IR&D Studies of Light Weight Ablator for Future Reentry Capsule Heatshield

IHI AEROSPACE Co., Ltd.

Kenichi HIRAI

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JAXA

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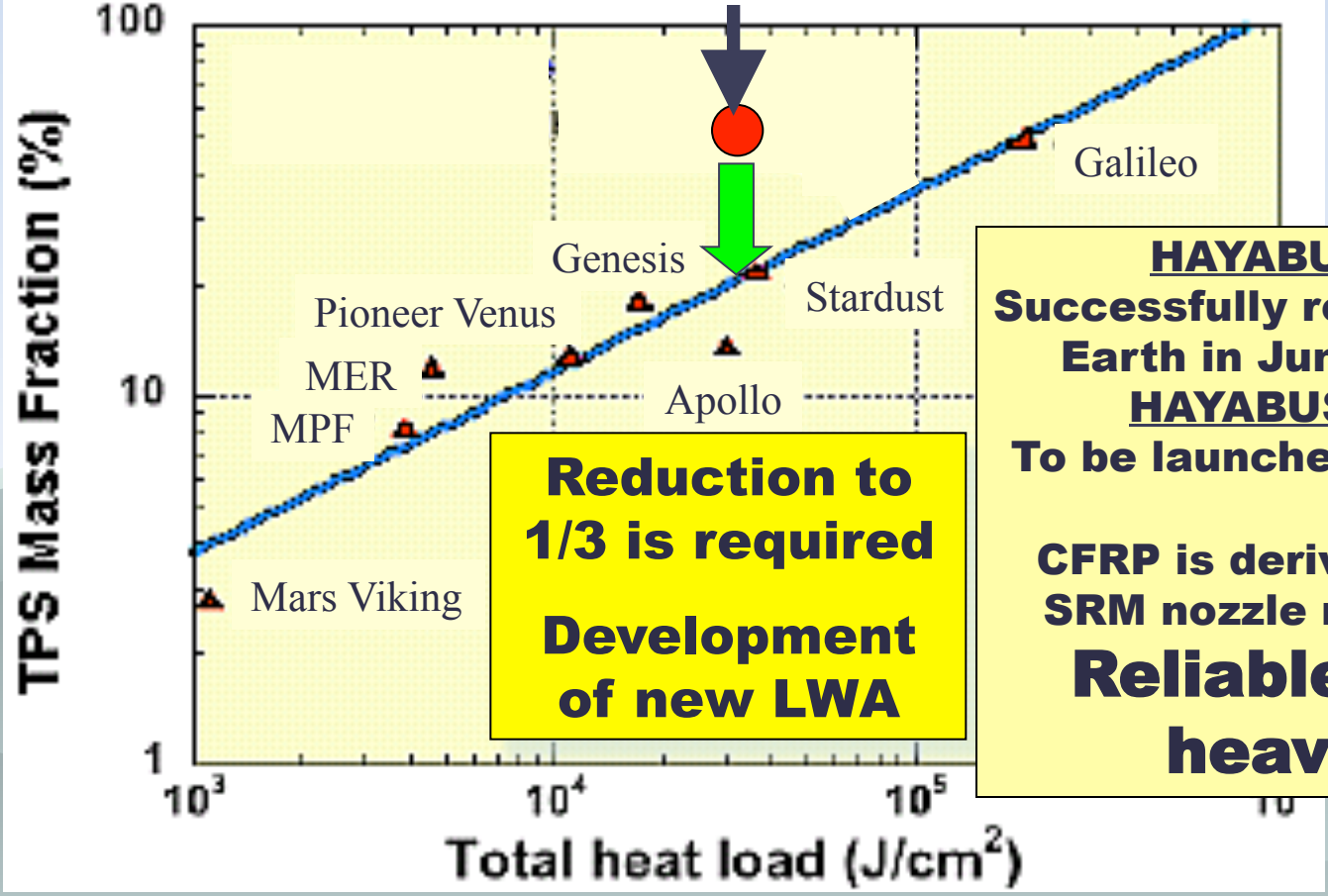
1.Objective of this study

HAYABUSA (300MJ/m2,53%)



Reduction to 1/3 is required

Development of new LWA

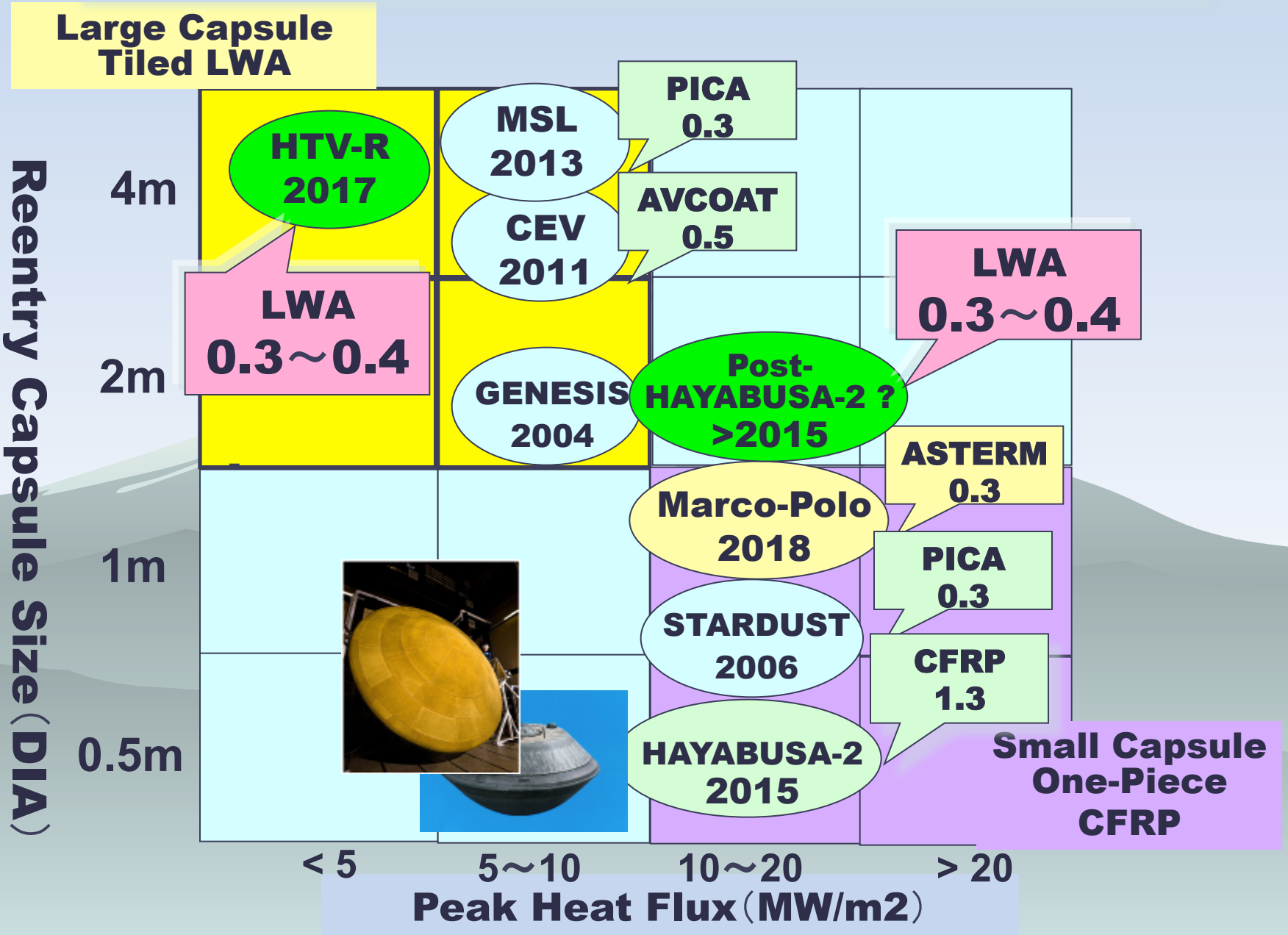
HAYABUSA
Successfully returned to Earth in June 2010
HAYABUSA-2
To be launched in 2014

CFRP is derived from SRM nozzle material

Reliable but heavy!

【Source】 Laub & Venkatapathy：”Thermal Protection System Technology Facility Needs for Demanding Future Planetary Missions”, International Workshop on Planetary Probe Atmospheric Entry and Descent Trajectory Analysis and Science, (2003)

The Possible Future Directions



2. Our Strategy(1/2)

Carbon Preform（0.15<ρ<0.3）

CBCF (Carbon Bonded Carbon Fiber)

X ●FIBERFORM

●CALCARB

RVC (Reticulated Vitreous Carbon)

●Grafoam

●JFOAM

Resin Impregnation

Phenolic

SC-1008

Polyimide

JAXA Original

LWA

(0.25<ρ<0.4)

