GEN3D – Experimental and Numerical Development of GEN3 Durability Life Models

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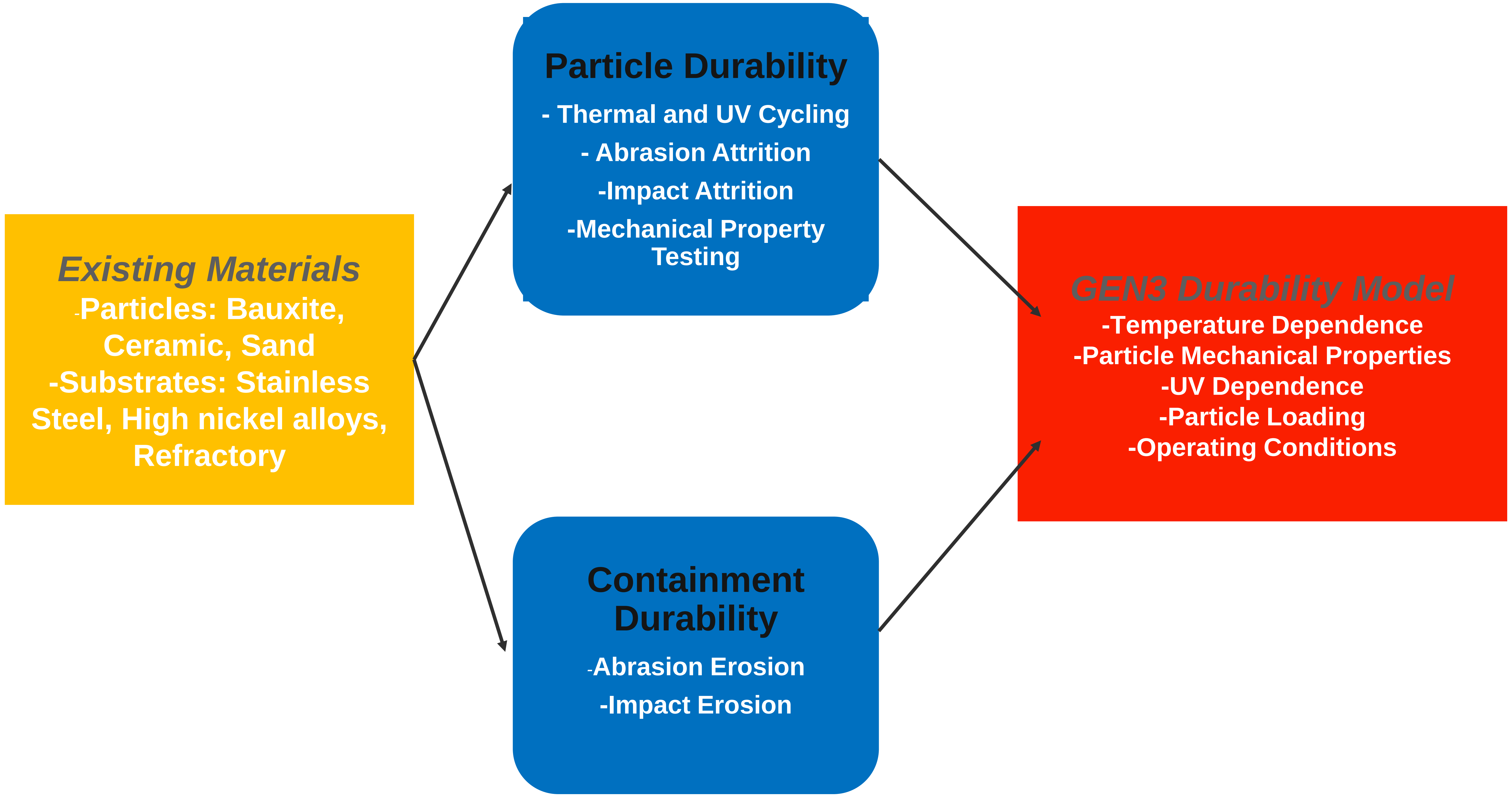
BOISE STATE UNIVERSITY

PROJECT SUMMARY

- Development of experimental facilities
- Mechanical property characterization under relevant GEN3 conditions
- Development of comprehensive durability model
- Wear rates
- Optical property changes

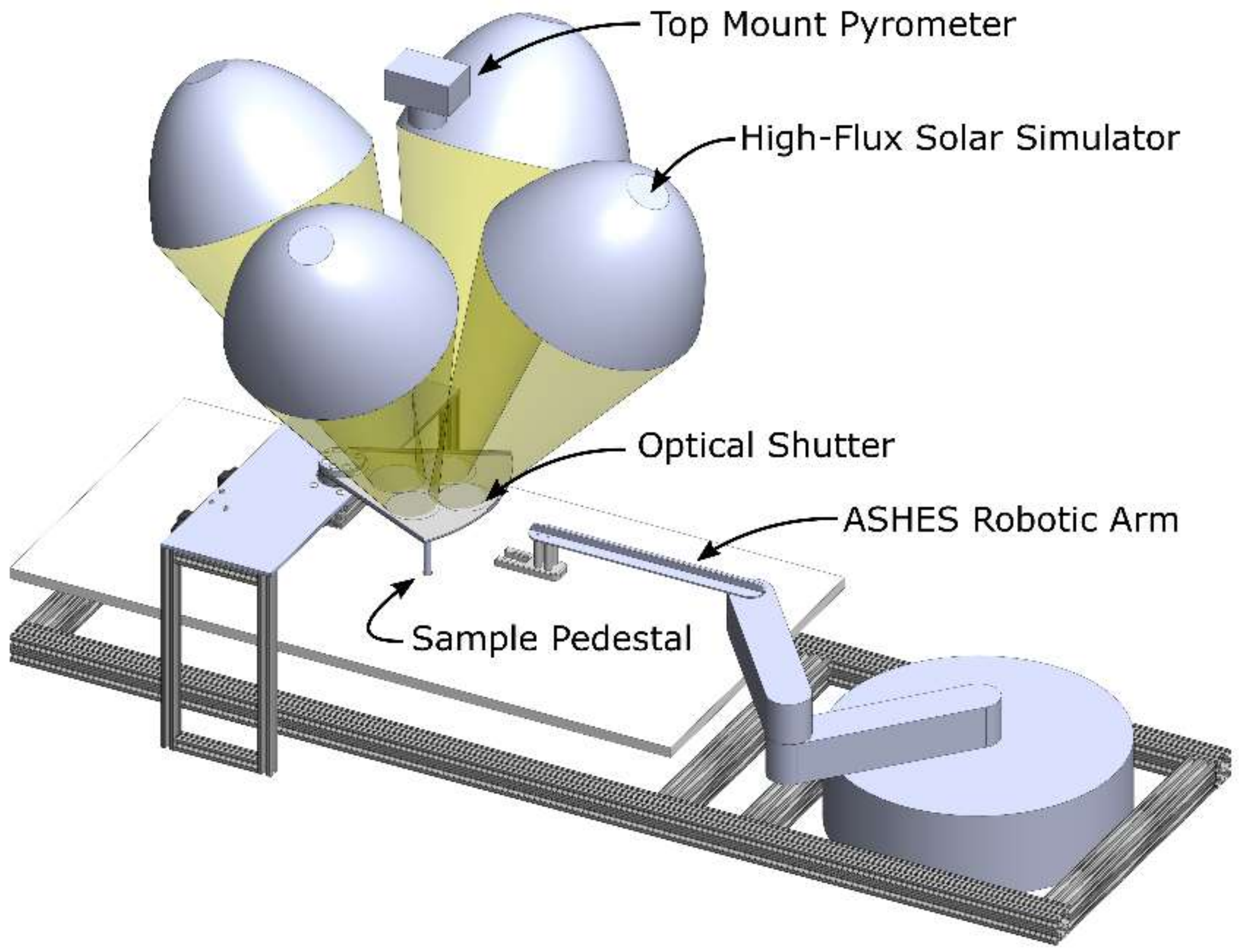


- Attrition: particle breakdown due to wear against other particles or containment materials.
- Abrasion: wear of substrate materials and particles resulting from particle sliding across substrate at extremely shallow angles.
- Impact: wear of substrate materials and particles resulting from particle impact upon containment materials

PARTICLE UV AND THERMAL CYCLING

Optical degradation of particles:

