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Renewable low-Z wall for fusion reactors with built-in tritium recovery

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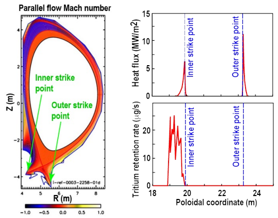
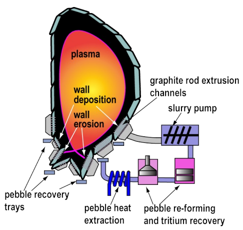
Introduction



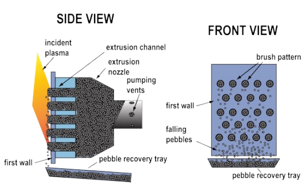
ITER simulations adapted from [Khan, JME, 2019]

- *First wall of magnetic fusion reactors will have erosion regions with huge heat loads (up to 40 MW/m^2 steady-state) and erosion rates (up to 1 cm/week) which will destroy the wall.*
- *Will also have cold deposition regions with tritium deposition, which robs expensive fuel from reactor.*
- *Fixed solid walls of any material (high or low Z) cannot fully address these issues.*
- *Liquid metal walls have problems with vapor pressure, MHD, impurity clogging, and return flow.*



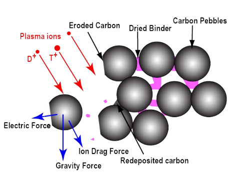
Overview of proposed pebble-based first wall concept

- *Propose renewable pebble-based first wall concept at erosion and deposition regions.*
- *Start with carbon-based concept for lowest cost and best core plasma performance.*
- *Pebbles are delivered to first wall mixed into slurry.*
- *Slurry is baked into conglomerate near first wall and extruded as rods.*
- *Rods disintegrate into pebbles on being hit by huge plasma heat flux.*
- *Pebbles are recovered in trays to extract heat and tritium.*



First wall brush pattern of extruded rods

- *Different rod patterns could be used to optimize wall coverage.*
- *Brush pattern shown here.*
- *Want extrusion rate at up to 0.5 cm/s to handle reactor heat loads.*



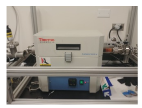
Forces on pebbles falling into plasma

- *Want pebbles ~mm size scale so that gravity dominates forces on pebbles.*
- *Want to use as little binder as possible (to avoid dust flying into plasma).*
- *Want pebbles to heat to about 2000 C before falling off (to carry away heat, but not release carbon vapor).*
- *Want ejection velocity low (< 1 m/s) to avoid pebbles entering plasma.*

Overview of project

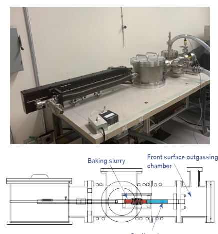
- *Study key elements of reactor extruding element using different test stands:*
  - *- **Extrusion test stand** to study friction force on extruded slurry.*
  - *- **Heat flux test stand** to study slurry response to high front-surface heat loads.*
  - *- **Baking test stand** to make samples quickly and study backfilling with different gases.*
  - *- **Breaking stand** to study baked rod mechanical strength*
- *Extrapolate to reactor environment using finite-element modeling (BISON code) including neutrons*

Baking stand



- *Allows baking up to 1000 C and backfilling of pebbles with different gases.*

Extrusion test stand completed



- *Measure slurry friction at range of velocities from 0 – 2 cm/s*
- *Bake slurry while extruding at up to 1000 C.*
- *Measure front-surface outgassing rate of slurry while baking.*

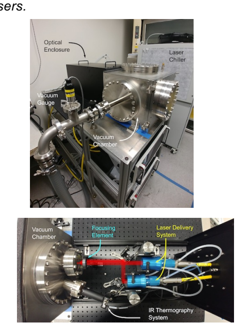
Wide range of pebble rods created

- *Wide range of pebble materials (amorphous graphite, glassy carbon, boron nitride)*
- *Wide range of filler/binder materials (acetone, graphite powder, ethylene, phenolic)*
- *Wide range of baking times/levels and sample sizes.*
- *Best results at present with glassy carbon + phenolic binder.*

BN spheres

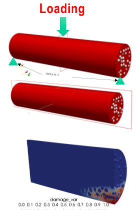
Heating test stand completed

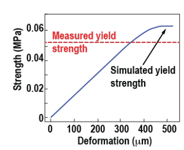
- *Create front-surface heat loads up to 50 MW/m^2 on 1 cm^2 sample.*
- *Uses two steady-state 3 kW fiber lasers.*



Simulation progress

- *Simulations first working on simulating rod stress tests.*
- *Can tune simulations to match binder strength.*
- *Will then move to simulating disintegration during large front surface heat loads.*



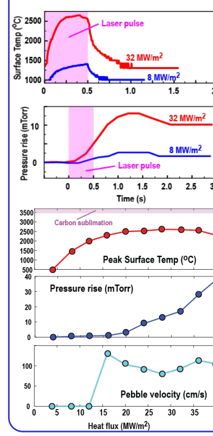


Simulated sample deformation

Breaking stand

Experimental highlights

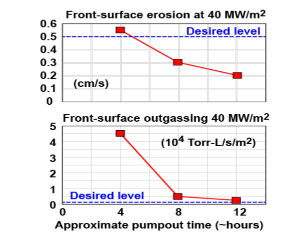
Reactor-relevant heat flux handling demonstrated



- *Front-surface heating up to 40 MW/m^2 is tolerated without reaching sublimation temperature of carbon.*
- *Peak temperature saturates near 2000 C, exactly as desired.*
- *Pebbles are observed to fall away from front surface intact, as desired.*
- *Pebbles ejected at velocities around 1 m/s (at edge of tolerable level).*

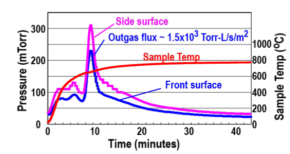
Front-surface erosion at desired rate demonstrated

- *Front-surface erosion at 0.5 cm/s achieved, but outgassing rate higher than desired*
- *Reducing trapped gas to desired level gives slightly lower erosion rate of 0.2 cm/s*



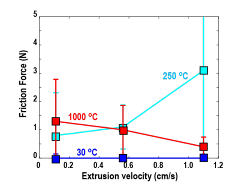
Bake-out in extrusion stand demonstrated

- *Front-surface outgassing during bake-out ~2x higher than upper limit, need to reduce this.*



Extrusion friction force is low

- *Friction force during slurry extrusion found to be low (< 0.5 lb for 10 cm long sample in stainless steel tube) at desired extrusion velocity ~0.5 cm/s.*



Summary

- *Extruded carbon pebble rods are promising solution for high erosion/deposition regions of fusion reactor first wall.*
- *Have demonstrated reactor relevant heat load handling 40 MW/m^2 steady state without going into carbon sublimation.*
- *Have demonstrated desired rate of front-surface erosion ~0.5 cm/s.*
- *Friction force during slurry extrusion at 0.5 cm/s is tolerably low.*
- *Outgassing from slurry front surface is too high at moment – needs to be lower both during baking and also during front surface erosion (a main focus for future research !).*
- *Finite element simulations are in progress – first starting with breaking tests, will then move to erosion simulations.*