1. Issues of Imported preforms

- **Expensive**
- **Long Delivery Time (EL)**
- **Sustainability**

2.Persuit of unique LWA

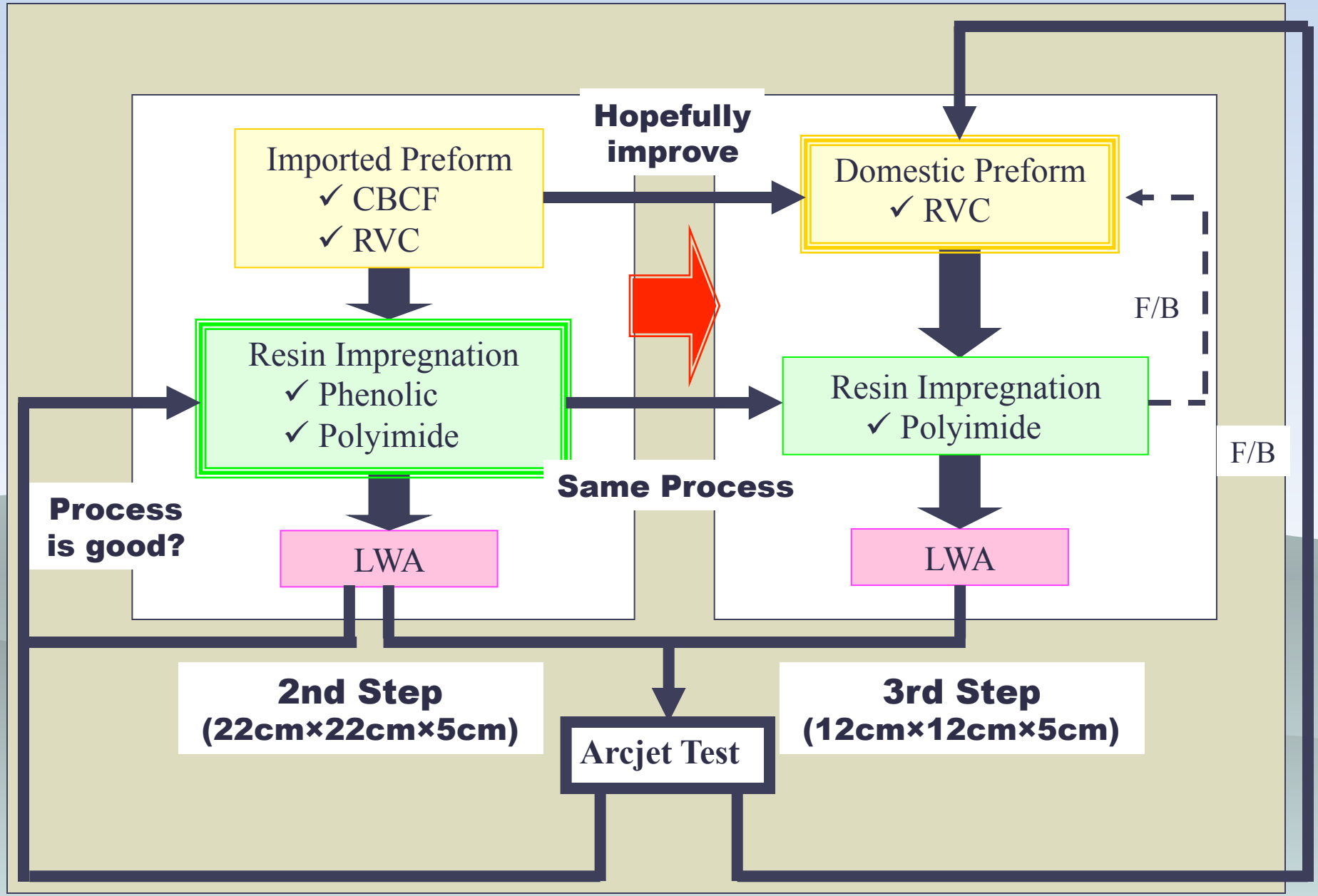
- **Unique Preforms(RVC)**

I don't want to imitate PICA

3. Preform microstructure Tailoring for successful JAXA PI impregnation

Development of Domestic RVC JFOAM

2. Our Strategy(2/2)

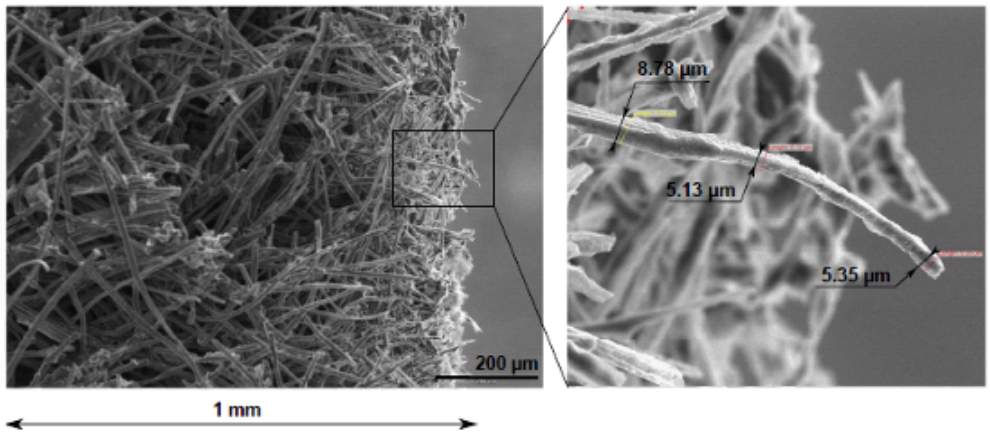


3. Overview (1/3) candidate carbon preforms

Carbon Preform（ρ<0.2）

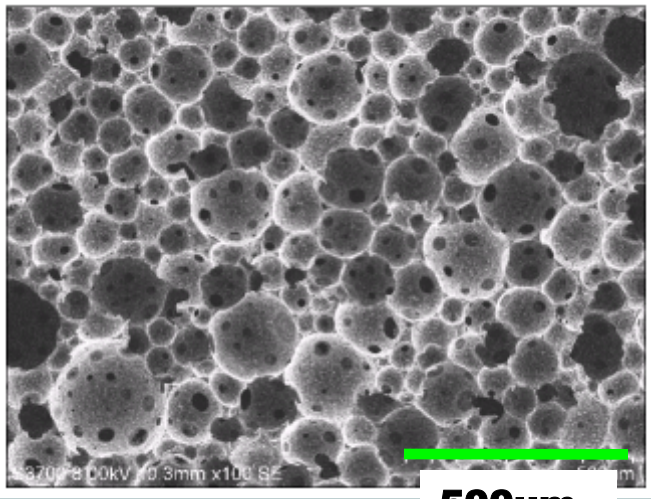
CBCF
Carbon Bonded Carbon Fiber

Chop/Milled Fibers Connected by Phenolic Resin



【Source】: Lachaud et al : "Validation of a Volume-Averaged Fiber-Scale Model for the Oxidation of a Carbon-Fiber Preform", AIAA 42nd Thermophysics Conf 2011 (Extended Abstract).

RVC
Reticulated Vitreous Carbon



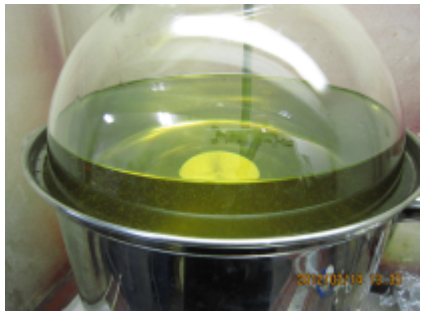
Grafoam（ρ=0.16）SEM photo

3. Overview (2/3)
JAXA Polyimide Resin Impregnation

s-BPDA / BAFL / DMAc Solution

Stir

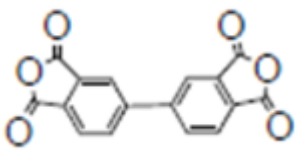
60-80℃



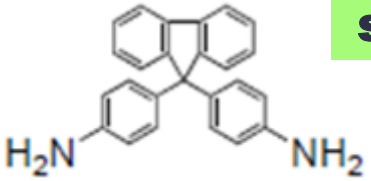
Gellant

RT

Resin Solution



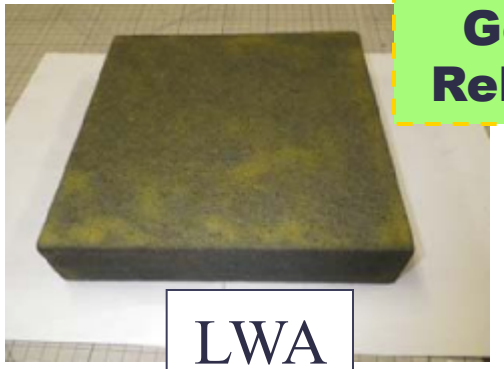
s-BPDA



BAFL

sufficiently long gel time (several Hrs)

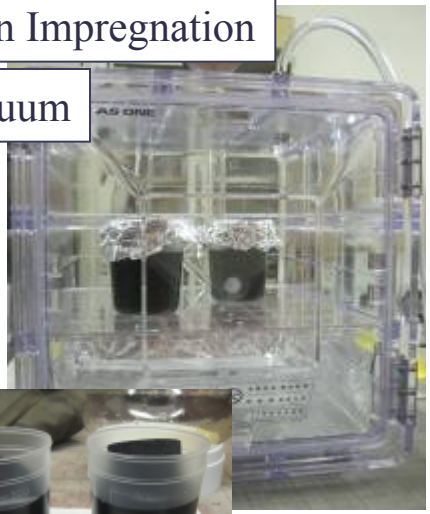
Gelation at RT!
Reliable Process!



LWA

Resin Impregnation

vacuum



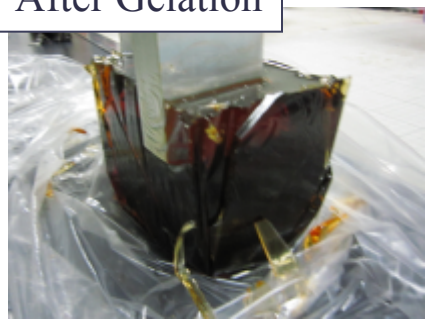
Cure

240℃,air

Remove Solvent

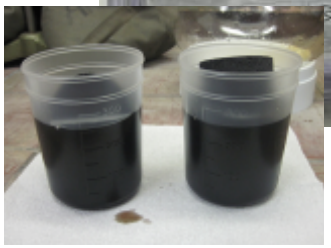
50-200℃
vacuum

After Gelation



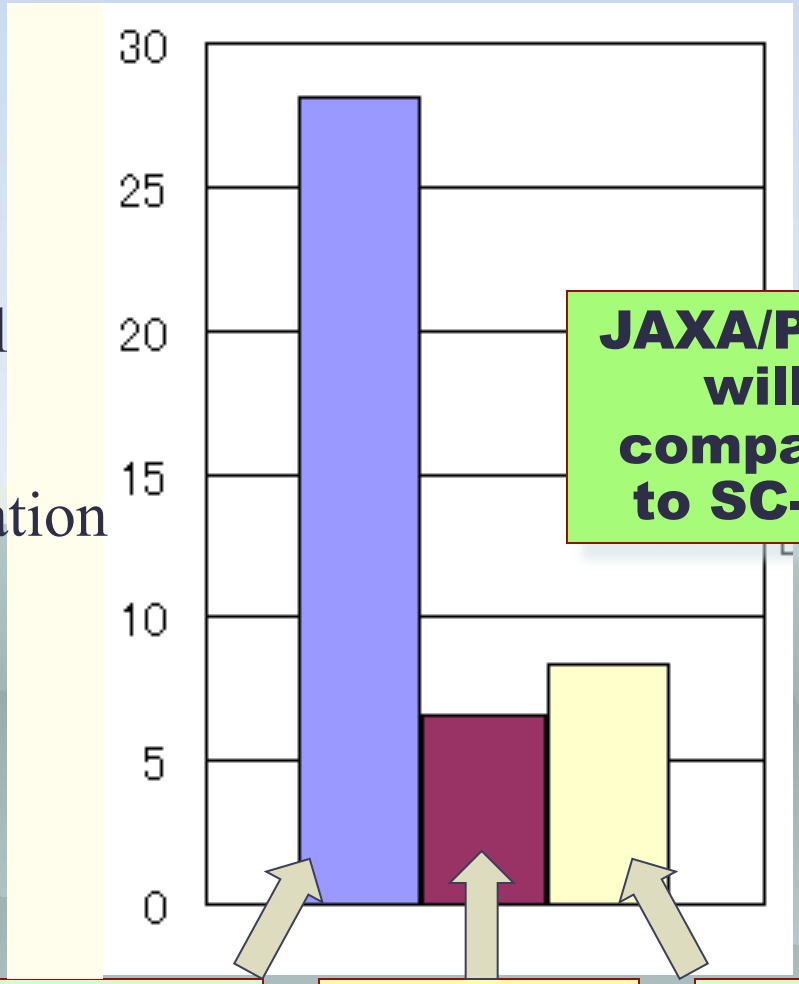
Gelation

RT, air



3. Overview (3/3)
JAXA Polyimide Raw Material Cost

Raw Material Cost for □25cm×5cm Panel Fabrication (10,000Yen)



JAXA/PI Price will be comparative to SC-1008!

JAXA/PI
In the Past

JAXA/PI
Expected in 2012?