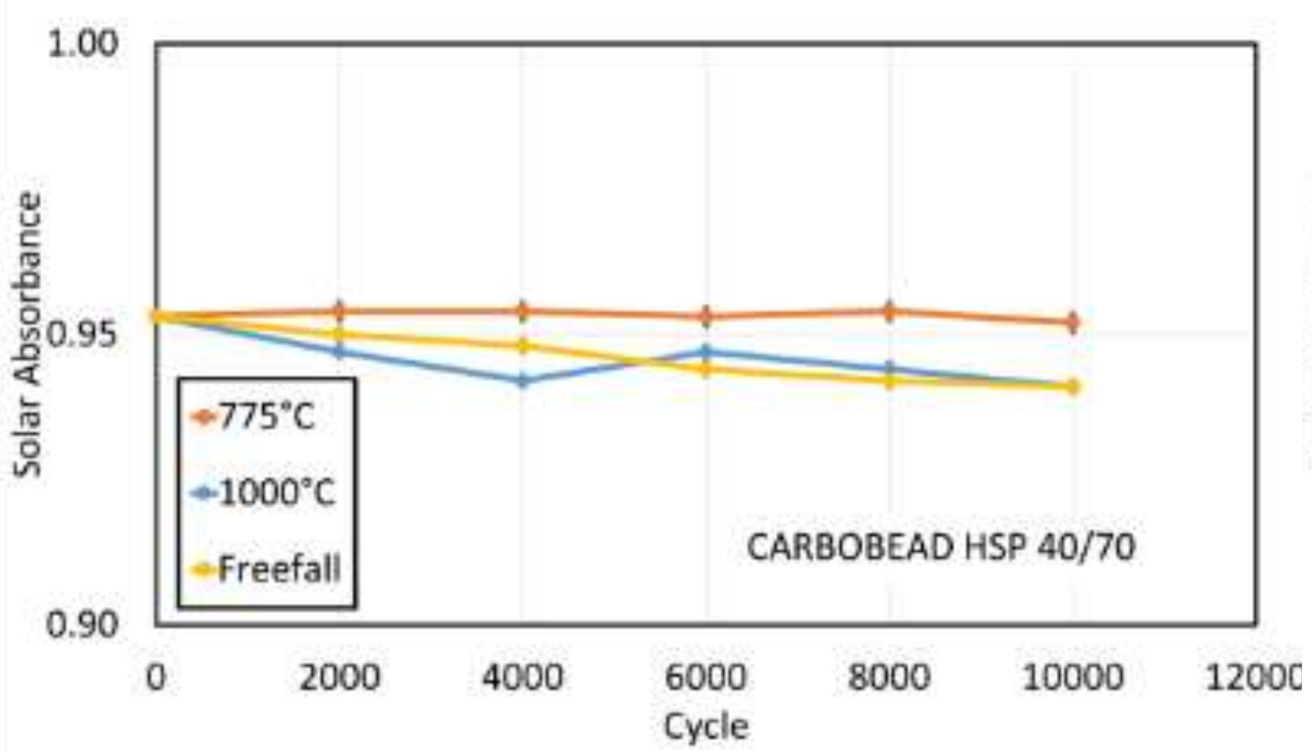
- Thermal cycling for packed beds of particles has been conducted for peak temperatures of 775°C and 1000 °C
- ASHES high flux solar simulator
- Pure thermal cycling in a tube furnace.

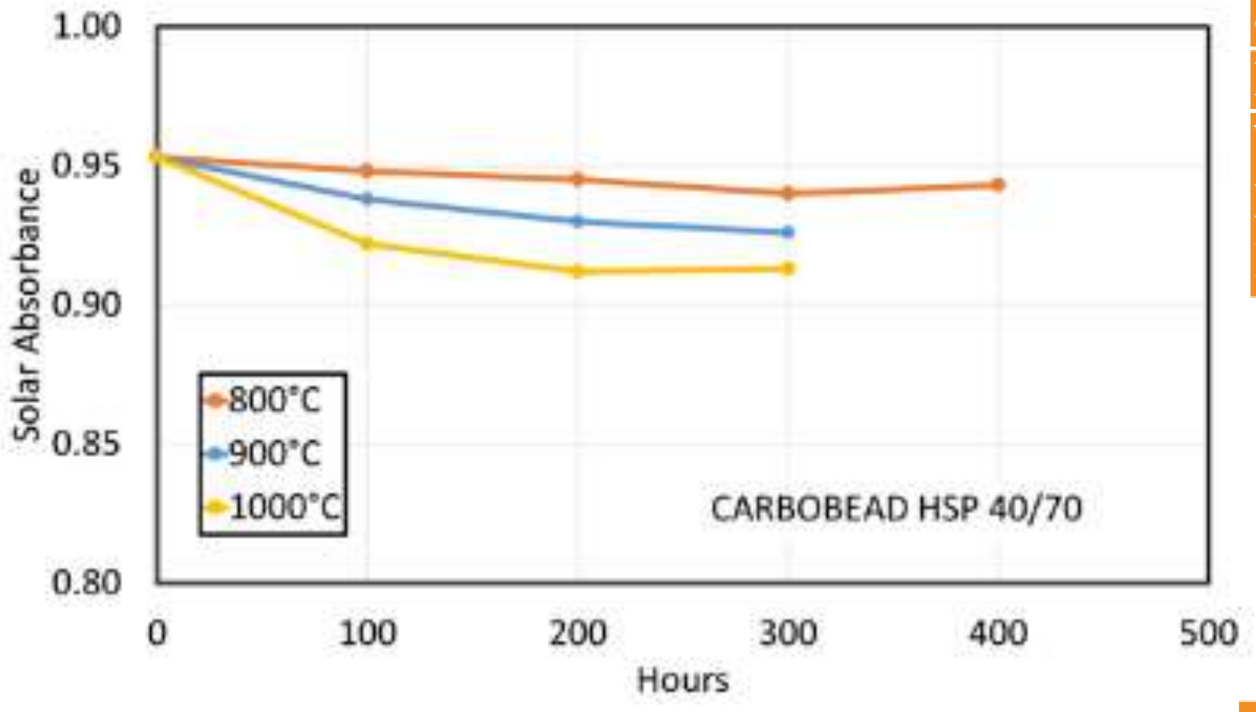


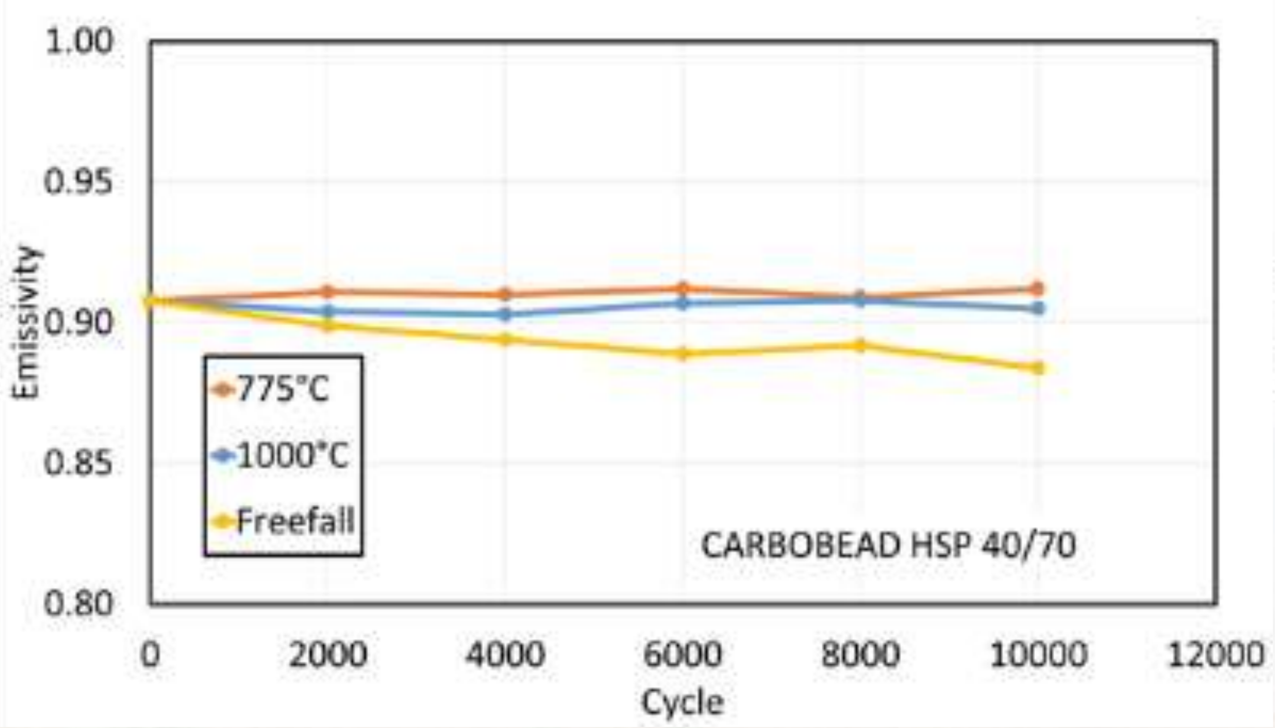
ASHES system at Sandia National Lab

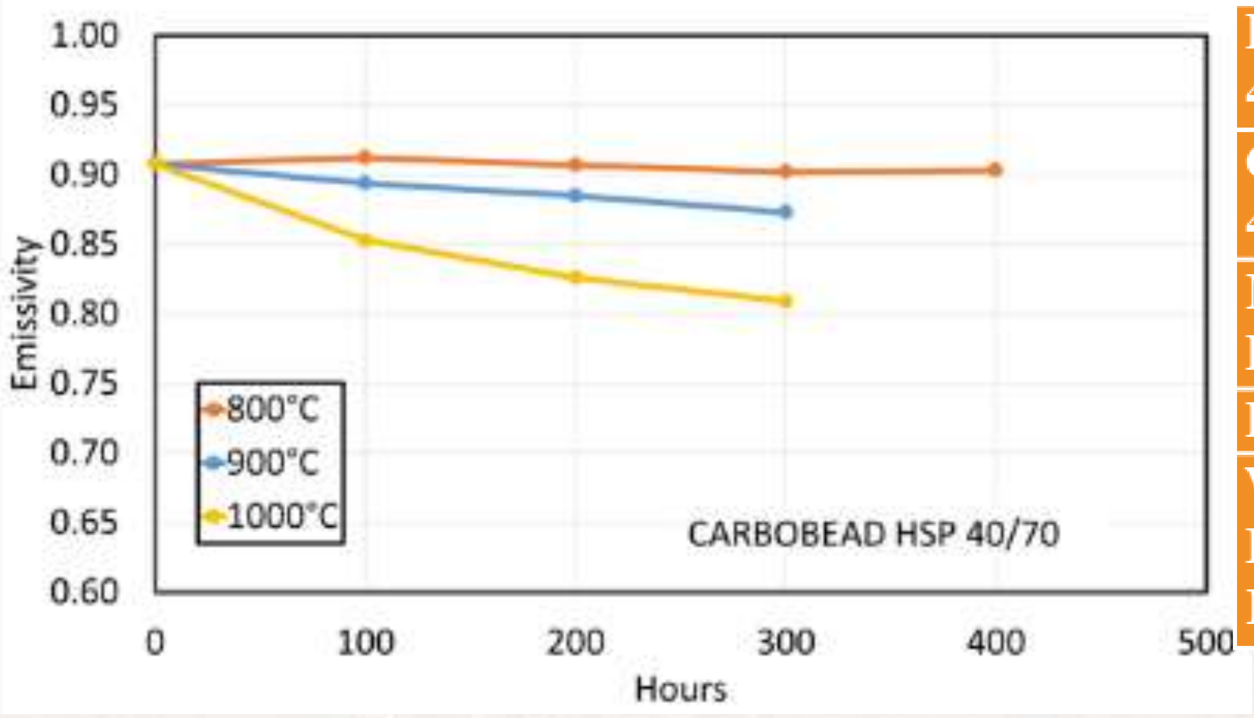
Experimental set up to test the mechanical properties of particles

