Size dependent crush analysis of lithium orthosilicate pebbles for fusion reactors

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Introduction

Lithium Orthosilicate (OSi) in the form of pebbles is the candidate breeder material for Helium Cooled Pebble Bed (HCPB) solid breeder concept. For a safe and sustained fusion cycle, the pebble bed should offer good thermomechanical integrity. Mechanical integrity of a pebble bed depends on the crush probability of individual pebbles. Hence, the knowledge of the crush loads of OSi pebbles is important to guarantee a feasible breeder material for fusion reactors. Crush experiments on single OSi pebbles of diameter 500 μm have been conducted in the past at Fusion Materials Laboratory(FML) of Karlsruhe Institute of Technology (KIT). However, crush load for pebbles of different sizes has not been investigated. Crush experiments have been conducted on OSi pebbles of 10 different sizes ranging from 250 μm to 800μm and the corresponding results are discussed in the following. The experimental data obtained will be helpful in developing a micro mechanics based damage model to investigate the macroscopic response of a crushable polydisperse pebble assembly.

Experimental Procedure

- Pebbles (as received) are heated up to 300°C for up to 1 hr in Nitrogen environment to remove any moisture present in the pebble.
- The crystal structure of the pebble materials is not altered due to the above mentioned heat treatment process.
- Crush experiments are conducted (in glove box) at room temperature in an inert gas (Nitrogen) environment.
- Each pebble is placed between the compressions platens (made of BK-7 glass) of a table top UTM.
- The pebble size is measured as the distance between the two plates used to compress the pebbles.
- The pebble size and sphericity are measured using an image correlation procedure by placing the pebbles in a single layer on a surface as shown in Figure. 1(a).
- Figure. 1(b) shows difference in transparency levels of the pebbles in the same batch.
- The pebble marked 'T' is more transparent which fails at a very low crush load while the pebbles marked 'O' are less transparent showing a larger crush load.
- In the experiments, if the crush loads are too low (indicating pebble type 'T'), then they are discarded in the analysis.