Phenolic
SC-1008

4.Validation of Resin Impregnation Process Imported Preform based LWA Fabrication(1/6)

Candidate Carbon Preforms

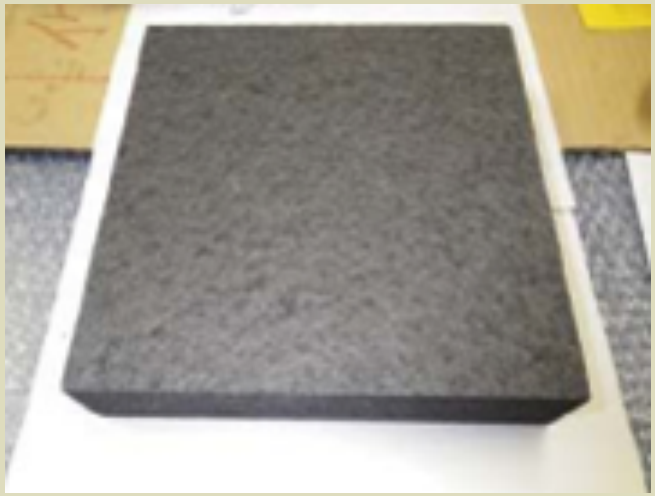
	Bulk Density [g/cm^3]
Imported RVC (Grafoam FPA-10)	0.18
Imported CBCF (CALCARB 18-2000)	0.19
Domestic RVC (JFOAM-1, -2, -3)	0.15, 0.21, 0.28
Domestic CBCF	NA

Fabrication Matrix of LWA

	Polyimide Resin	Phenolic Resin
Imported RVC (Grafoam FPA-10)	NA	○
Imported CBCF (CALCARB 18-2000)	○	○
Domestic RVC (JFOAM-1, -2, -3)	○	○
Domestic CBCF	NA	NA

RVC : Reticulated Vitreous Carbon
CBCF : Carbon Bonded Carbon Fiber
LWA : Low Weight Ablator

4.Validation of Resin Impregnation Process Imported Preform based LWA Fabrication(2/6)

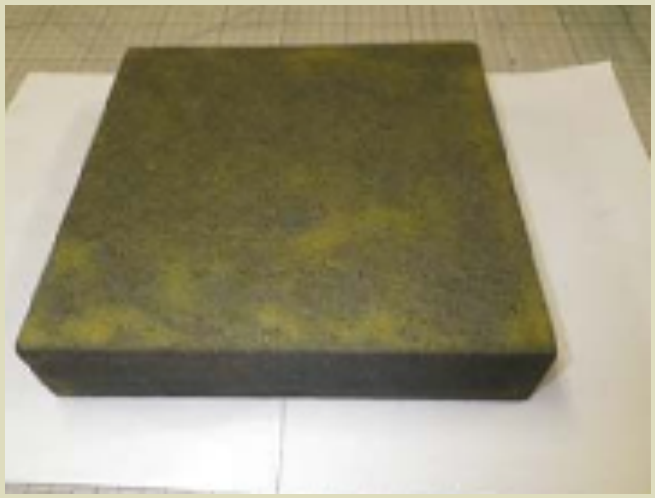


CBCF/Preform

Size : 22cm×22cm×5cm

Weight : 473.4g

Bulk Density : 0.196g/cm^3



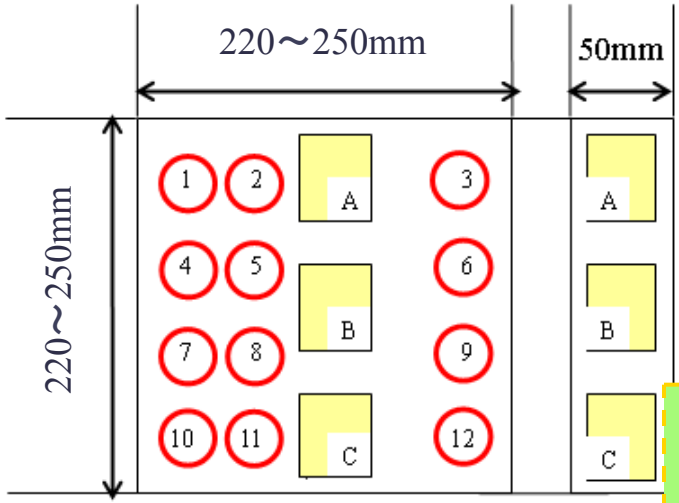
CBCF/PI LWA

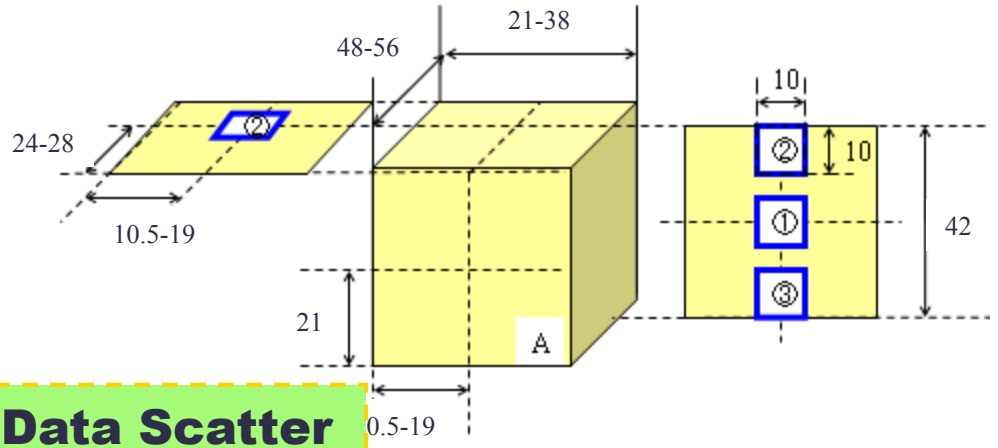
Size : 21.98×21.99×4.65cm

Weight : 799.7g

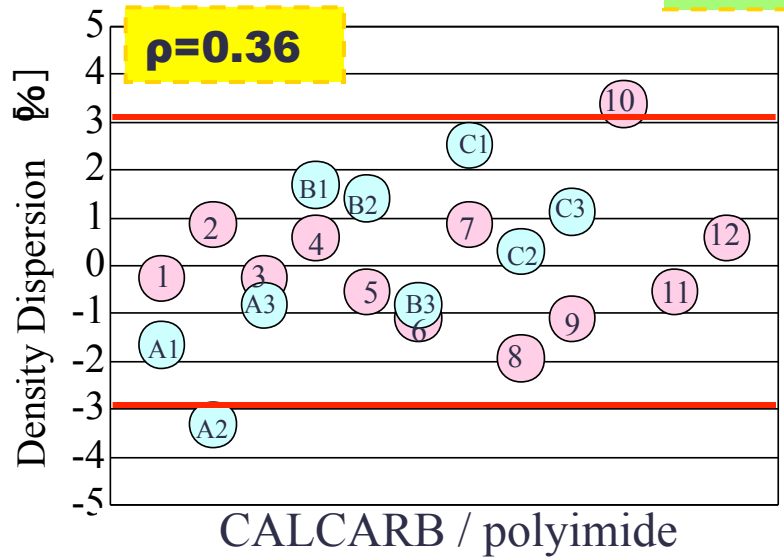
Bulk Density : 0.356g/cm^3

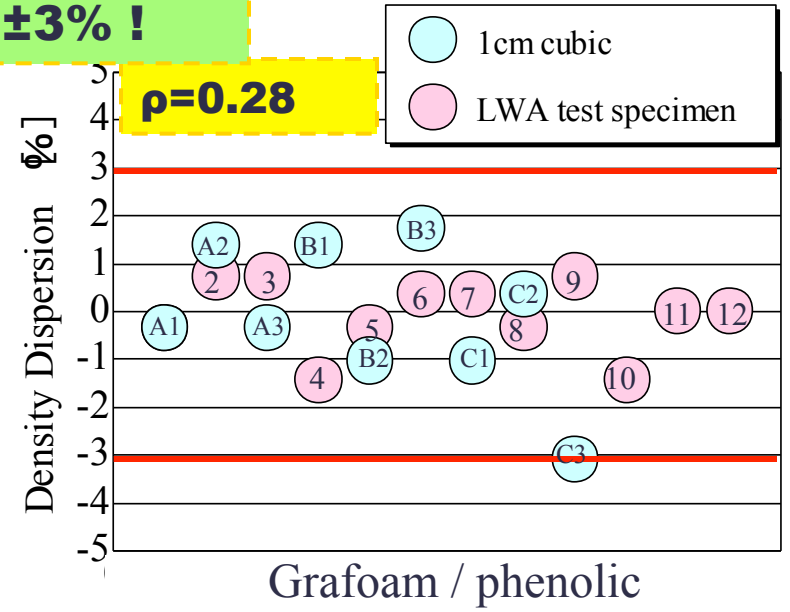
4.Validation of Resin Impregnation Process Imported Preform based LWA Fabrication(3/6)





Data Scatter < ±3% !





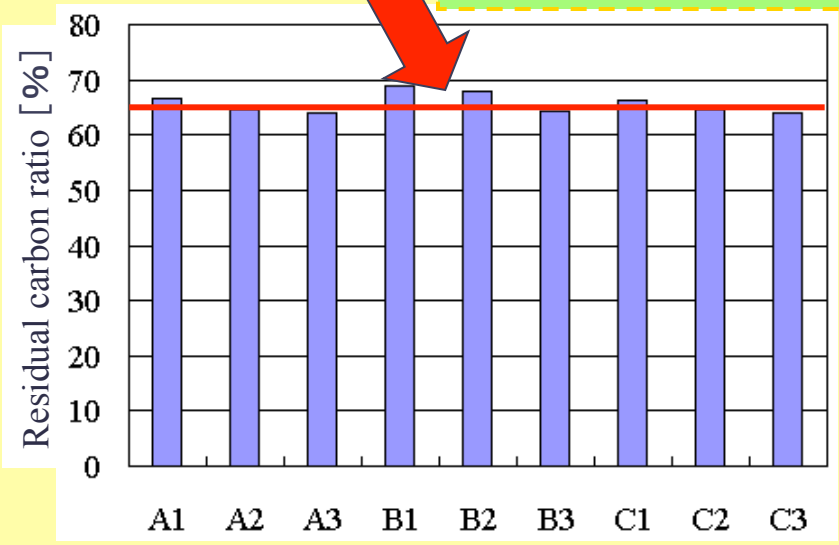
Validation of Resin Impregnation Process Imported Preform based LWA Fabrication(4/6)

Residual carbon ratio [%] within impregnated "resin +solvent"

$$= \frac{W_{final} - W_{preform}}{W_{initial} - W_{preform}} = \frac{Charred\ \ Resin}{Resin + Solvent}$$