HIGH FLUX CYCLING AND ISOTHERMAL AGING









HSP 40/70 Cycled *HSP 40/70 Aged*

Cycling Results after 10,000 Cycles

Particle	As Received Particle Absorptance	Final Temp. 775 °C	Final Temp. 975 °C	615 °C + 1.7 seconds
HSP 40/70	95.3%	-0.12%	-1.3%	-1.3%
CP 40/100	94.1%	0.06%	-1.1%	-1.2%
MAX HD 35	88.0%	1.1%	-0.16%	-1.7%
HD 350	95.6%	-.29%	-1.3%	-1.7%
WanLi Diamond Black	96.4%	-4.3%	-4.4%	-2.6%

Aging Results after 300-400 hours

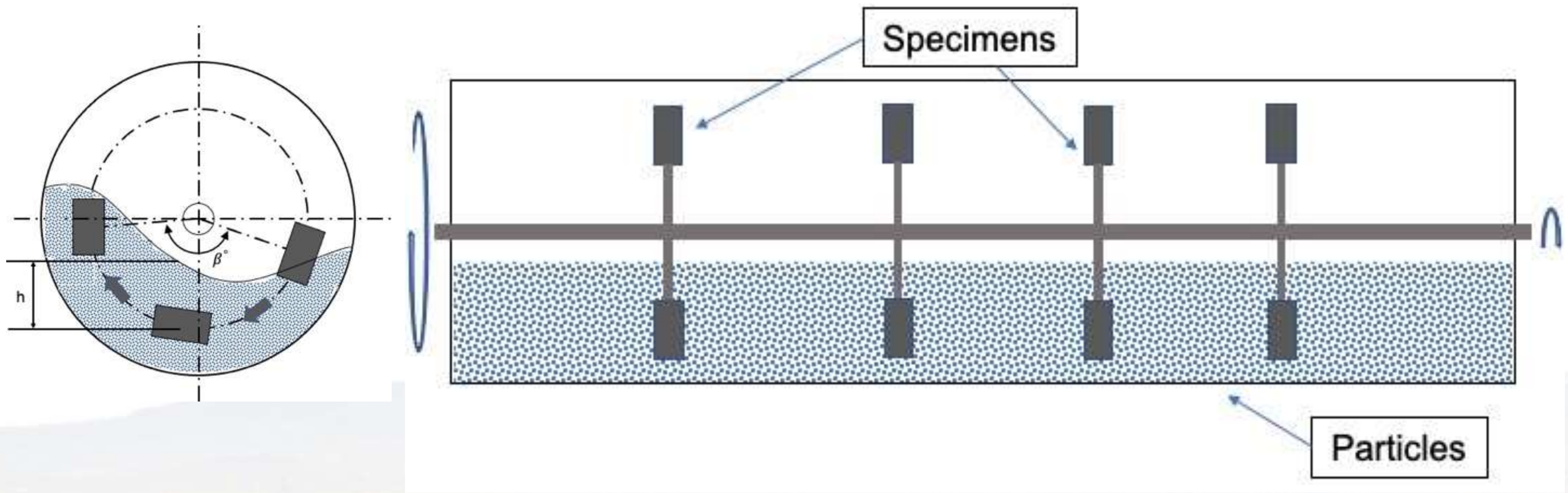
Particle	As-Received Particle Absorptance	400 hours @ 800 °C	300 hours @ 900 °C	300 hours @ 1000 °C
HSP 40/70	95.3%	-1.1%	-2.9%	-4.2%
CP 40/100	94.1%	-0.7%	-1.8%	-6.4%
MAX HD35	88.0%	-1.0%	-5.2%	-3.8%
HD 350	95.6%	-1.7%	-2.8%	-3.8%
WanLi Diamond Black	96.4%	-3.4%	-4.0%	-5.9%

ABRASION EROSION TESTING

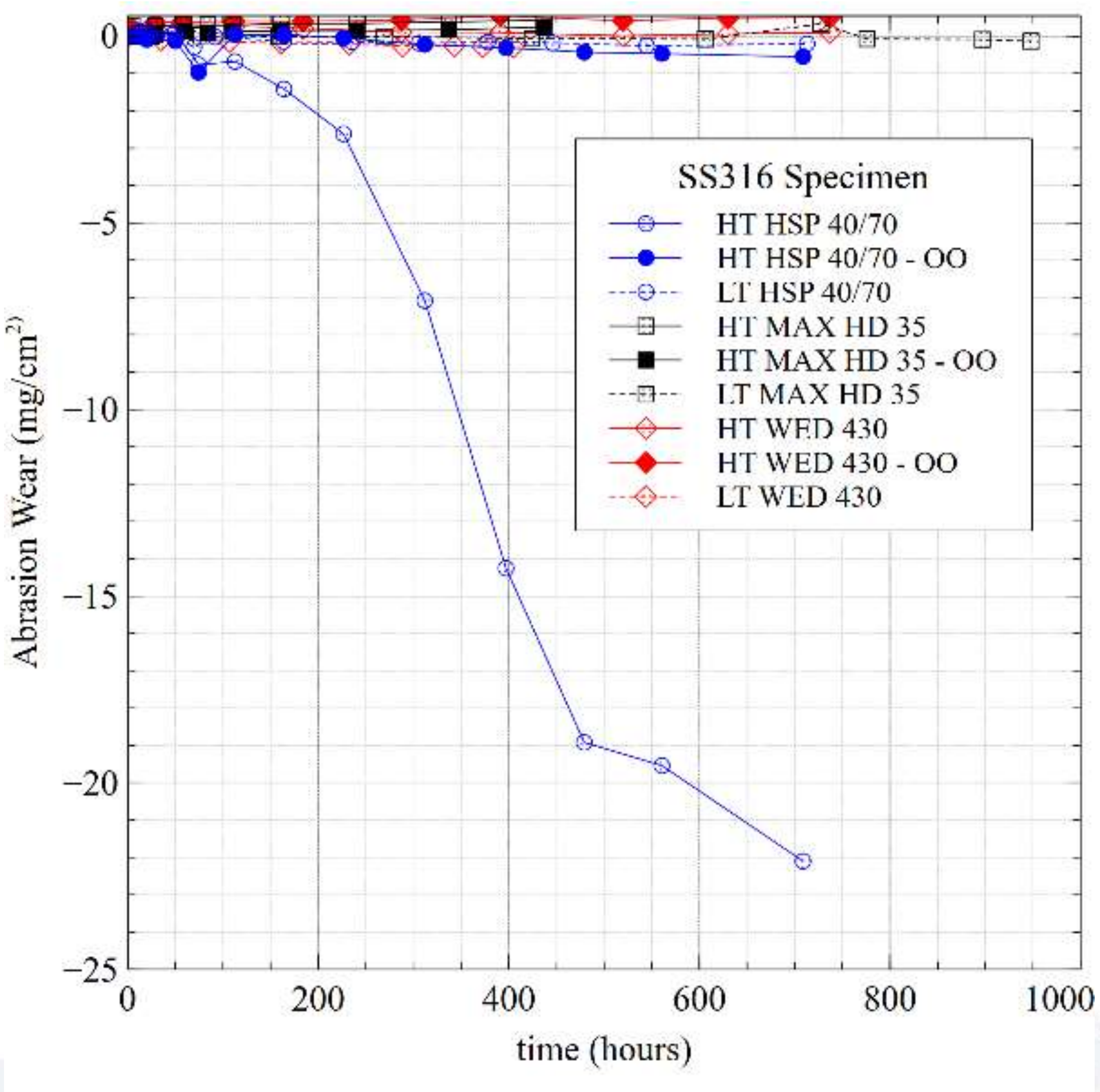
Testing methodology and setup:

