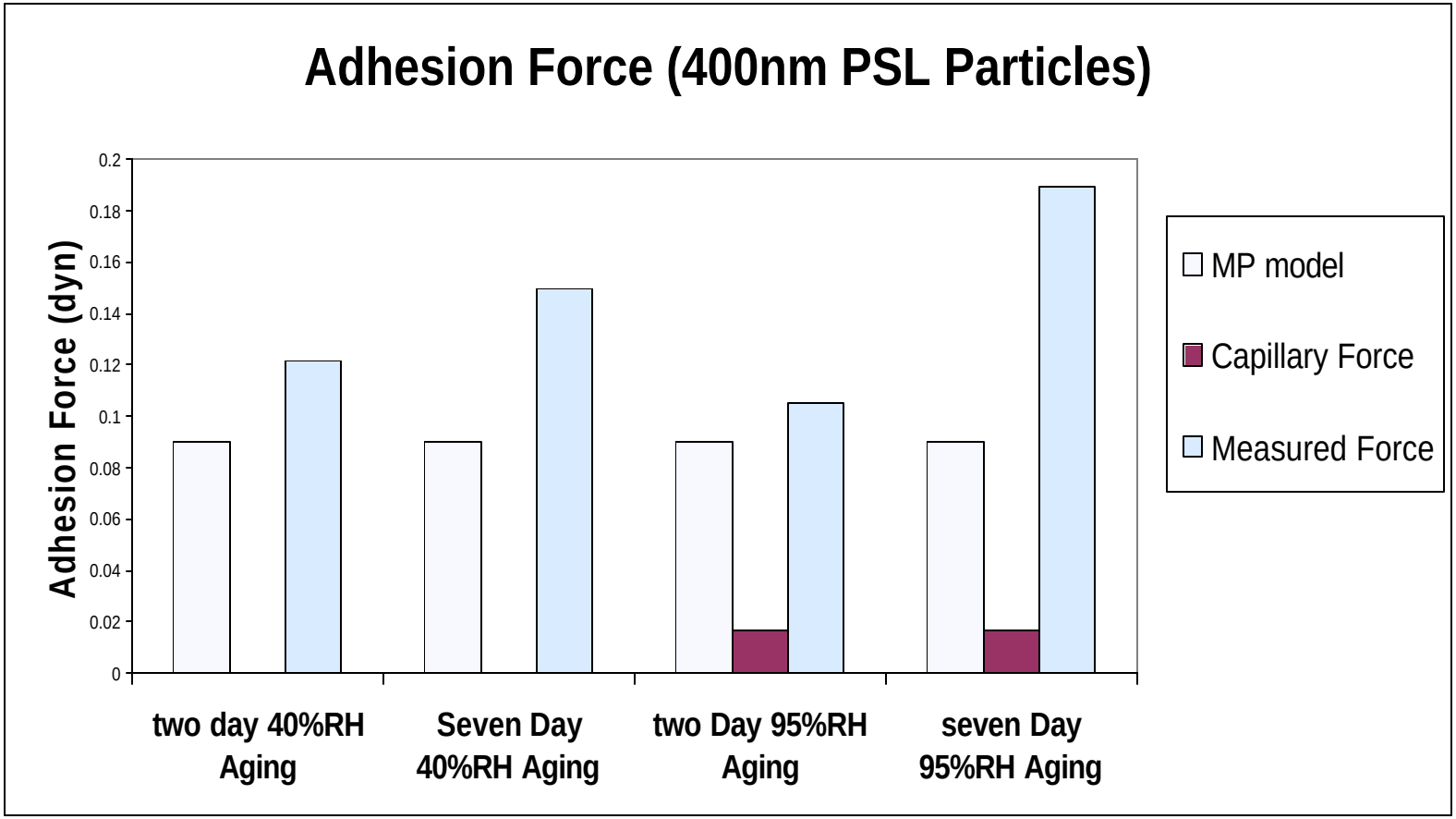
RESULTS


40% Relative Humidity Effect on the Ratio of
Contact Diameter/Particle Diameter as a Function of Time
Contact Diamter/Particle Diameter
0.51
0.49
0.47
0.45
0.43
0.41
0.39
0.37
0.35
0
1
2
3
4
5
6
7
8
Aging Time(day)
400nm experiment data
600nm experiment data

RESULTS


95%RH Relative Humidity Effect on the Ratio of
Contact Diameter/Particle Diameter as a Function of Time
Contact Diameter/Particle Diameter
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0
2
4
6
8
Aging Time(day)
400nm experiment data.
600nm experiment data

RESULTS


Adhesion Force (400nm PSL Particles)
Adhesion Force (dyn)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
two day 40%RH Aging
Seven Day 40%RH Aging
two Day 95%RH Aging
seven Day 95%RH Aging
MP model
Capillary Force
Measured Force

SUMMARY

- **Moisture plays a significant role in silica particles' adhesion on silicon oxide substrate. The adhesion force significantly increases with moisture.**
- **The large meniscus indicates that initially, hydrogen bond forms and as moisture reacts between the surface and the particle, covalent bond forms around the periphery of the particle. If considering practical surface condition, the measured adhesion force fall between hydrogen and covalent bonds.**

SUMMARY

The average pressure exerted by surface force between PSL particle and silicon oxide surface is

$$P = \frac{2w_A}{z_0}$$

P is found to be 1.6´10^9 Pa, which is comparable to the Young's modulus of the polystyrene (2.55 ´10^9 Pa) and far in excess of its yield strength (10.8 ´10^6 Pa). This confirms that it is plastic deformation taken place.

- **Contact diameter between the particles and the substrate increase with time logarithmically.**
- **For the same aging time, high humidity (95%RH) shows significant increase in particle deformation compared to the 40%RH conditions. Capillary force tends to accelerate the adhesion-induced deformation process.**
- **For the same aging conditions, smaller particles encounter larger deformation.**
- **The plastic deformation is caused by adhesion and capillary stresses that exceed the yield strength of PSL particles.**