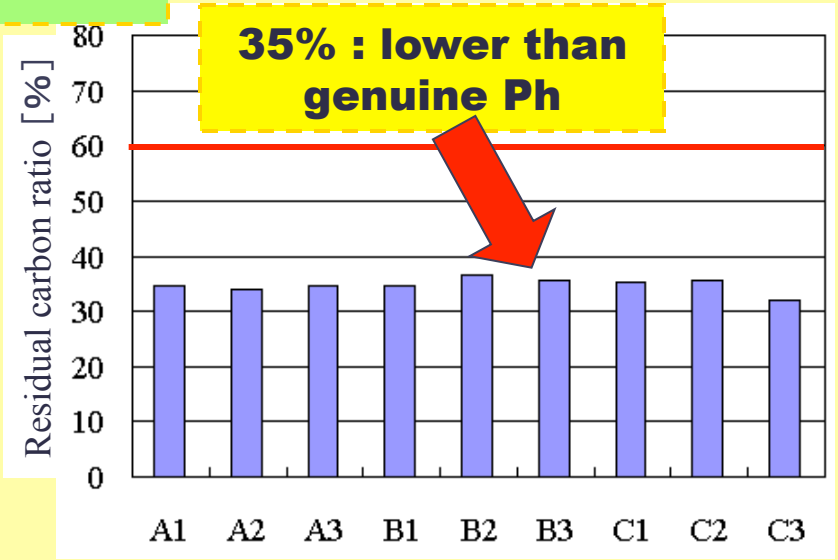
65% : Same as genuine PI

Data Scatter is small, so resin impregnation process is judged reliable



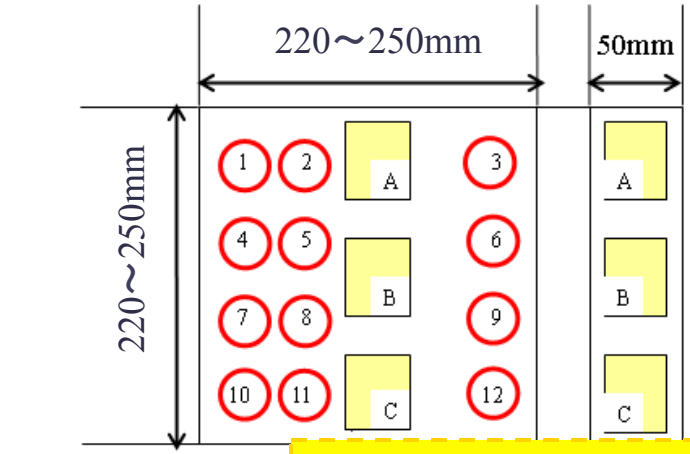
CALCARB / polyimide

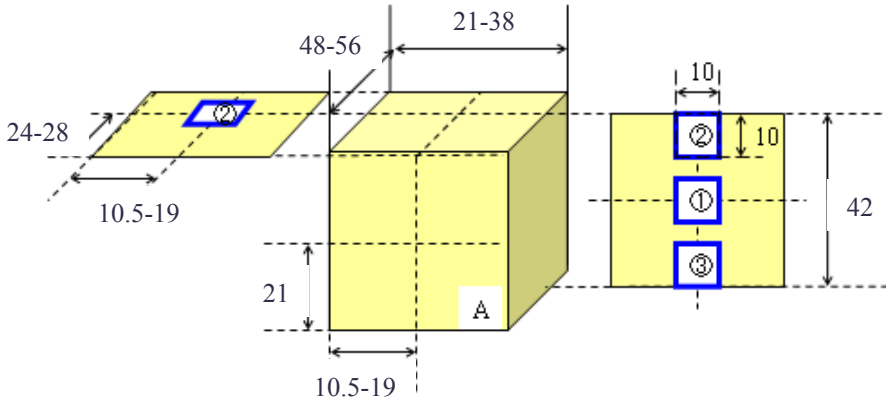
35% : lower than genuine Ph

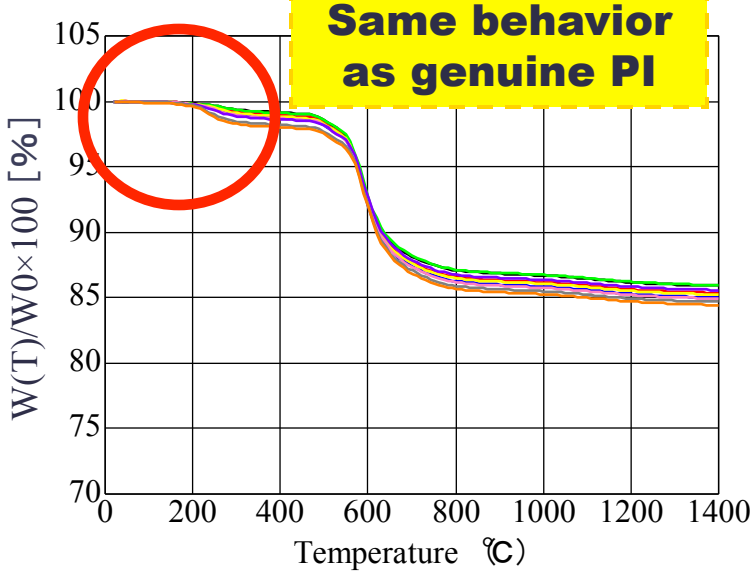


Grafoam / phenolic

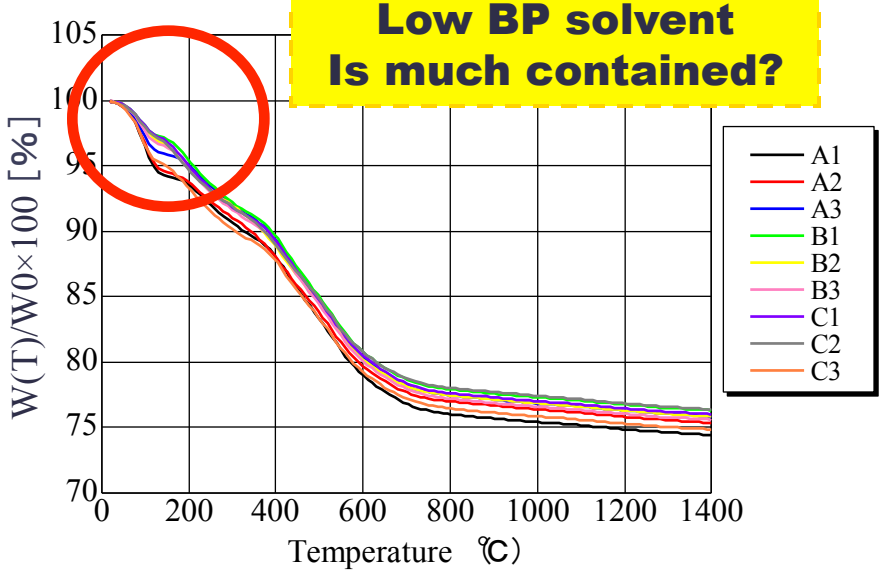
4.Validation of Resin Impregnation Process Imported Preform based LWA Fabrication(5/6)





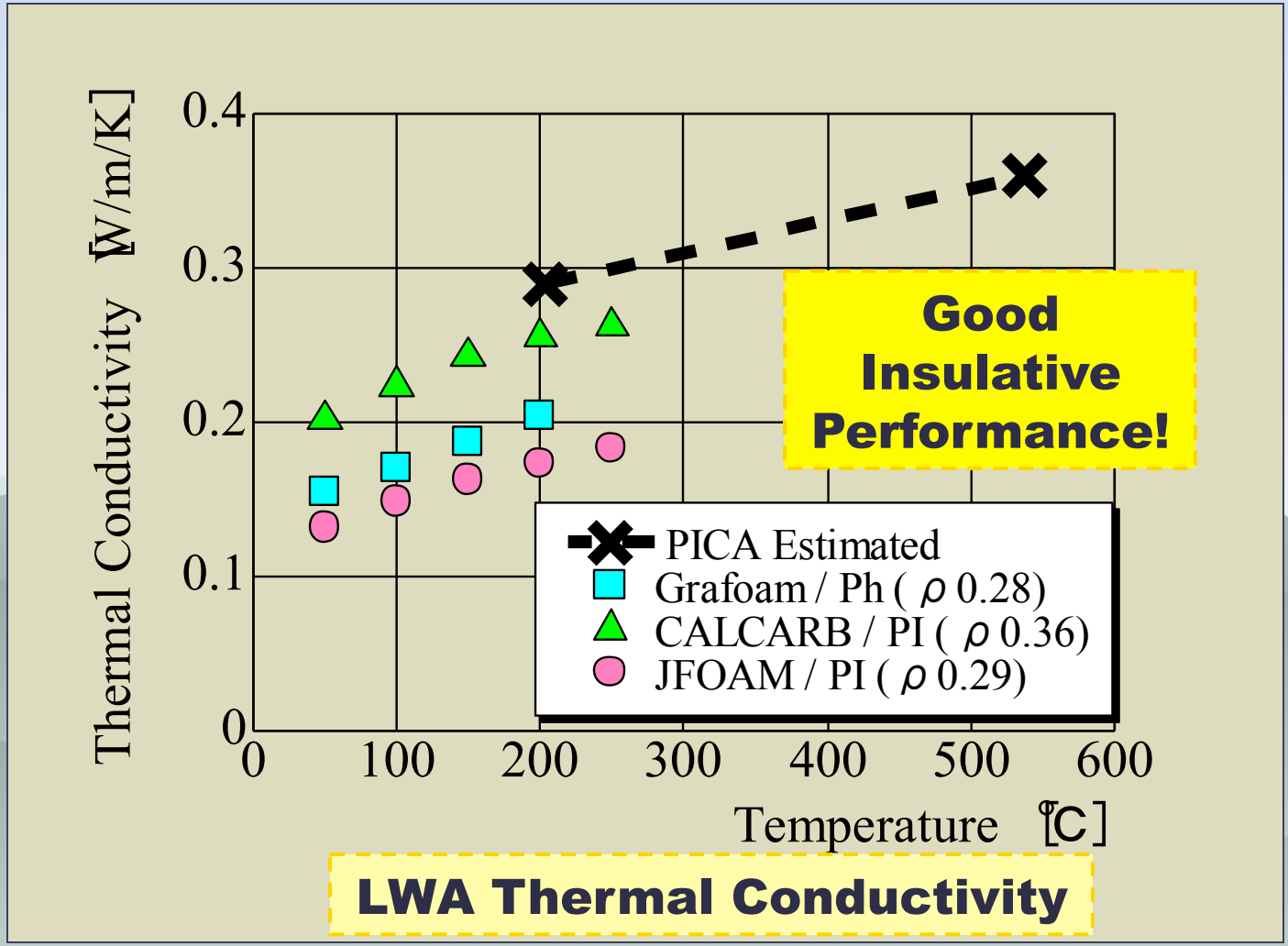


CALCARB / polyimide



Grafoam / phenolic

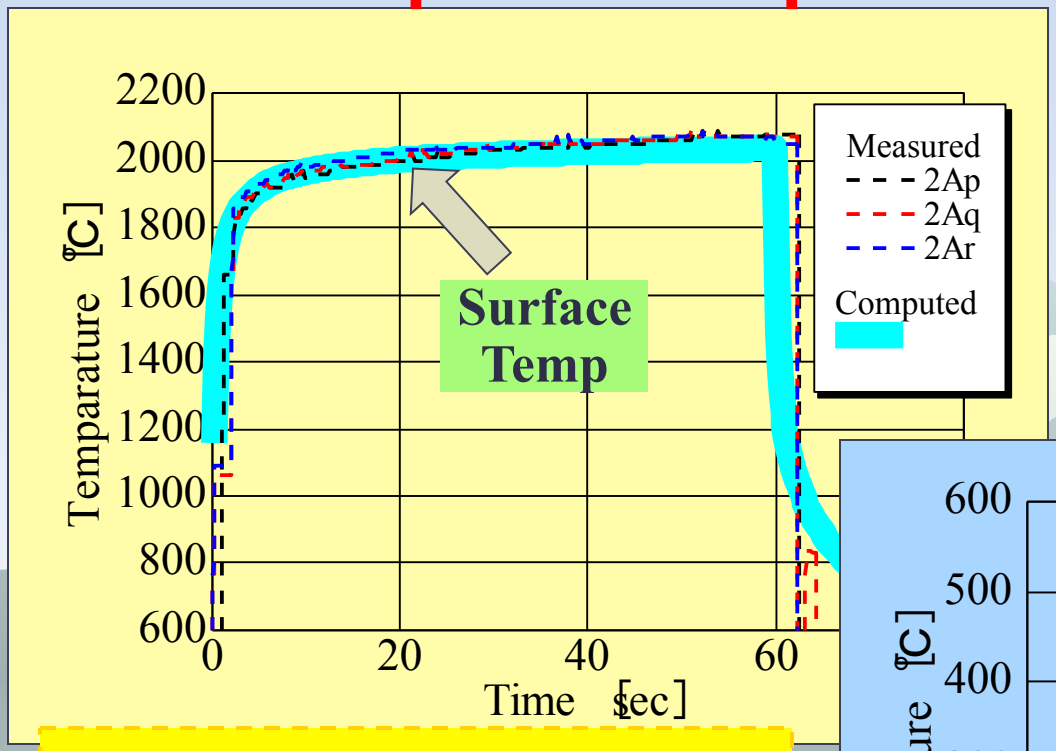
4.Validation of Resin Impregnation Process Imported Preform based LWA Fabrication(6/6)



【Source】 Tran et al：" Phenolic Impregnated Carbon Ablators (PICA) as Thermal Protection Systems for Discovery Missions, NASA TM 110440, (1997)

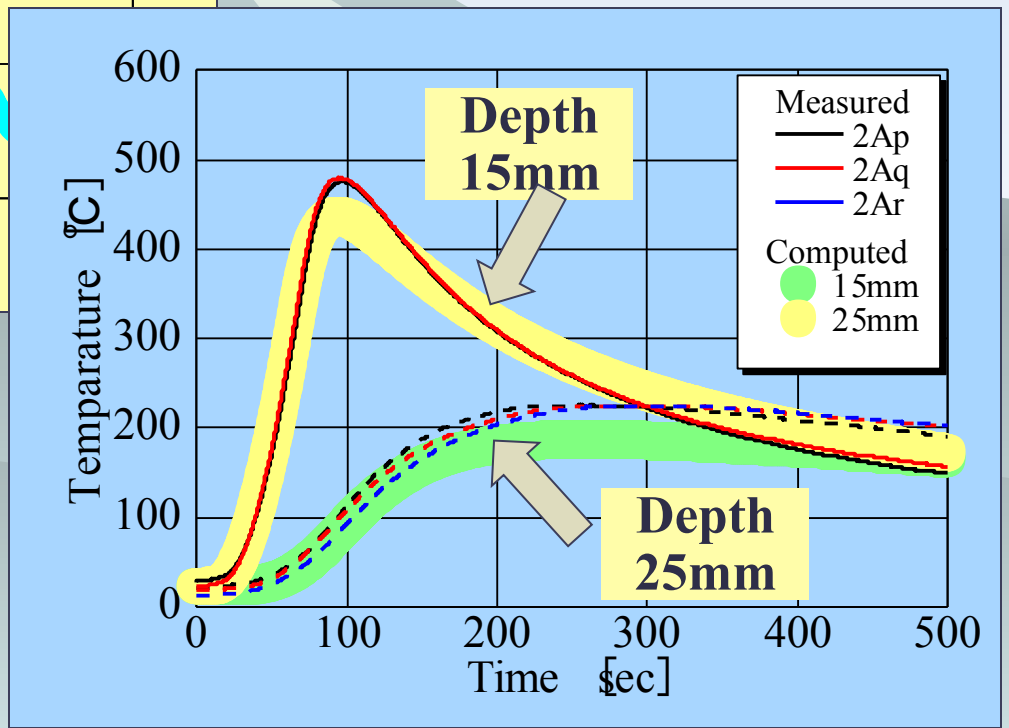
4.Validation of Resin Impregnation Process Imported Preform based LWA Fabrication(7/7)