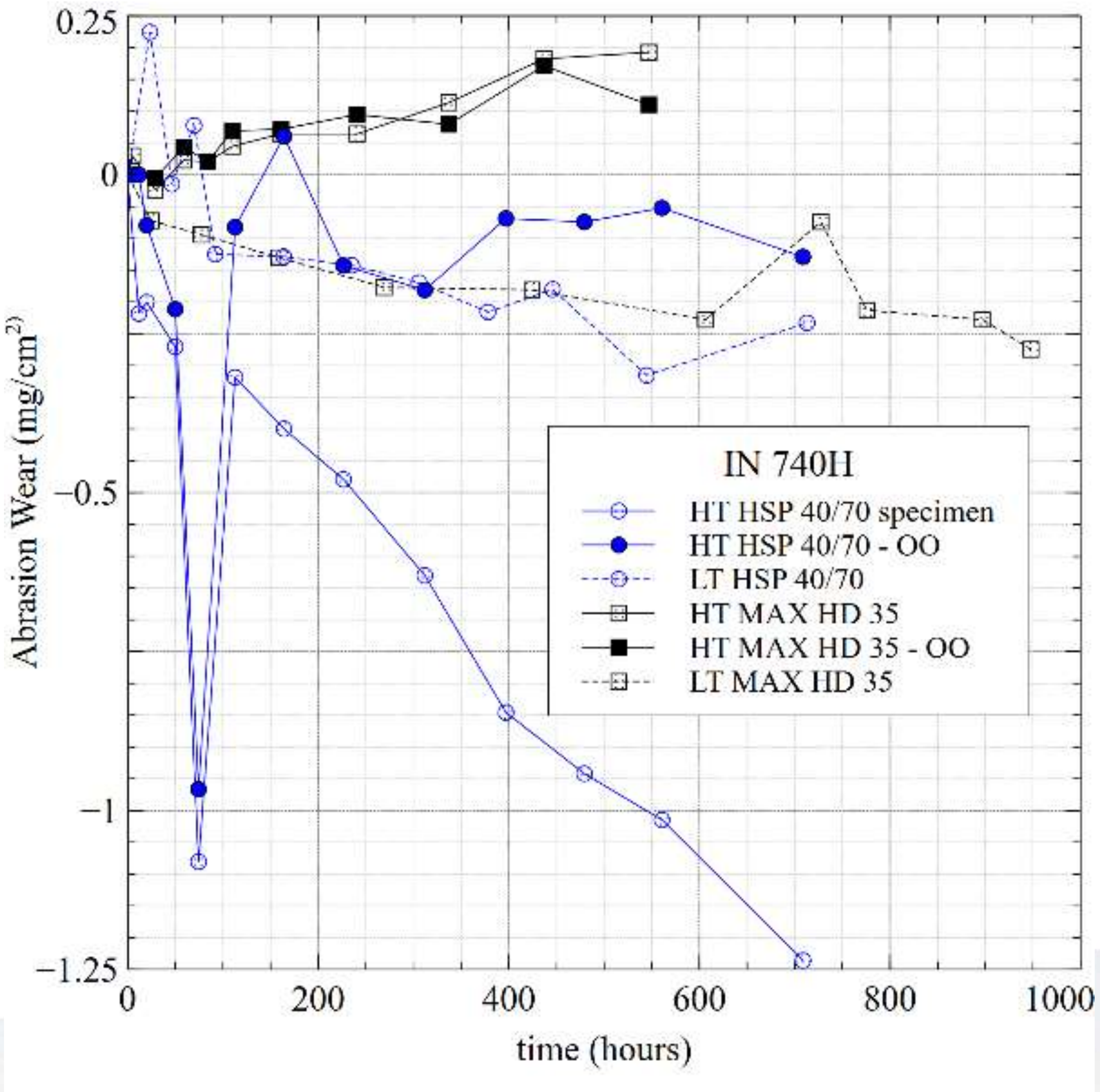
- 8 specimens are mounted on a shaft and rotated about the central shaft through a bed of particles.
- The current tests are performed at a relative speed of ~1.8 cm/s
- The specimens are rotated through the particle bed and periodically weighed for change in mass to determine abrasion rate.
- Testing complete for SS316, SS316H, Inconel 740H, Haynes 230, and refractory ceramics

Note: 1 hour of real time testing is equal to 1 hour of equivalent 1MW plant operation.



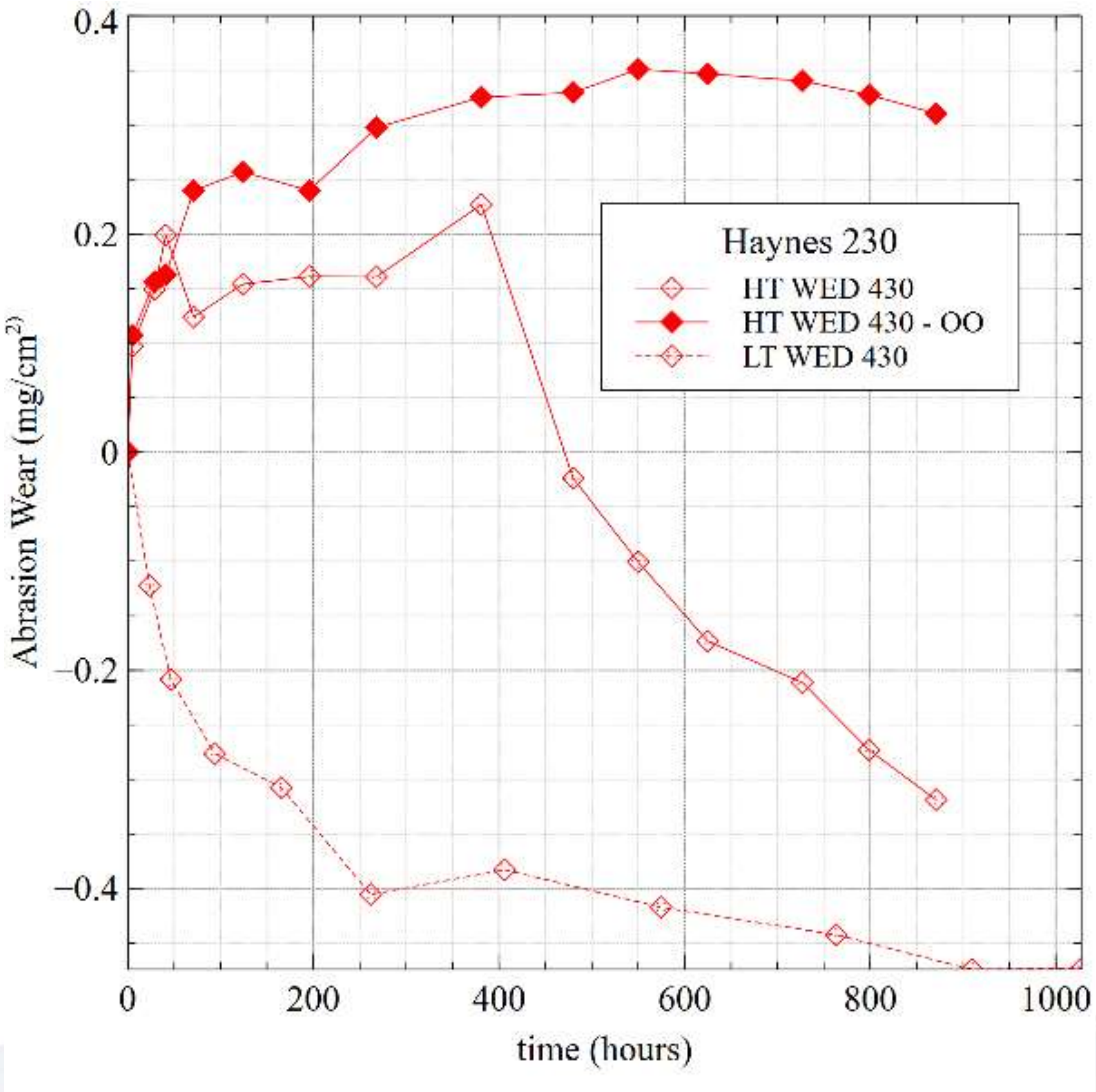
ABRASION FOR SS316 AND INCONEL 740H

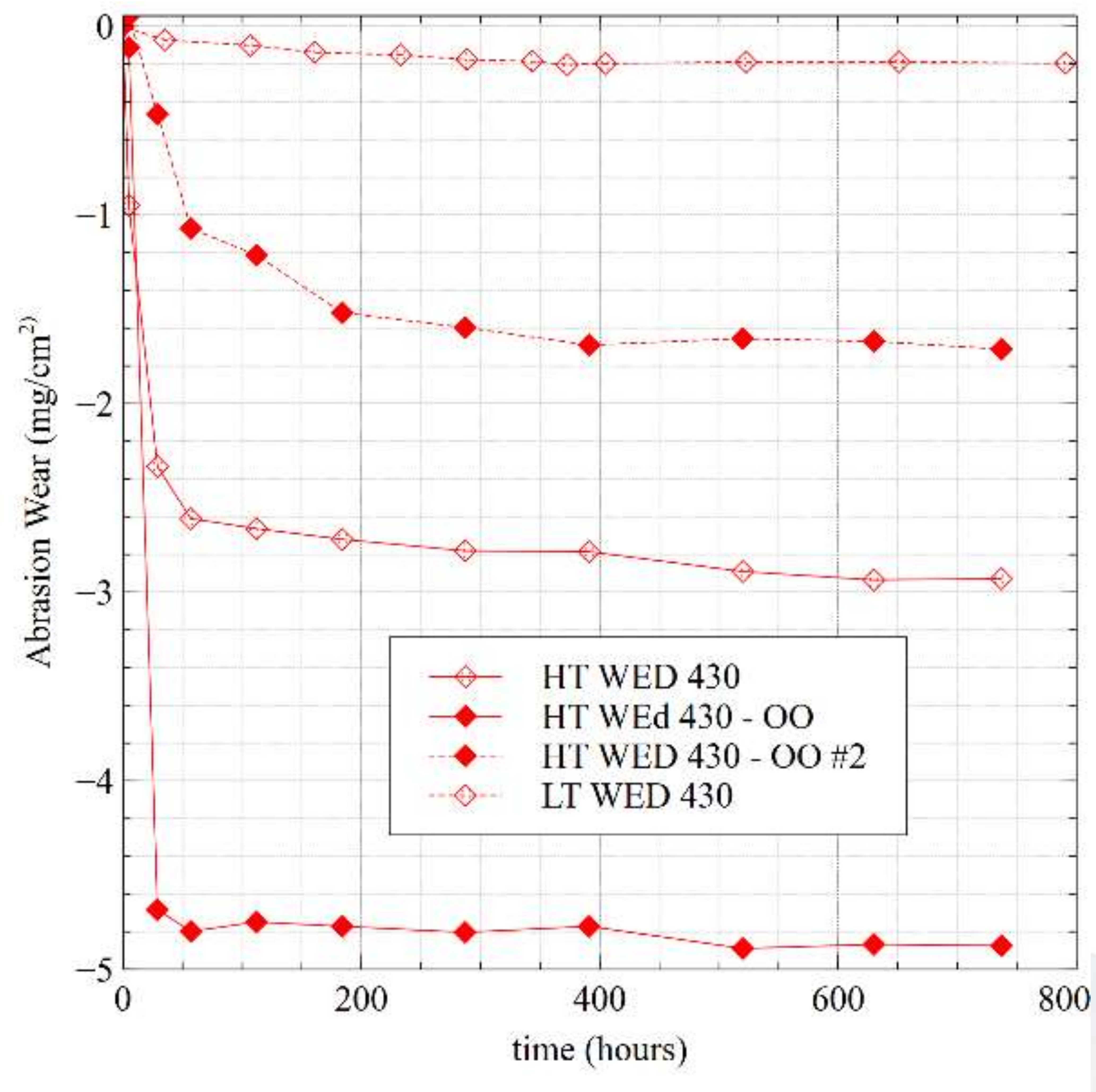




Stainless Steel at high temperature has significantly enhanced erosion-oxidation compared to high nickel alloys