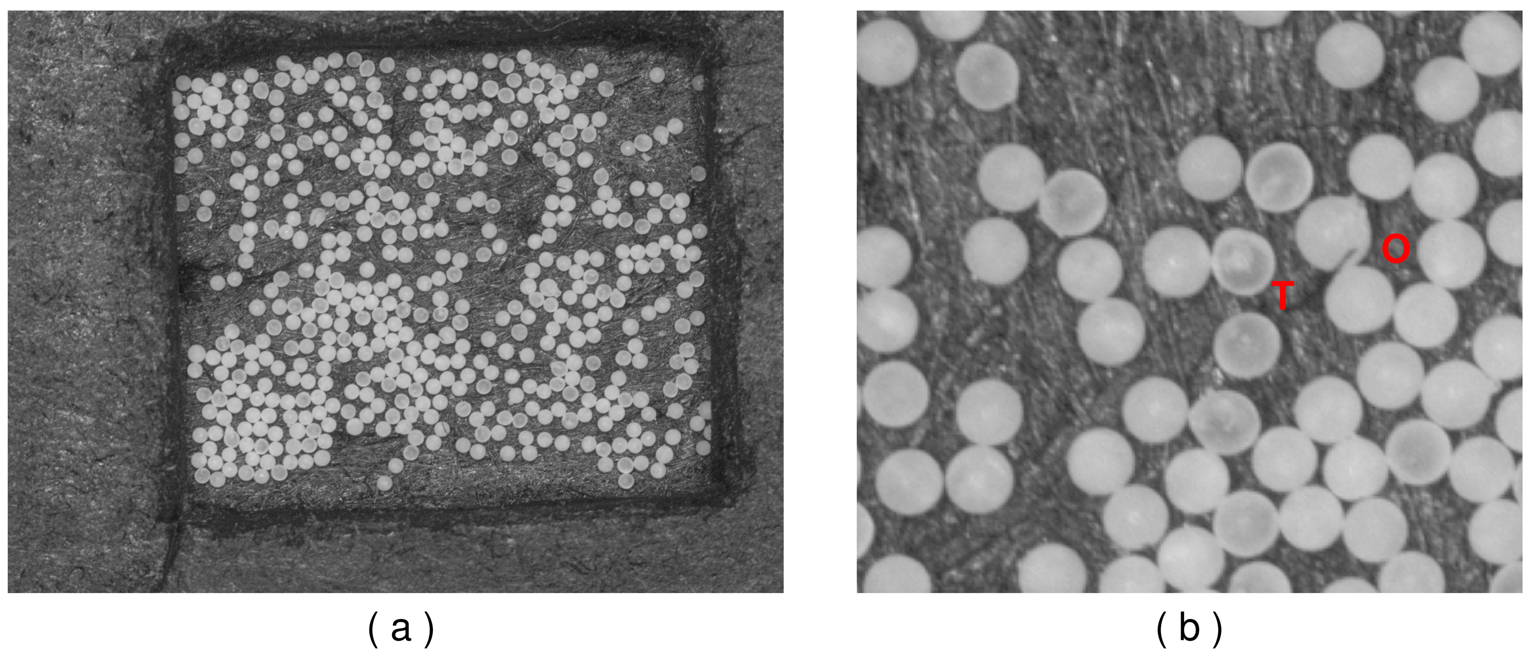

Figure 1: *(a) Optical image of a batch of OSi pebbles of size 250 μm used for crush tests. (b) Zoomed view of the batch showing different transparency levels for pebbles. The transparent pebbles (marked with red color 'T') show a significantly lower crush load compared to opaque (or less transparent, marked with red color 'O') pebbles. Also, some of the pebbles are not completely spherical and hence the sphericity is also measured during the tests.*

Results and Discussion

- Figure. 2(a) shows the crush load F (average of 45 measurements) as a function of average pebble diameter.
- The crush load and the standard deviation increases with increase in pebble size.
- The increase in standard deviation may be related to increase in number of defects or internal crack density with increase in pebble size.
- The data point corresponding to 355 μm shows a lower mean crush load compared to the expected trend. This is due to the presence of large fraction of transparent pebbles (pebbles of marked type 'T') as shown in Fig. 1.
- Figure. 2(b) shows the variation of a measure of crush stress as a function of pebble size. Here, the crush stress is calculated by dividing the crush load with the area of a circle of same diameter as the pebble size. We can observe a size dependent crush stress which increases with decrease in pebble size. The data point corresponding to 355 μm is an exception due to the presence of large number of transparent pebbles in the measurements.
- Critical failure energy (W_c) of a pebble in elastic contact is given by

$$W_c = \sum_{i=1}^{N_c} \frac{1}{5}\left(\frac{9}{16R_i^*}\right)^{\frac{1}{3}} \frac{1}{E^{*\frac{2}{3}}} F_i^{\frac{5}{3}}, \qquad (1)$$

where N_c is the number of contacts, F_i is the normal contact force due to i^{th} contact, $E^* = E/(1-\nu^2)$ is the equivalent Young's modulus and R_i^* is the relative radius of curvature of the i^{th} contact. For a monosize assembly $R^* = R/2$.

- For the present experiment, the crush test is performed by compressing a single pebble between two plates which is analogous to a single contact implying $N_c = 1$ in Eq. 1.
- Figure. 3 shows the crush load as a function of pebble diameter (log-log plot) for all the samples (red filled circles) tested in the experiment. If we assume certain failure energy W_c for the pebbles, we can actually estimate the crush load from Eq. 1. The blue curve shown in Figure. 3 is obtained from Eq. 1 by assuming $W_c = 0.02$ mJ and $E = 90$ GPa.
- The blue curve nicely fits the data showing a size effect on the crush load. However, we need to obtain the value of W_c through experiments.