Temperature Response of CALCARB/PI LWA

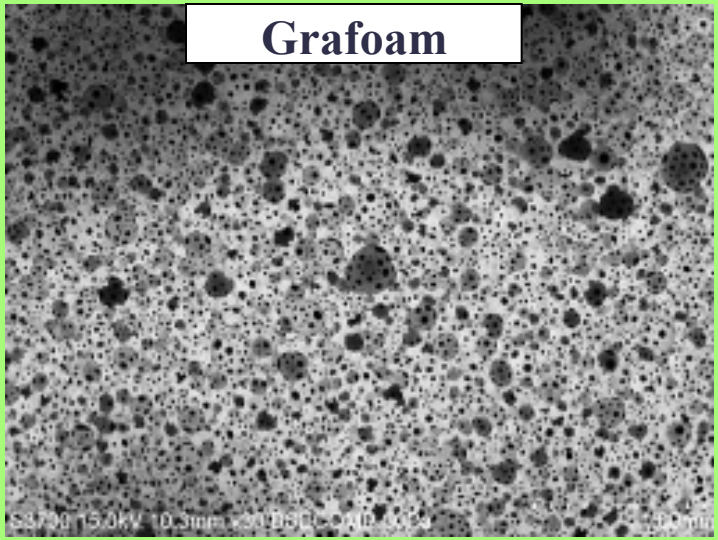


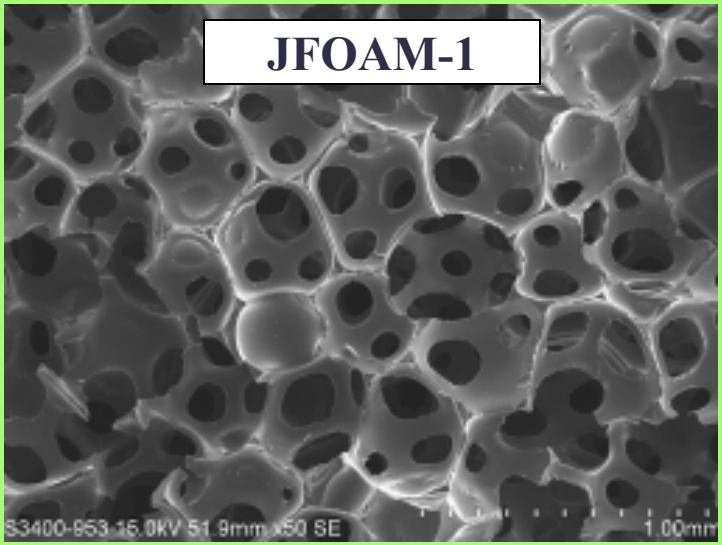
Repeatability of LWA Temperature responses is fairly good!

Temperature responses of LWA's are well predicted by the present tentative ablation calculation!



5.Domenstic RVC based LWA Development
Development of JFOAM(1/5)





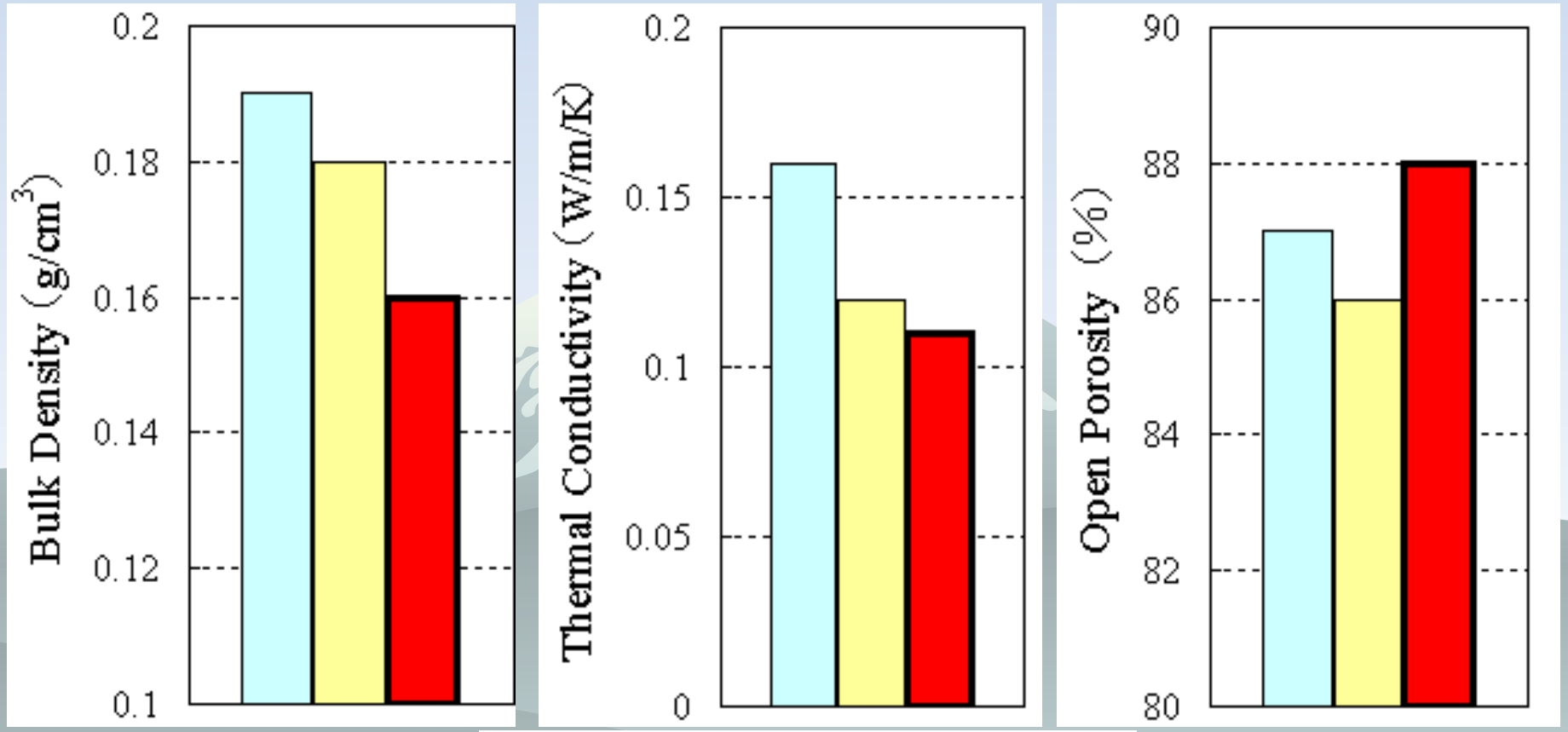
Current microstructure of JFOAM is much coarser than existing imported CBCF/RVC!

SEM Photographs of various kinds of lightweight carbon preforms
(Our RVC’s are designated as JFOAM-1(density=0.16g/cm3))

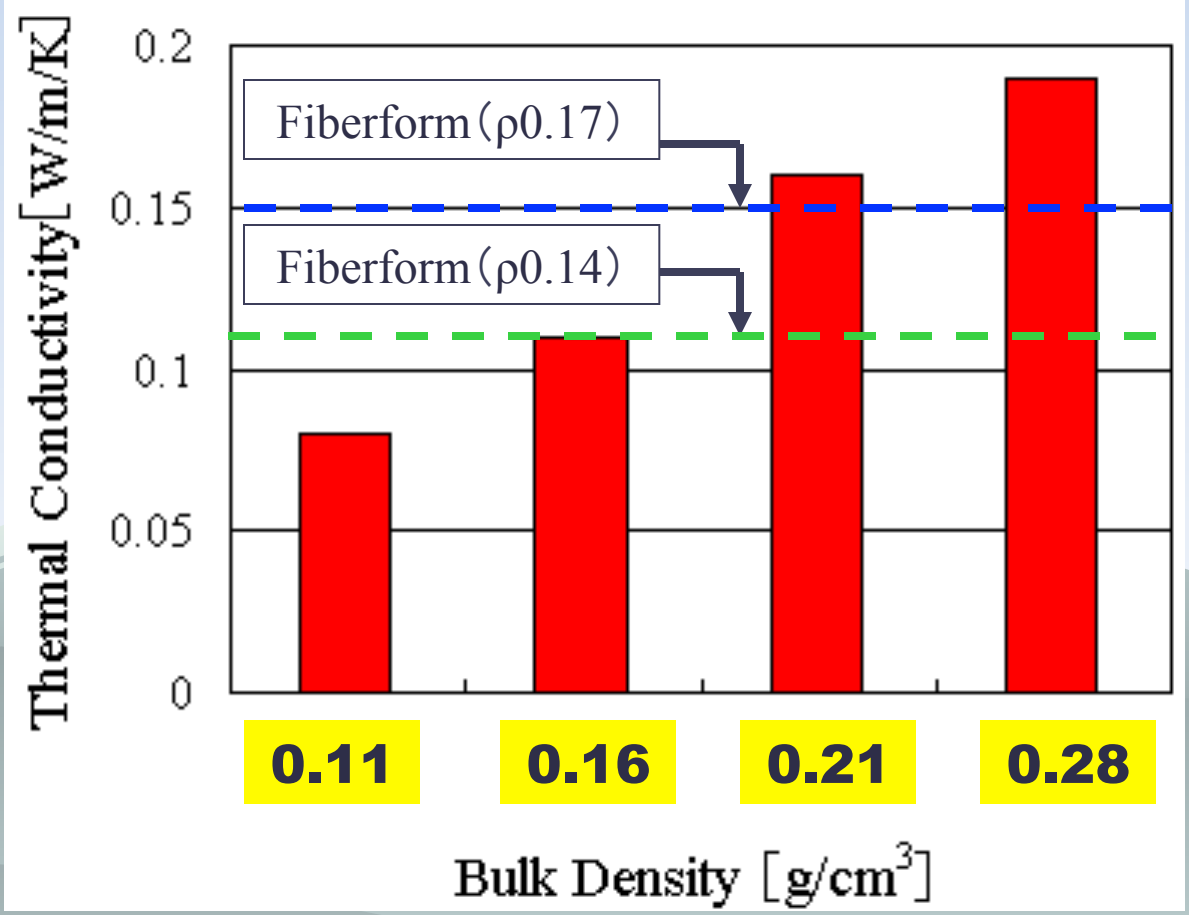
5.Domenstic RVC based LWA Development

Development of JFOAM(1/5)

Similar Properties as Existing Carbon Preforms



5.Domenstic RVC based LWA Development
Development of JFOAM(1/5)