ABRASION FOR HAYNES 230 AND SS 316H

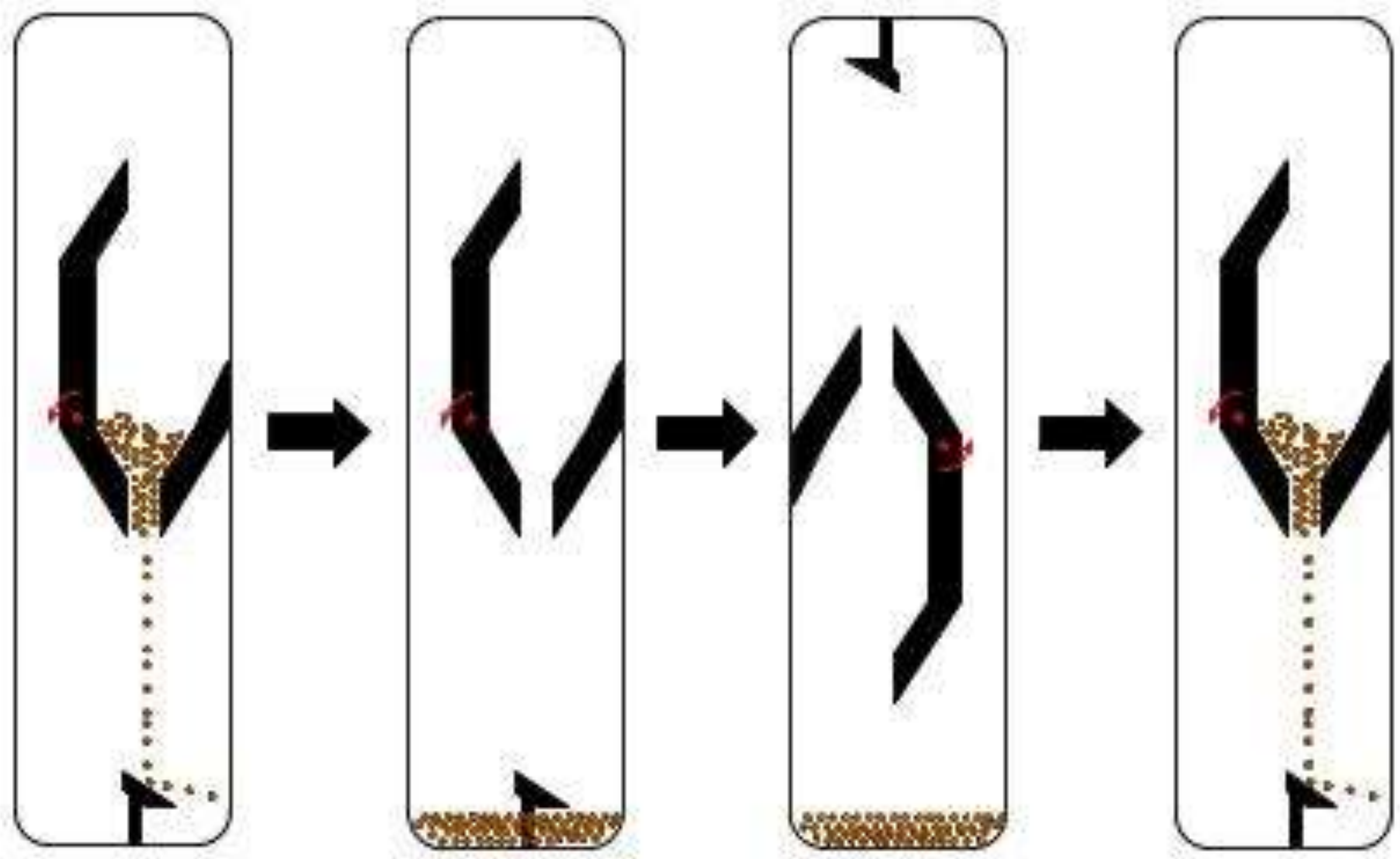




IMPACT EROSION TESTING

Testing methodology and setup:

- 0.5 kg of particles are loaded into the test chamber.
- Particles are allowed to freely fall on specimen till the reservoir is empty.
- Once all the the particles are collected in the discharge chamber, the setup is rotated about the horizontal axis to recharge the system by moving the particles from discharge chamber to the reservoir.
- Distance from Nozzle end to specimen is ~12.7 cm
- Particle impact velocity ~1.5 m/s.
- Erosion ratio is defined as substrate mass loss over the particle throughput



IMPACT EROSION RESULTS

	SS316	TUFFCRETE 60M	INCONEL 740H
HSP 40/70	3.80E-09	3.22E-07	2.47E-08
Carbobead CP 40/100	7.71E-09	1.07E-07	1.54E-08
Carbomax HD 35	4.30E-09	3.24E-07	4.82E-08

Erosion ratio from impact erosion testing at low temperature

	SS316	TUFFCRETE 60M	INCONEL 740H
HSP 40/70	2.64E-06	3.78E-06	5.39E-08
Carbobead CP 40/100	3.00E-06	Upcoming	1.11E-07
Carbomax HD 35	1.46E-07	Ongoing	1.18E-07

Erosion ratio from impact erosion testing at 800 °C

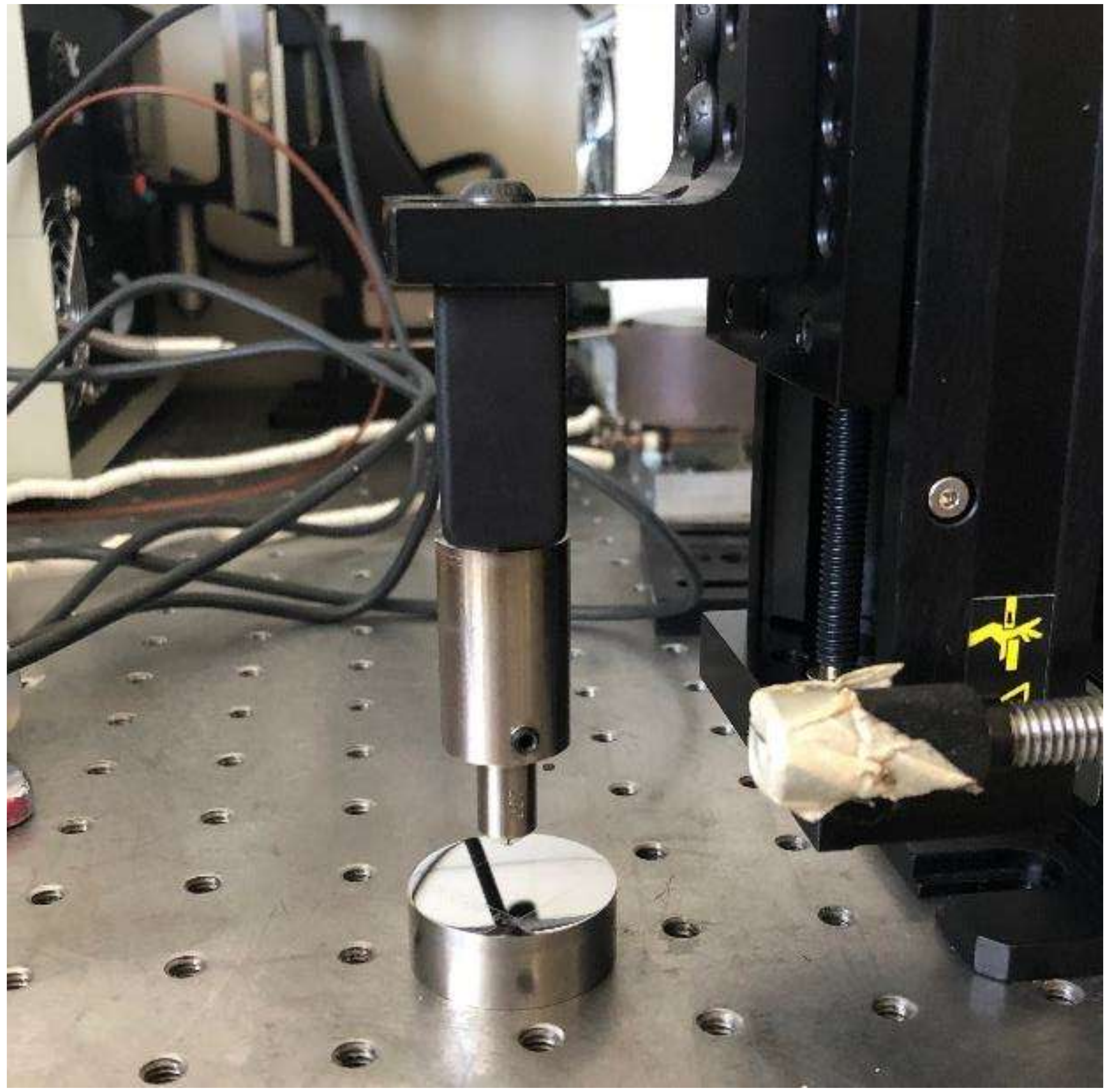
Stainless Steel at high temperature has significantly enhanced erosion-oxidation compared to high nickel alloys (~2-3 orders of magnitude)

