Fracture toughness of nuclear graphite

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Introduction

Some graphite/gas nuclear reactor projects are presently under design studies.
These projects have pushed the graphite producers to wake up nuclear grades and to start the detail characterization of the several potential grades.
Historically all the graphite grades employed in the large scale graphite reactors: AGR, HTR (Fort St Vrain USA, Schmehausen Germany) have been produced using mainly the extrusion process associated with an isotropic coke and a relative coarse grain size (1600 µm max).
More recently the Japanese graphite gas HTTR demonstration reactor has been built with a graphite grade obtained by isostatic moulding with a small grain size (60 µm max).
For these potential projects, SGL today is offering an extruded grade called NBG-10 and an alternative isostatic moulded grade NBG-25. After measuring the classical standard mechanical properties: Young modulus, Flexural strength, Compressive strength, we compare the 2 materials with the crack propagation energy criteria GIc, link with the fracture toughness by the relation : $GIc \times E' = (KIc)^2$.

Experimental

The methodology for this property measurement has been set up in a similar way to the existing ASTM norm E399 for metal measurement [1], using a 3 point bending flexural method on notched sample.
Our graphite sample size is B 20 mm, W 30 mm, L 200 mm with a distance between supports of 180 mm.The loading speed was set up at 0.2 mm/mn and the acquisition of the sample bending is obtained with a displacement sensor, Fig. 1.
After several tests with different notches sizes, with ratio a_o/W from 0,3 to 0,6, it has been fixed at 0,5.
For the measurement we don't use the traditional loading/unloading cycles [2]
but only one loading cycle till the force load is decreasing at 1/3 of the max load.
This choice was made assuming that the plasticity effect [3] we observe on the cycling test are only due to the fact that the crack is not more able to close down, because some debris are present during the unloading the sample again, Fig. 2.
With this assumption of linear elastic property for this "ceramic material",we are able to determine the crack propagation energy by the compliance method.
The compliance variation δc and the crack length increase δa are related to the needed fracture energy : $G= F^2/2B * \delta c/\delta a$.
The crack length increase is calculated with the following relation :

$$A_{n+1} = A_n + [(W- A_n)/2*(C_{n+1} - C_n) / C_n]$$

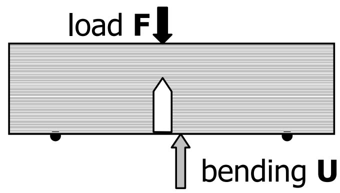

Fig. 1: measurement description

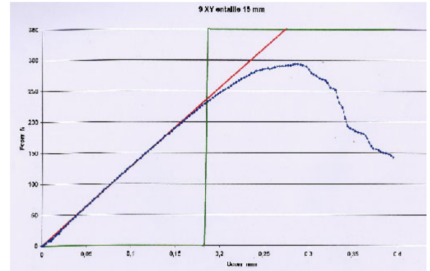

Fig. 2: measurement results

After this measurement , the broken samples 30 x 20 x 100 could be used for a four point bending flexural strength determination.

Results

Basic properties measured on NBG-10 and NBG-25 are the following:

NBG-10	AD=1.79	YM =9.0 Gpa	Fl.Str.= 28 Mpa
NBG-25	AD=1.81	YM =8.5 Gpa	Fl.Str.= 40 Mpa

In order to get a valuable crack propagation energy measurement for this two grades , 16 samples in both direction (W and A the grain) were taken out from an industrial product blocks.
Differences between samples behaviour depending on the grade could be observed during the test :the max load is obtained for the extruded grade NBG-10 at 300 Newton with a bending of 0.3 mm and for isostatic grade NBG-25 at 250 Newton with a bending of 0.2 mm ,despite the much higher flexural strength of NBG-25, Fig.3.
For the extruded product NBG-10, the crack propagation energy value is 330 J/m² with a similar value for both directions.
Comparatively with our isostatic graphite grade NBG-25, we observe a lower value at 180 J/m² with a small influence of the sample orientation, Fig 3.
Standard deviation obtained for both grades on the 16 measurements is in the range of 10 J/m² to 15 J/m².

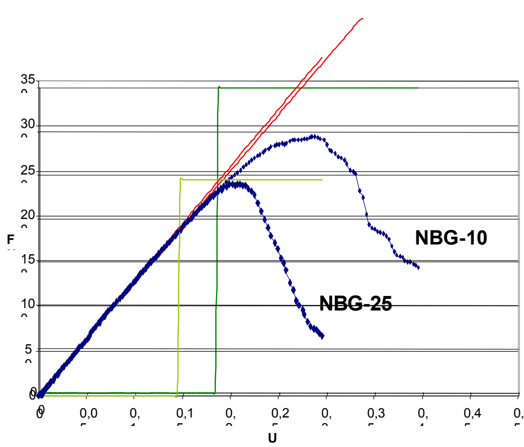

Fig. 3:comparison of grades behaviour

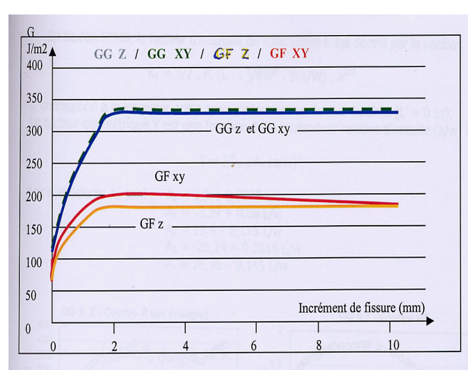

Fig. 4: G curves for NBG-10 and NBG -25

Conclusion

This way of measuring the crack propagation energy for a graphite grade appears to be a relevant method to be applied for a standard norm.

The extruded graphite with the bigger grain size shows a much better resistance to the crack propagation compared to the fine grain isostatic moulded graphite.
We confirm with graphites measurements and grades comparison, the well known ceramic properties : higher is the mechanical strength , lower is the crack propagation energy .The graphite grade choice will correspond to the need to find a good compromise between both properties.

References

[1] ASTM norm E399 ,Philadelphia 1981
[2] D.Rouby ,Carbon Conference ,Paris 1990
[3] M.Sakay and al ,Journal of American Ceramic Society, Vol 66 n°12