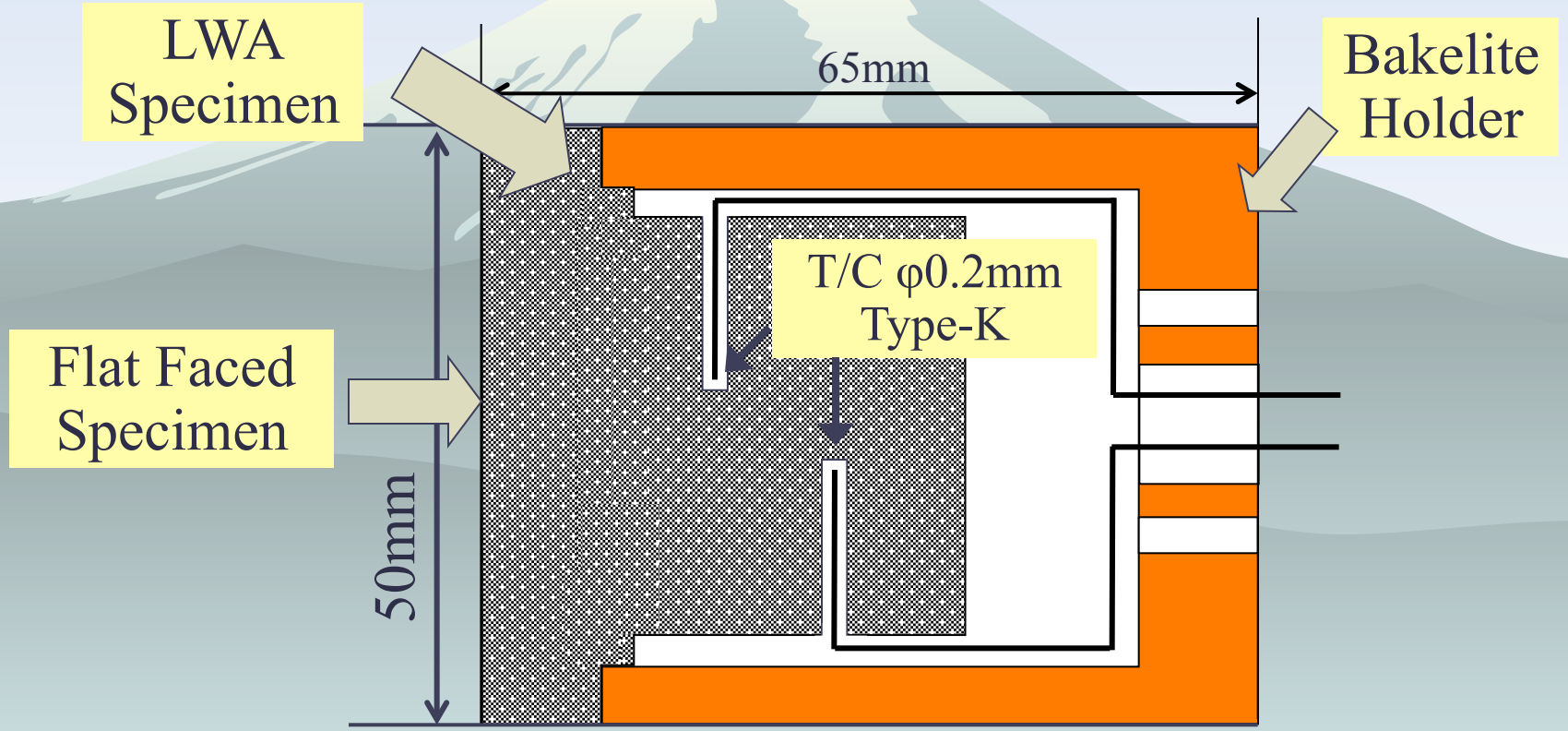
JFOAM bulk density vs thermal conductivity

【Source】 Tran et al：" Phenolic Impregnated Carbon Ablators (PICA) as Thermal Protection Systems for Discovery Missions, NASA TM 110440, (1997)

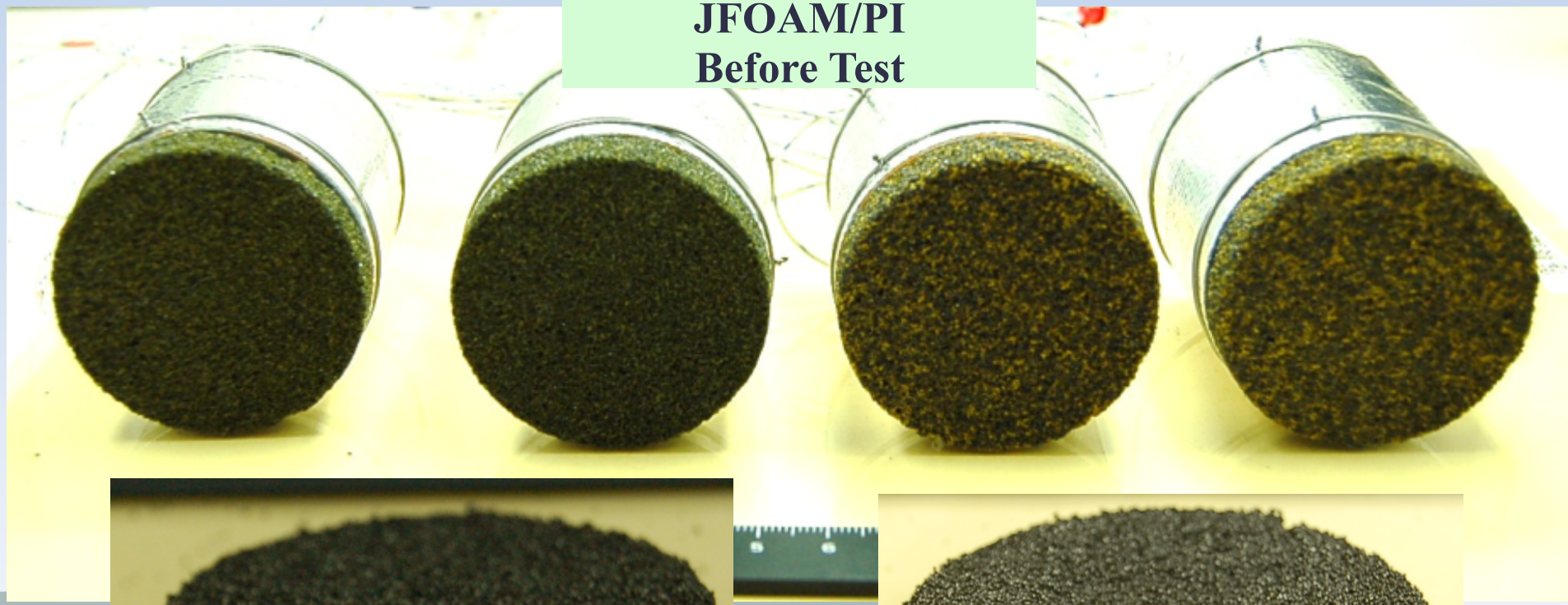
5.Arcjet Tests of LWA(1/6)

Test Conditions of Arcjet Experiments

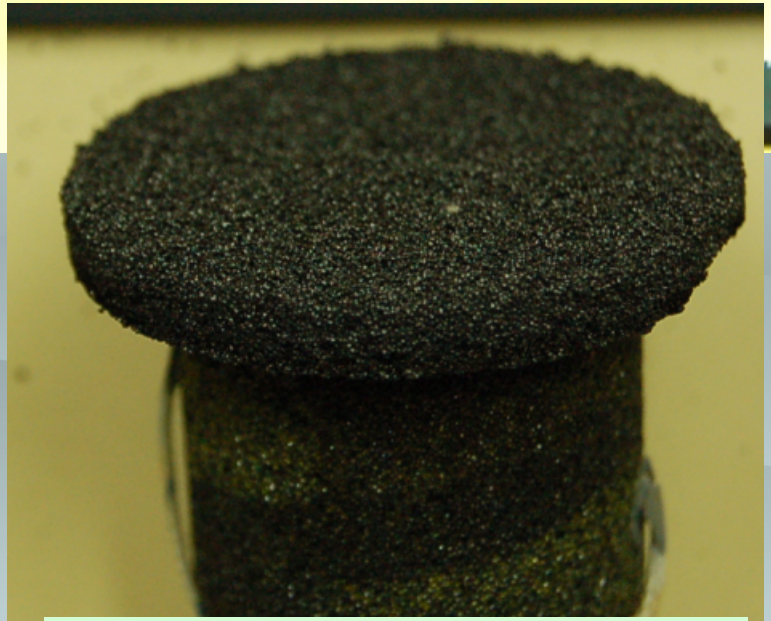
	CW Heat Flux [MW/m^2]	Impact Pressure [KPa]	Heating Time [s]
#1	**1.8**	4.4	30
#2	**3.4**	13.7	30
#3	**6.0**	19.6	30



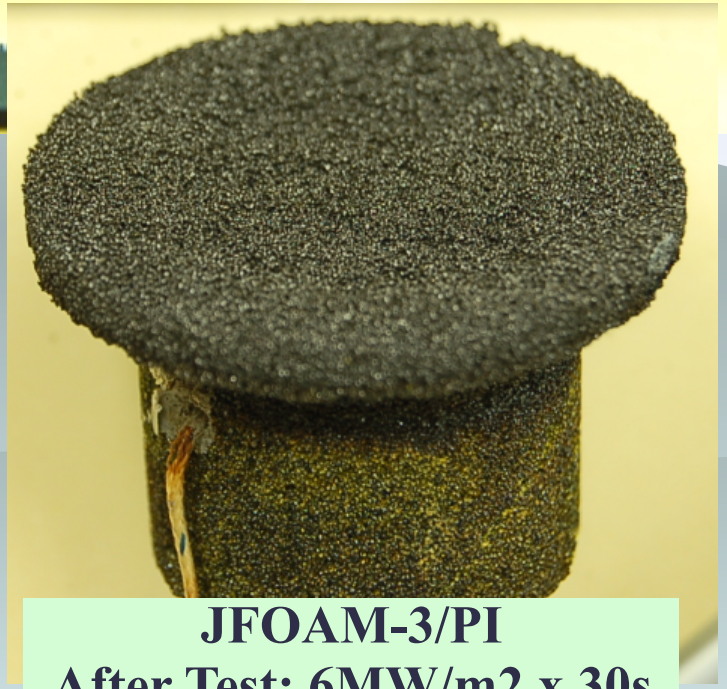
5.Arcjet Tests of LWA(2/6)