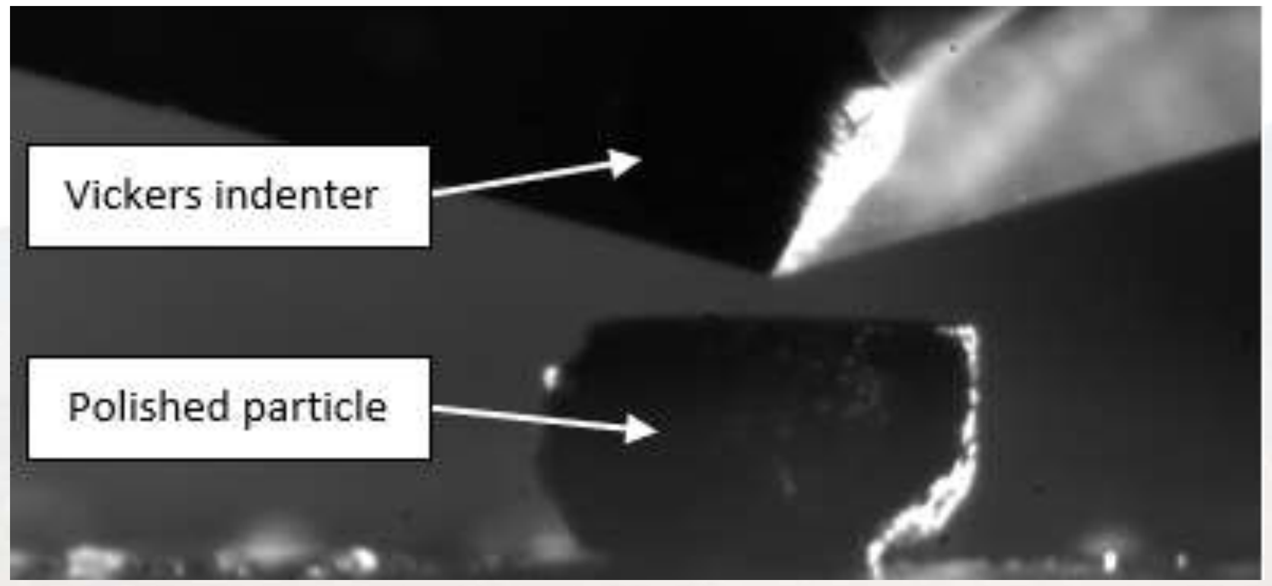
MECHANICAL PROPERTIES TESTING

Establish a technique to accurately measuring the Vicker's hardness at 800 ℃.

Testing methodology and setup:

- The particles are set in a dissolvable, epoxy-like substance, and sanded and polished on two parallel sides.
- For testing at 800 ℃, the particle is placed on a substrate heater and indentation is made after the particle reaches set temperature.
- Additional testing of containment materials as well

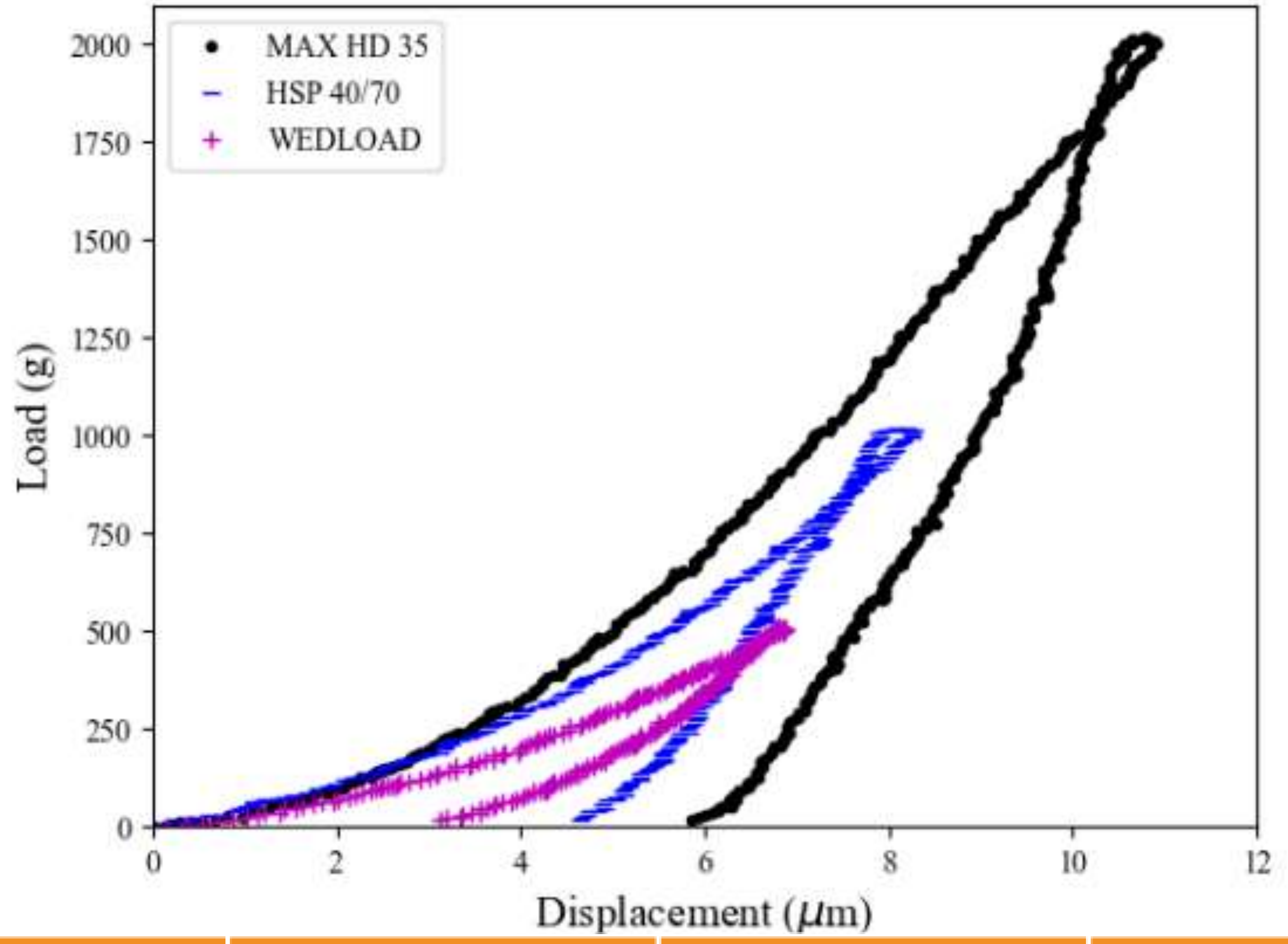




Experimental set up to test the mechanical properties of particles

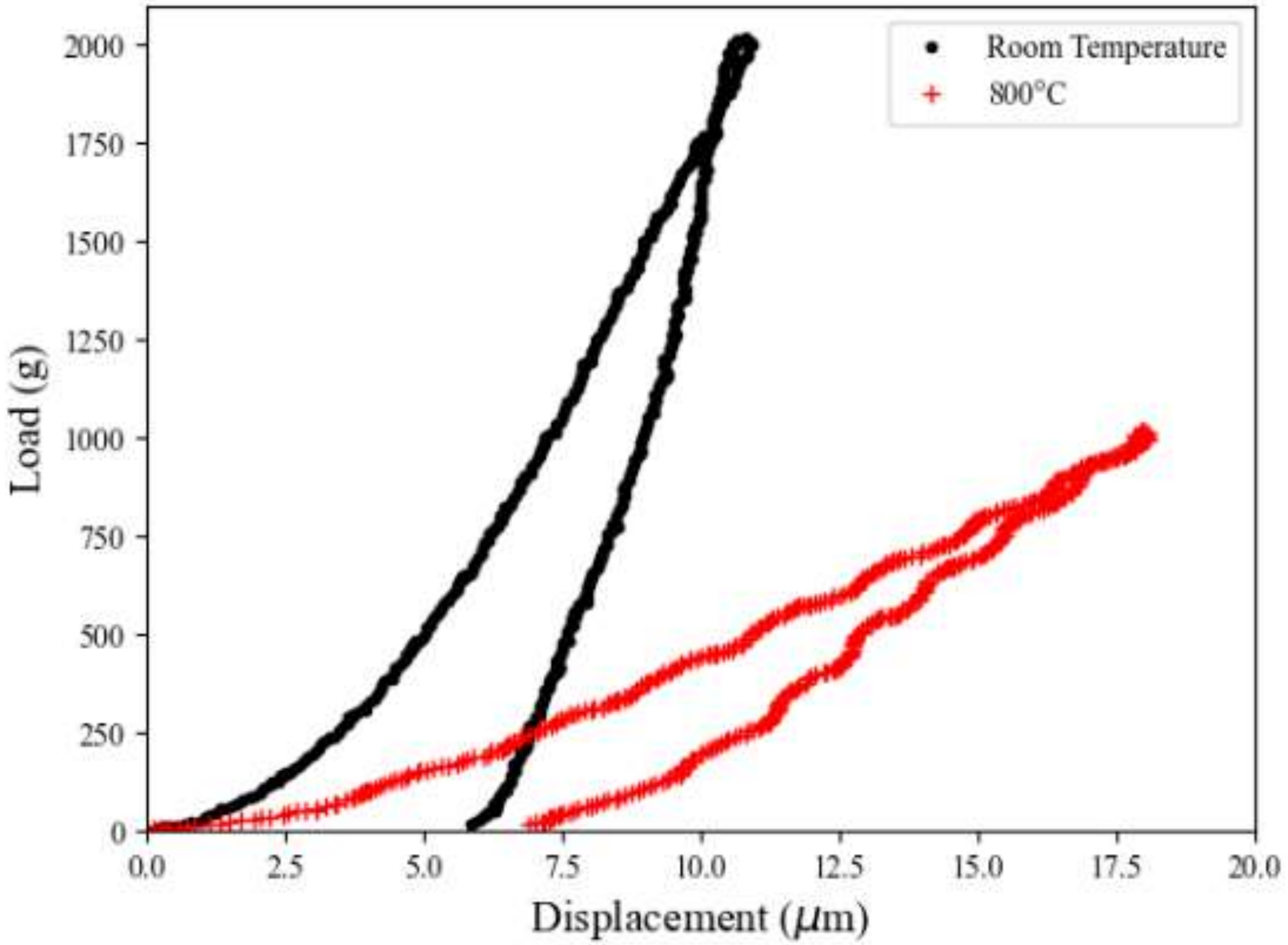
MECHANICAL PROPERTIES RESULTS

Load-displacement behavior at Room temperature



	HSP 40/70	WEDLOAD 430	MAX HD 35
Average Hardness (HV)	1268.5 ± 171.9	917.6 ± 121.3	1363.2 ± 103.2
Elastic Modulus (psi)	17.9E6 ± 2.6	11.2E6 ± 1.7	16.0E6 ± 5.6