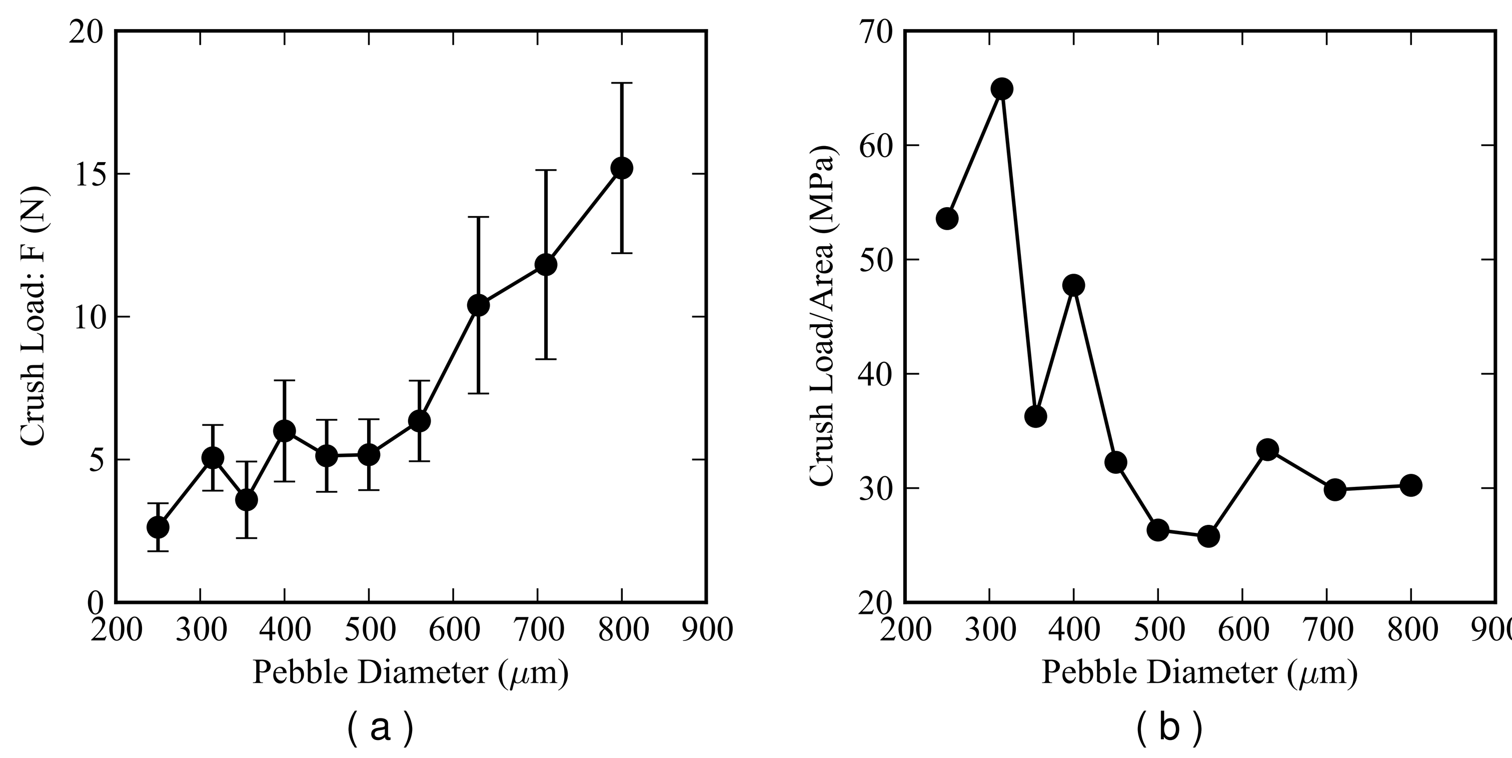

Figure 2: *(a) Crush Load and (b) Equivalent Crush Stress for OSi pebbles as a function of pebble size obtained from FML.*

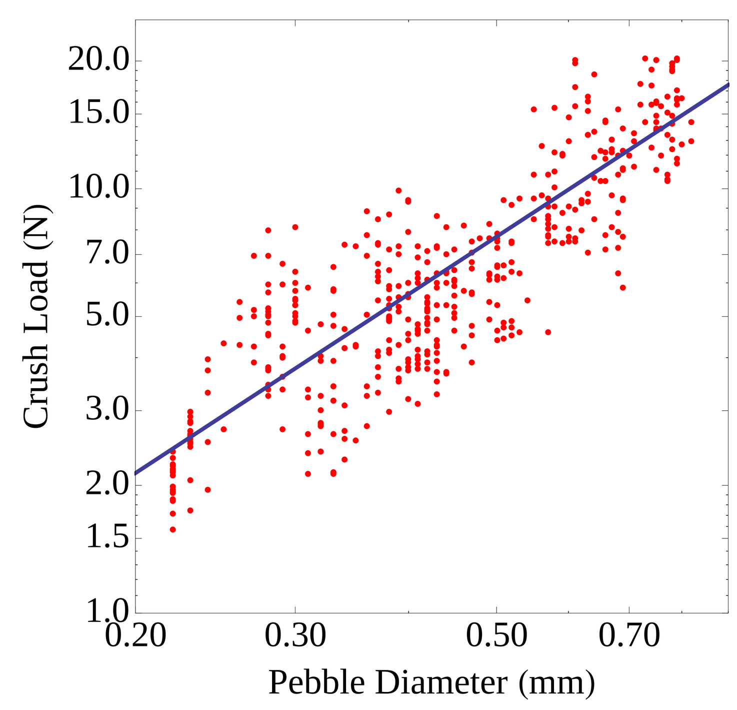

Figure 3: *Crush load vs pebble diameter raw data (filled circles) and the blue line shows the crush load calculated from Eq. 1 assuming $W_c = 0.02$ mJ.*

Conclusions

- The crush load data for OSi pebbles as a function of size has been obtained under inert gas environment.
- The data clearly shows a size dependence of the crush load necessitating the incorporation of such a trend in the future modelling tools.
- The data shows a linear variation (on log-log plot) of crush load as a function of pebble size.
- A damage model incorporating the observation of size dependent crush load to study a crushable polydisperse assembly is expected to give more insight into the micro-macro coupling of these systems.