JFOAM/PI
Before Test

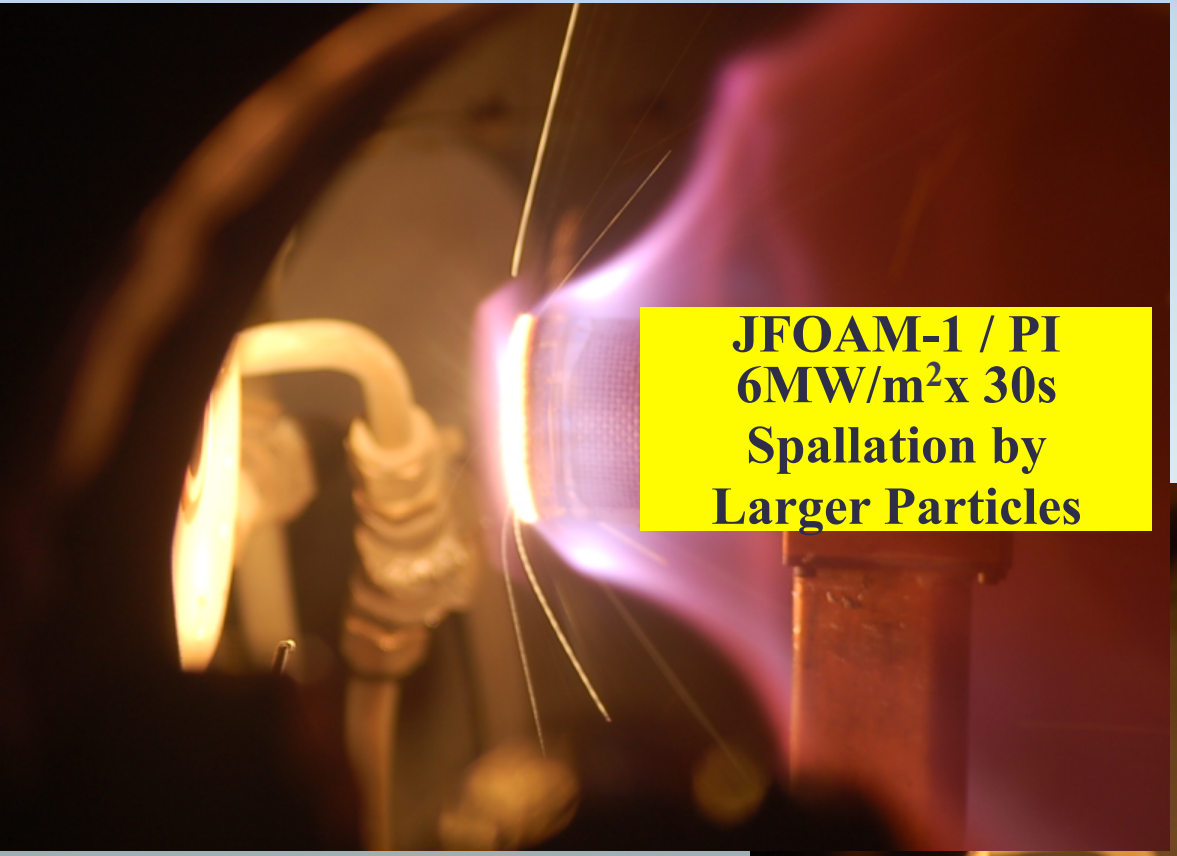


JFOAM-3/PI
After Test: 3.4MW/m2 x 30s



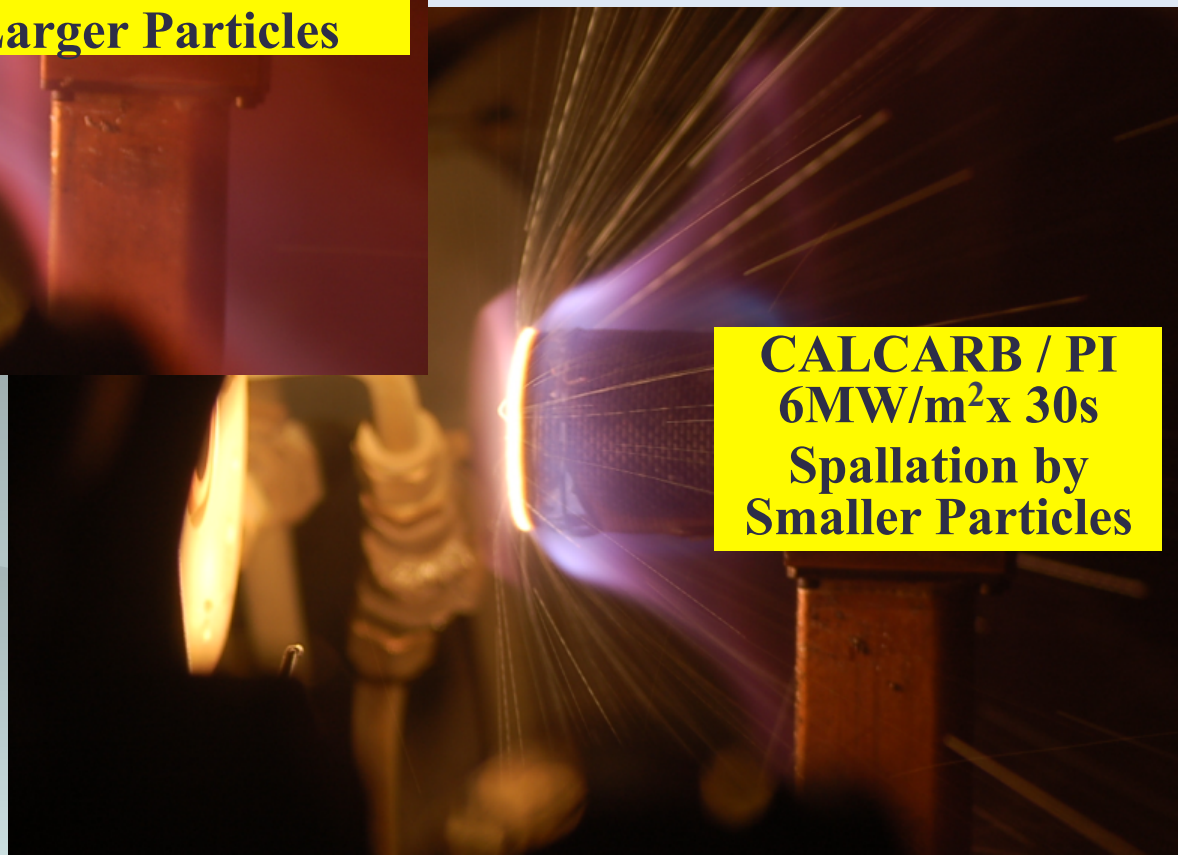
JFOAM-3/PI
After Test: 6MW/m2 x 30s

5.Arcjet Tests of LWA(3/6)



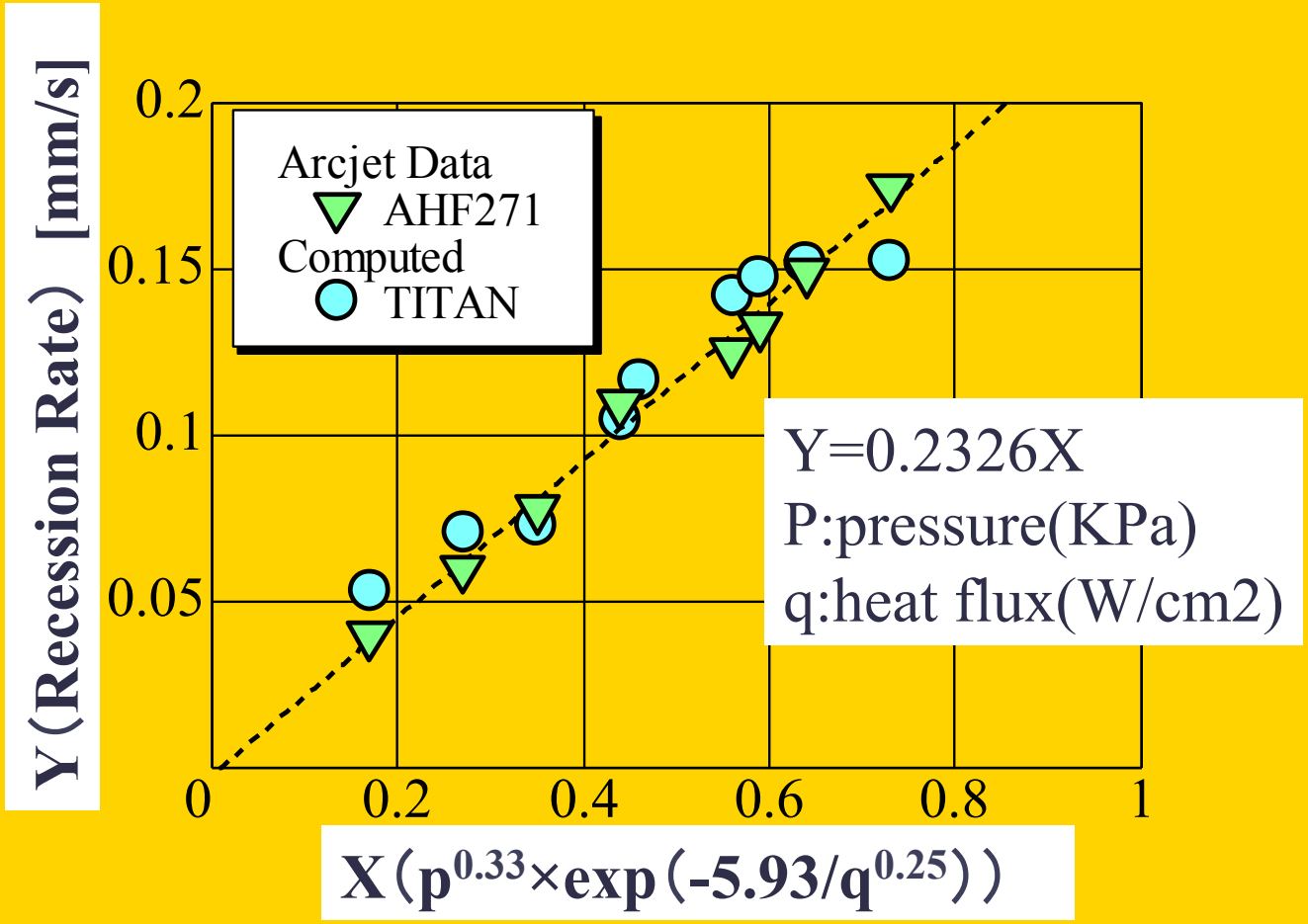
JFOAM-1 / PI
6MW/m^{2}x 30s
Spallation by
Larger Particles

JAXA/ISAS
Arcjet Tests Photographs
By Degital Camera



CALCARB / PI
6MW/m^{2}x 30s
Spallation by
Smaller Particles

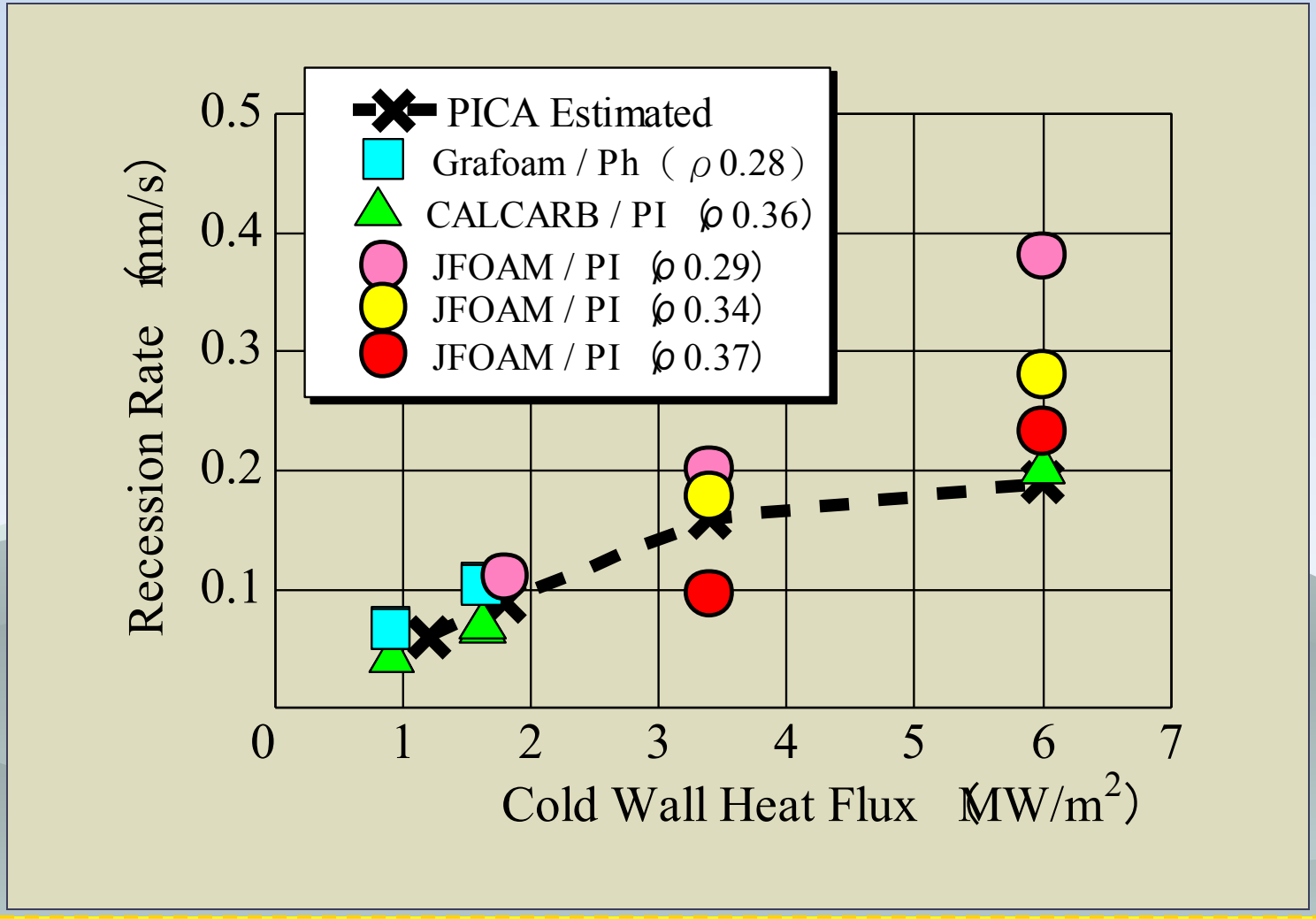
5.Arcjet Tests of LWA(4/6)
PICA Recession Characteristics