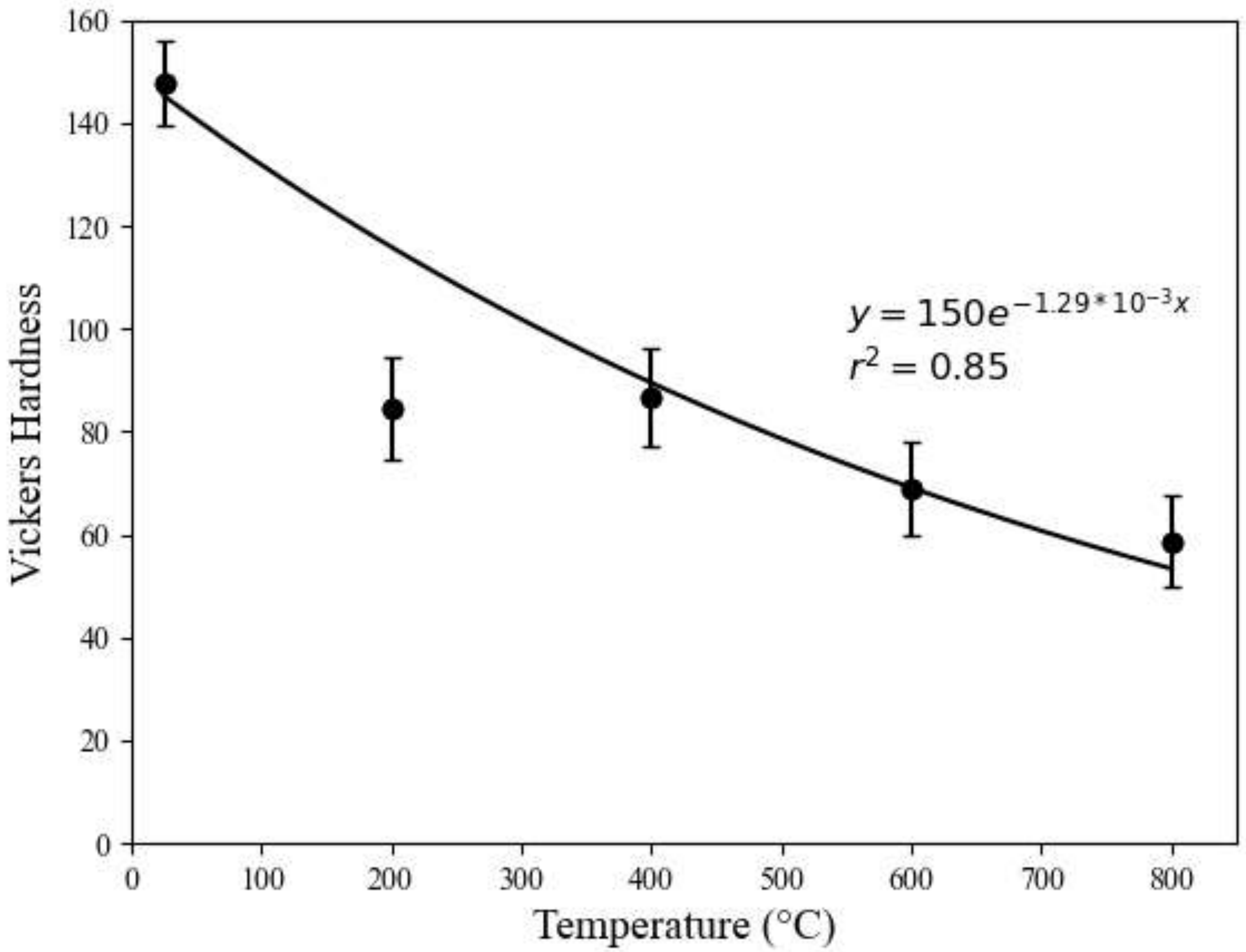
Load-displacement behavior comparison for MAX HD35



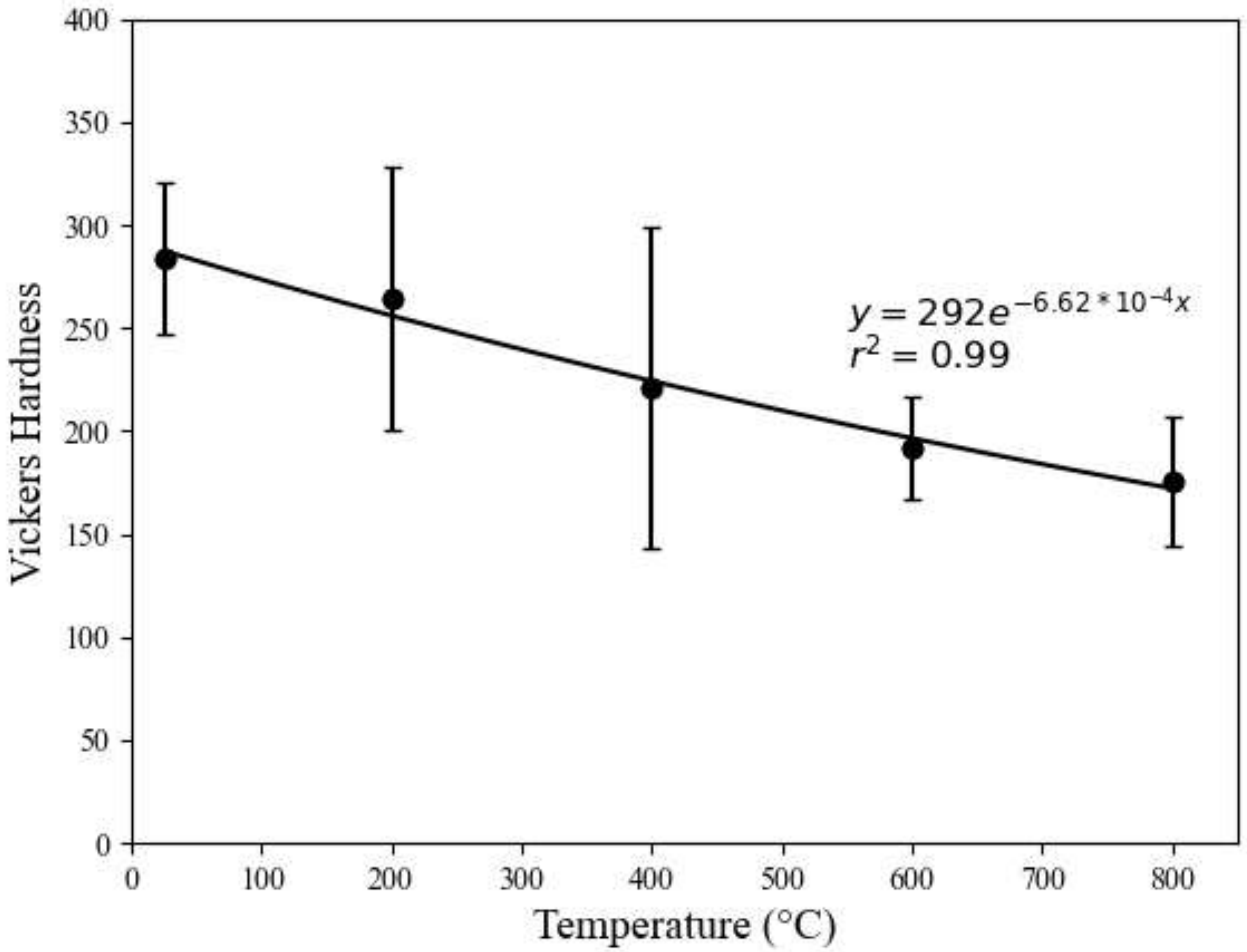
	HSP 40/70	WEDLOAD 430	MAX HD 35
Average Hardness (HV)	912.6 ± 214.8	407.0 ± 68.6	862 ± 199.5
Elastic Modulus (psi)	9.5E6 ± 1.2	3.0E6 ± 0.29	10.9E6 ± 3.5

