Karlsruhe Institute of Technology

THERMO-MECHANICAL SCREENING TESTS TO QUALIFY BERYLLIUM PEBBLE BEDS WITH NON-SPHERICAL PEBBLES

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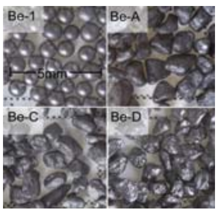
Objectives

- In present ceramic breeder blankets, pebble-shaped beryllium is used as a multiplier. As candidate material, spherical pebbles with diameters of d ≈ 1mm are considered.
- Non-spherical particles are of significant economical interest. Except of packing factors[1], no thermo-mechanical pebble bed data exist for non-spherical beryllium grades.
- Qualification tests were performed in helium atmosphere at ambient temperature: Uniaxial Compression Tests (UCTs) combined with the Hot Wire Technique (HWT) to measure the thermal conductivity k.

Experimental



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Investigated beryllium grades:
Be-1: spherical 1mm pebbles, NGK, Japan
Be-A, Be-C: 2.5mm pebbles, different grain sizes, Bochvar, Russia,
Be-D: 2mm pebbles, Materion, USA

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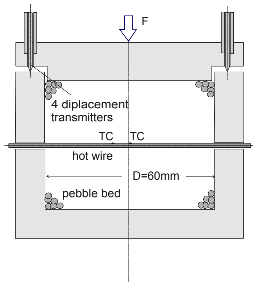
UCT and HWT experimental set-up: Only ≈ 120cm³ of non-spherical beryllium grades were available. This resulted in a small set-up with a somewhat reduced measurement accuracy, "screening tests". Therefore, the comparison with the spherical beryllium pebbles was important.

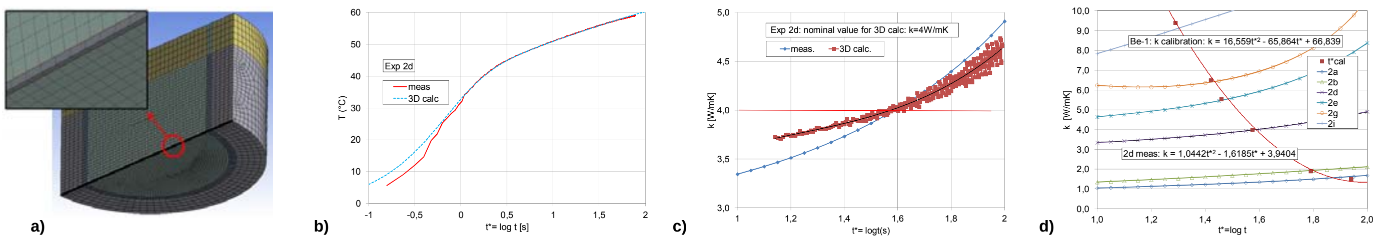


Batch	Exp N°	γ(%)	σ_{max} (MPa)
Be-1	1	61.6	7.0
Be-1	2	62.4	4.8
Be-A	3	61.8	4.3
Be-A	4	63.2	4.7
Be-C	5	59.7	3.9
Be-D	6	60.9	4.7
Be-D	7	62.1	4.4

↑ **Experimental parameters**: packing factors γ and maximum uniaxial stresses σ

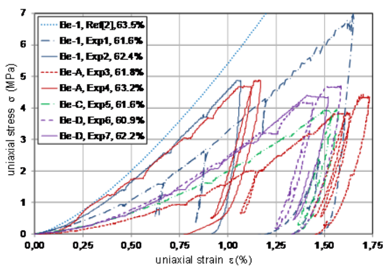
Hot Wire Modelling

The HW Technique is a standard technique for thermal conductivity k measurements of materials with *low* k values in *large* containers. Both requirements are not fulfilled in the present case. Therefore, a detailed modelling of the HWT is required for the interpretation of the HW signal.

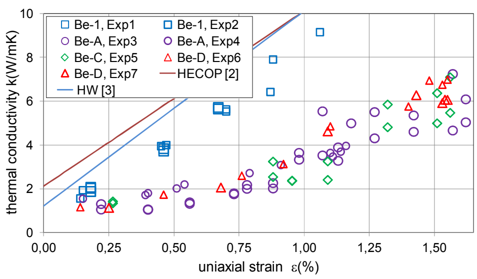


a) 3-D transient analyses with the FE ANSYS code were performed modelling in detail the HW (with inner structure) and the container.
b) A nominal value for the pebble bed thermal conductivity has been assumed, and then, the measured curve is approached by varying the HTCs at the HW and the container walls. After a first period of time, the slope of an ideal HW temperature curve becomes constant (half-log plot). This is not the case for both the measured and calculated signal.
c) Because of the varying slope, the measured and calculated values of k are not constant. As correct value t* that value is taken where measured and calculated values agree (iteration process)
d) This procedure is carried out for different values of k and a calibration curve is obtained . Different curves are determined for spherical and non-spherical pebble beds.

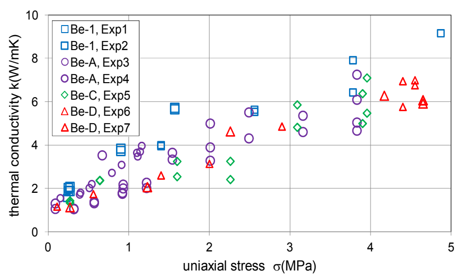
Experimental Results



↑ **UCT results: uniaxial stress σ = f(pebble bed strain ε).** With decreasing packing factor γ, the pebble beds become "softer", (larger strain ε for a given stress σ). Be-1 and Exp 4 with Be-A show the stiffest behaviour, the values are, however, below the correlation obtained with a larger experimental set-up[2].



↑ **HWT results: k = f(ε).** For non-spherical pebbles, k is distinctively smaller than for spherical ones, mainly caused by the softer σ–ε relation. No differences exist between the different non-spherical grades. Again, k is fairly linear dependent on ε as found previously[2,3].



↑ **HWT results: k = f(σ).** k for spherical pebbles is at the upper bound of the data which might be caused by different sizes of generated contact surfaces during compression.

Conclusions

- Compared to spherical pebble beds, the thermal conductivity for non-spherical pebble beds is lower caused by i) the softer bed behaviour (smaller stress s for a given strain e value), and, ii) the generation of smaller contact surfaces because of the non-regular shape.
- For blanket operation, the pebble bed strain is the primary parameter; for softer pebble beds the anticipated increase of the thermal conductivity during heating-up is smaller because of the reduced build-up of thermal stresses.

[1]Reimann, J.; Abou-Sena, A.; Nippen, R.; Tafforeau, P., Fus. Eng. and Des. 88 (2013) 2343-2347 [2]Reimann, J.; Piazza, G.; Harsch, H, Fus. Eng. and Des. 81(2006) 449-454 [3]Reimann, J.; Hermsmeyer, S.; Piazza, G.; Wörner, G.,CBBI-9, Toki, Japan, (2000) 199-214