Empirical Expression for Surface Recession Rate of PICA

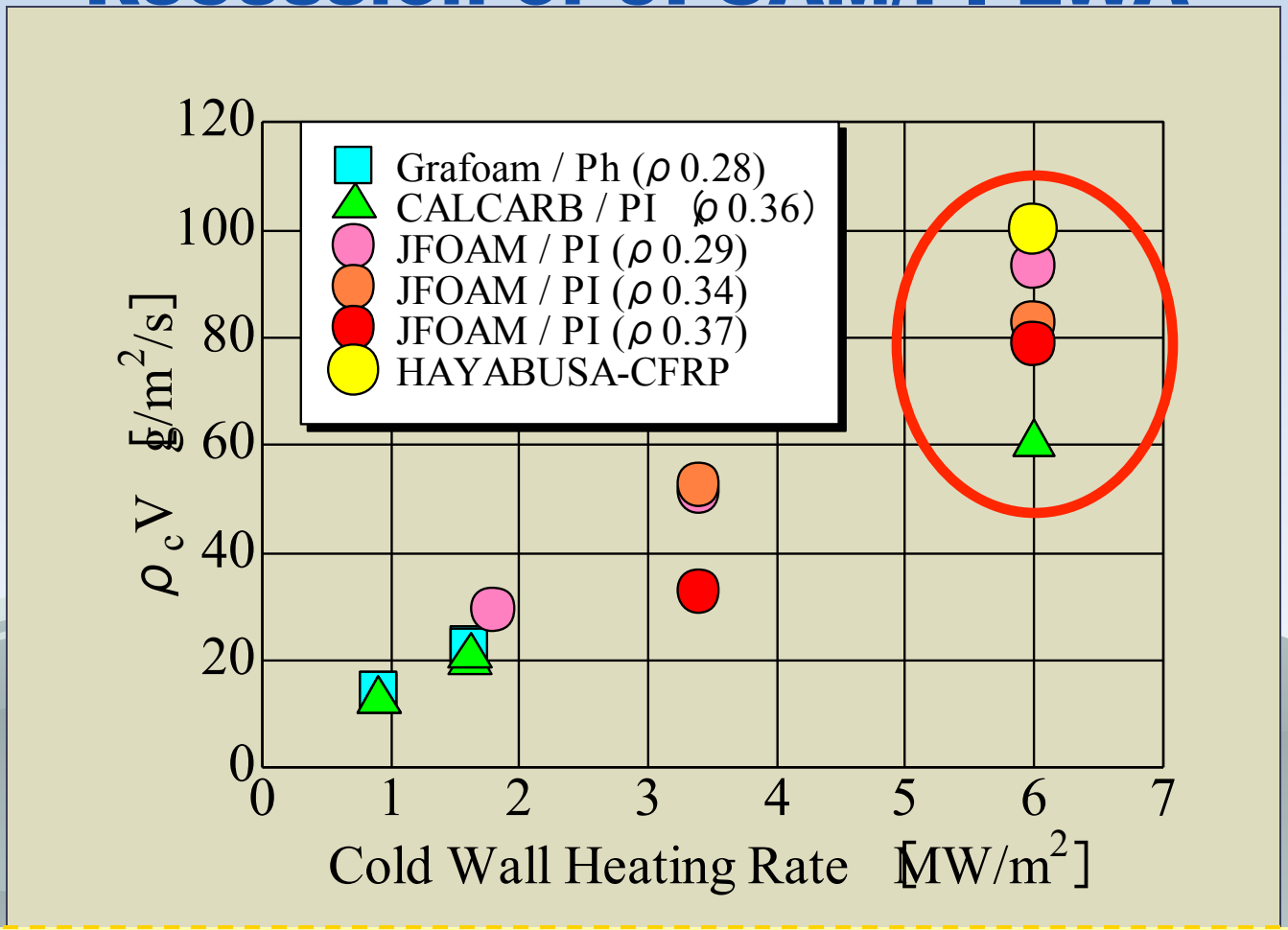
Hwang, et al., Race Towards Launch: Qualifying the Mars Science Laboratory Heatshield in under Ten Months, ICCE-17(17th International Conference on Composite/ NANO Engineering, (2009)

5.Arcjet Tests of LWA(5/6) Recession of JFOAM/PI LWA



Our LWA's surface recession rates are comparative to PICA, when the density values are around 0.36!

5.Arcjet Tests of LWA(6/6) Recession of JFOAM/PI LWA

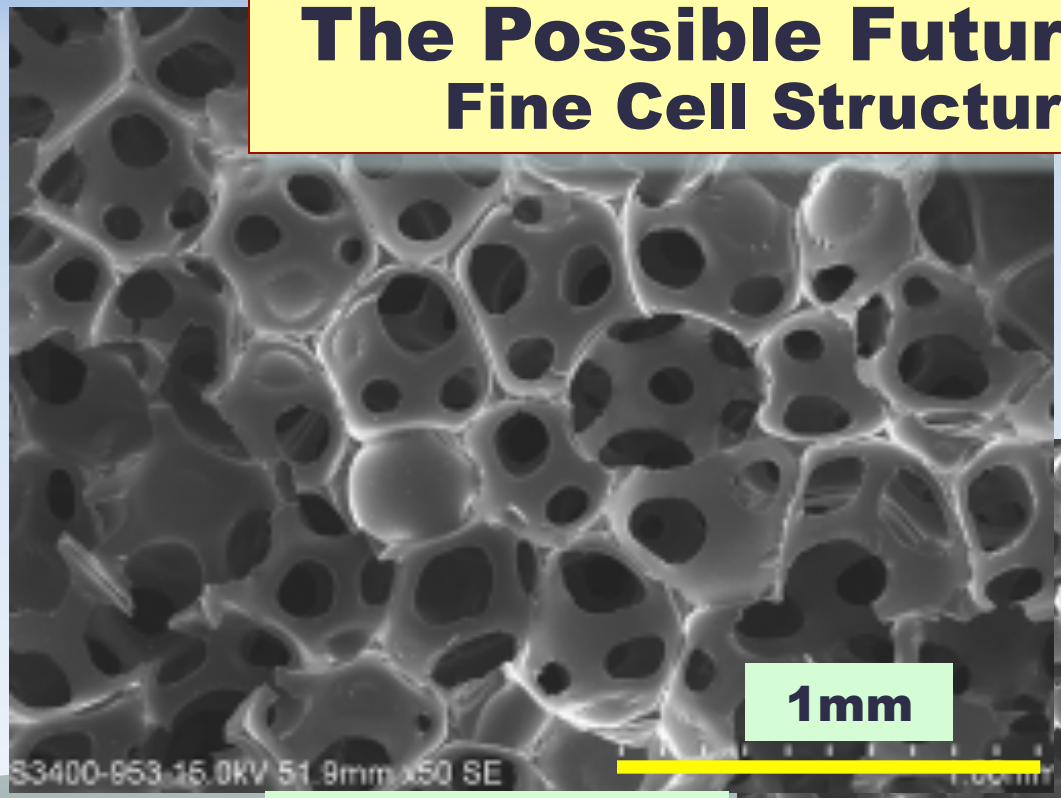


For the moment, char density values of RVC/LWA's are somewhat ambiguous, however, recession mass flux values of RVC/LWA seem to be almost constant. Are they independent of the microstructures?

5. Conclusions & Future Works

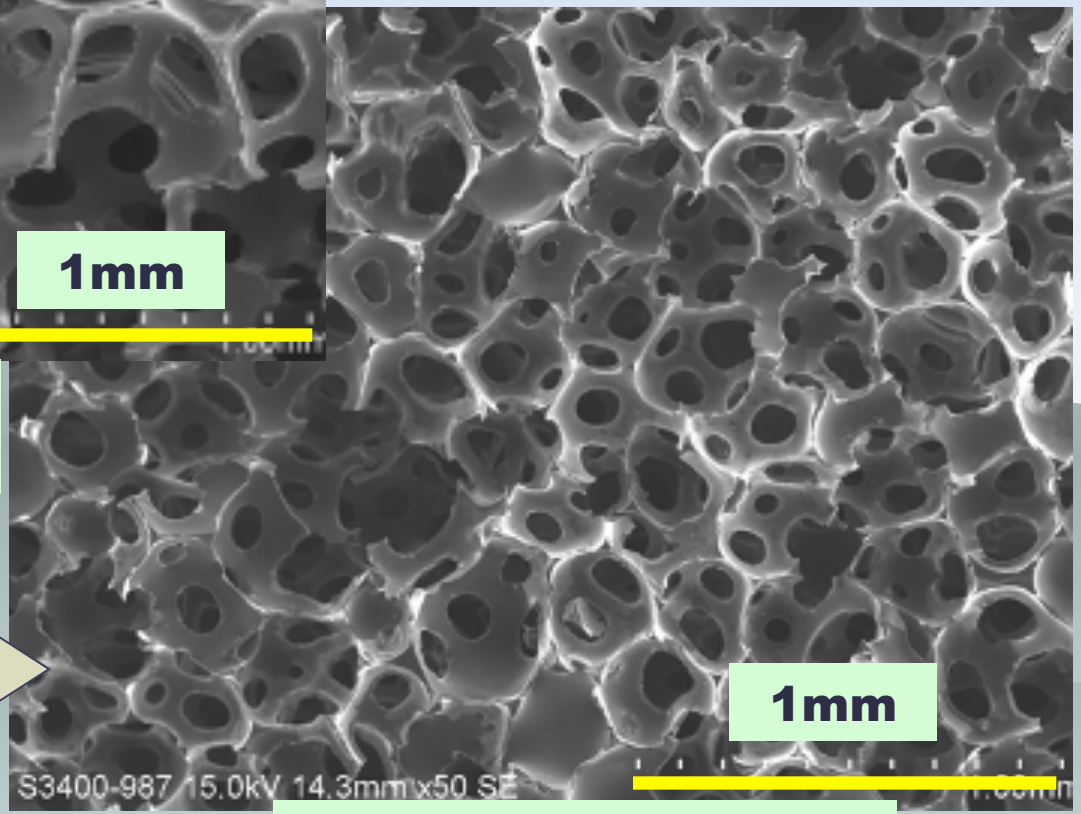
- We are currently conducting IR&D activity towards domestic RVC/LWA with density 0.3-0.4g/cm3 for future reentry missions.
- From the experiences of fabricating LWA panels of 22cm x 22cm x 5cm and density measurements, we have confirmed that our resin-impregnation process for LWA is quite stable and reliable.
  - CALCARB/PI <±3%
  - Grafoam/Ph <±3%
- The insulative peformance of current LWA's is judged acceptable.
- But the Arcjet tests revealed signs of spallation-driven recession especially for our domestic RVC/LWA, which may be attributed to the coarse microstructures peculiar to our current RVC's.
- Therefore, further modifications for our RVC are currently underway in order to improve recession resistance.
  - Fine Cell Structures

The Possible Future Directions
Fine Cell Structured JFOAM



Current JFOAM
(ρ0.22)

Fine Cell
Structure



Fine Cell Structured
JFOAM (ρ0.20)

Thank You for Your Attention!

Any Questions?