Particles exhibit reduced hardness and modulus at temperature

HARDNESS FOR CONTAINMENT MATERIALS



SS 316

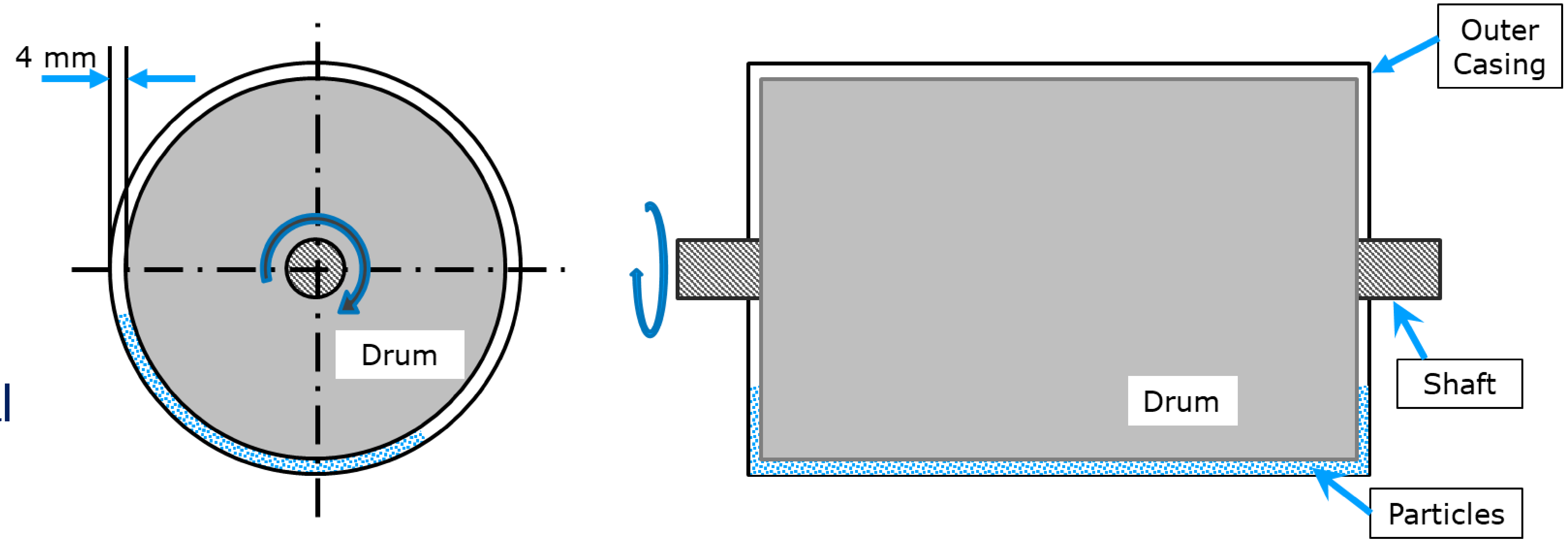


Inconel 740H

PARTICLE ATTRITION TESTING – TEST ONGOING

Testing methodology and setup:

- A steel drum is rotated around the major axis, particles fill gaps between drum and outer wall.
- The current tests are performed at a relative speed of ~3.5 cm/s
- Results are particle size distribution and spectral optical properties changes as a function of time.

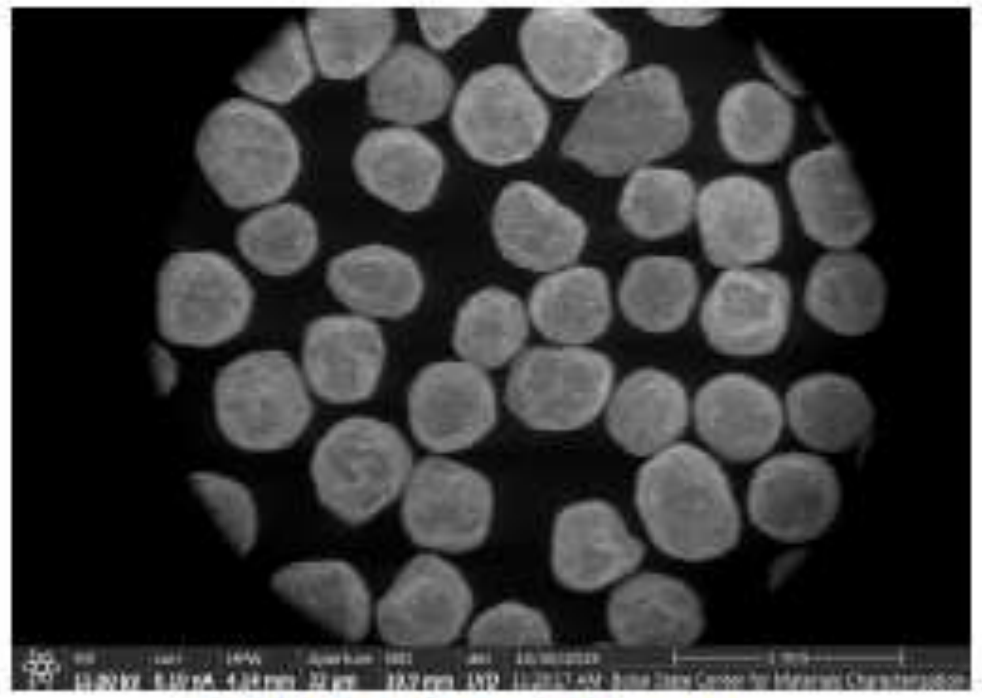


Note: 24 hours of testing was calculated to be equivalent to about 3,900 hours of operation of a 1MW CSP plant.

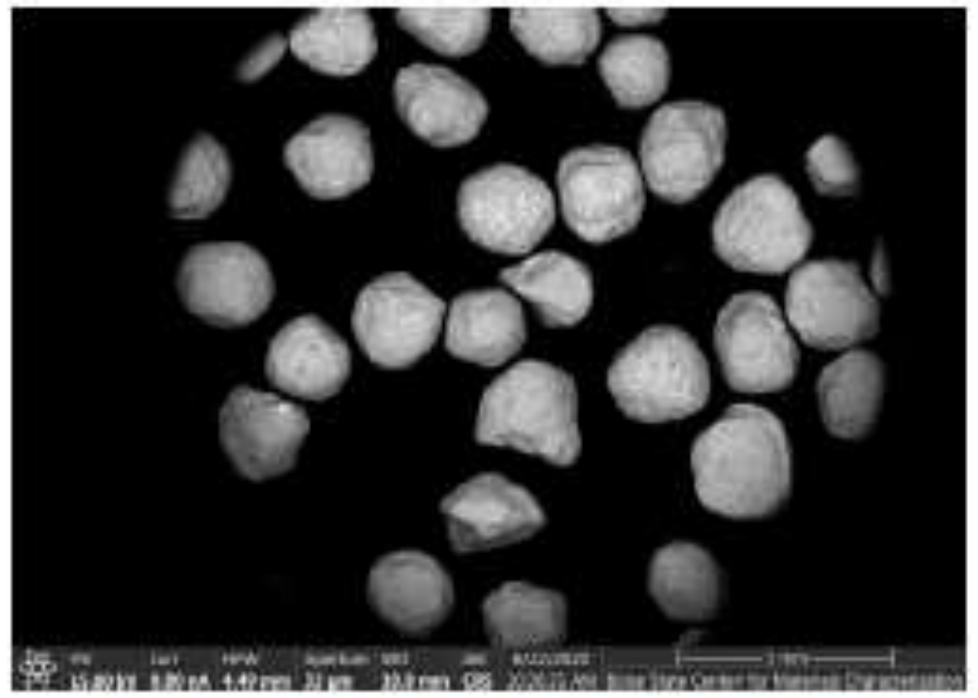
Particle size sampling from impact and abrasion testing reveal no major changes in particle size

CONCLUSIONS AND FUTURE PLANS

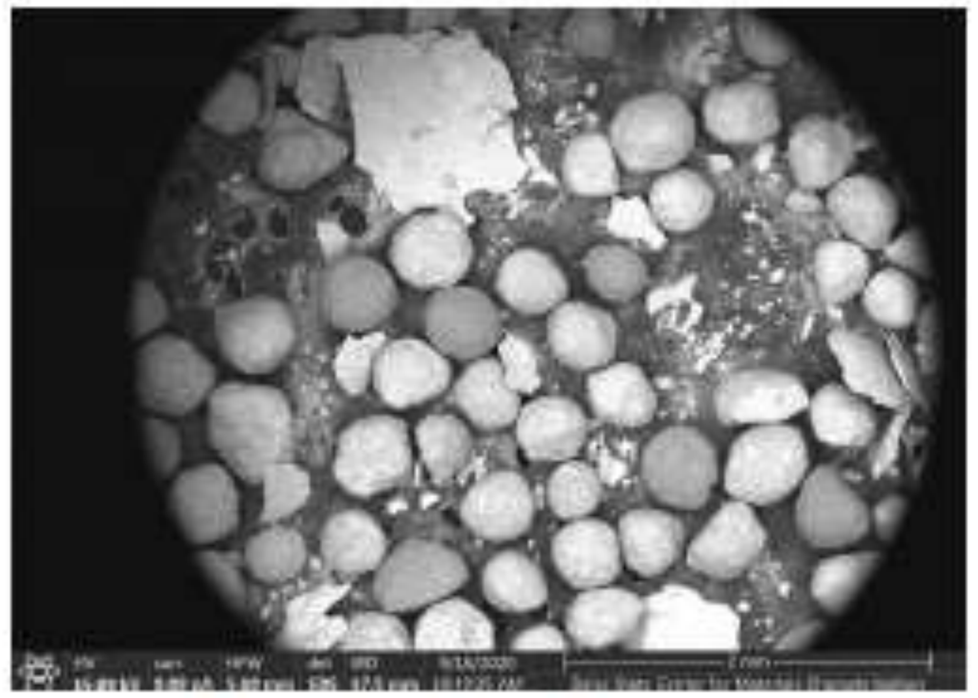
- Decreases in particle solar absorptance up to 6% may be observed from isothermal aging and high flux exposure
- High nickel alloys provide substantially higher erosion resistance at high temperatures relative to conventional and lower cost stainless steels.
- Stainless steel erosion is driven by a highly coupled erosion-oxidation mechanism. Results in substantially increased erosion relative to low temperature and significant generation of oxides “particles”.
- Future work to focus on the development of CSP specific formulations for wear prediction



SEM after 0 hours



SEM after 354 hours at room temperature



SEM after 123 hours at 800°C

ACKNOWLEDGEMENTS

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