LATERAL COMPRESSIVE STRENGTH OF GRAPHITE FUEL ELEMENTS

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INTRODUCTION

Prismatic fuel element made of graphite are used in the core of the High-Temperature Gas-Cooled Reactor (HTGR) as moderator and structural components [1]. These elements are subjected to lateral impact loadings in a seismic event, in addition to thermal and irradiation-induced loads. The lateral seismic strength of fuel elements is needed in order to evaluate their structural integrity in a seismic event.

In the past, linear elastic stress analysis was performed on graphite structures to evaluate their strength. Comparison with experimental data showed that the data are always higher than the analytical predictions by a factor of as high as two. Because of the inability of the analysis to predict failure, the lateral strength of fuel elements cannot be estimated with high confidence. Hence, a test program was proposed. This abstract presents the experimental methods, results, and findings of the test program.

EXPERIMENTAL

Three fuel elements of the Fort St Vrain configuration [1] and made of H-451 graphite were selected for testing. Each element was cut into three equal sections along the axial length. These three sections are considered nominally identical, although slight variations exist in detailed geometry due to dowel/socket and blind fuel holes.

Flat face static compression tests were made on all nine sections. The loading rate was controlled at about 1 kN/s. A load deflection curve was recorded for each specimen and test machine itself. Acoustic signals with intensity of 90 db or higher were counted, accumulated, and recorded continuously on a chart.

Most of the specimens were tested monotonically to failure. A few specimens were either held at a constant load for a short period of time or unloaded and them reloaded once or twice. Two specimens did not fail at the maximum capacity of the test machine. They were held at the maximum load until the acoustic noises faded away.

RESULTS AND DISCUSSION

Ultimate load, P_u , maximum deflection, δ_m , stiffness at 89 kN (the maximum expected seismic load), k_s, for every section are given in Table 1. The average ultimate load of a whole element is about 787 kN. This ultimate load is equal to 1.7 times the linear elastic analysis result. The maximum tensile stress criterion was adopted in the analysis.

Almost linear load deflection curves of graphite sections are observed, consistent with the early test data [2]. A slight nonlinearity was gradually introduced when unloading and reloading at medium or high load levels occurred.

The fracture pattern falls into two categories. The first pattern was the splitting of an element section diagonally from corner to corner, making two equal segments that were trapezoidal in shape. The element in the second pattern disintegrated into three or four large triangular segments. A triangular section under the load was pushed into the specimen to split it into several pieces.

Macro-cracks were observed at many locations below or near the ultimate load. The crack front that propagated into physical separation of the element section is believed to start at the edge of the loaded area as evidenced by the extensive cracking pattern prior to catastrophic failure.

Acoustic emission data, indicated that some isolated noises were generated even at low load level. These are presumably due to cracking of some constraining "tight " ligaments in a porous graphite element. When the load increased to a certain level, the density of the acoustic count increased rapidly, expressing the start of intensive cracking. The cumulative count at this load level, N (P_i), was usually between 5,000 to 30,000 with an average of 13,000. This defines the initial cracking load, P_i, as about 70% of P_u. Beyond P_i the cumulative count increased exponentially to $\sim 1 \times 10^6$ at P_u. The general trend of the acoustic record was used to estimate the ultimate loads of the two specimens that did not fail.

Acoustic counts during loading, unloading, and reloading were analyzed. It appears that a load criterion separating the crack arrest and crack propagation is 90 to 93% of the ultimate load. This is in good agreement with the static fatigue test data of Wilkins [3].

CONCLUSIONS

Load deflection curves of the graphite fuel element under lateral compression were essentially linear, although uniaxial tensile stress strain curve usually showed a degree of nonlinearity. Stiffness of the element is 1.08 MN/mm and is in excellent agreement with the finite element results.

Ultimate static strength is 787 kN for the fuel element. This is about 70% higher than the linear elastic analysis results based on the maximum stress criterion.

Cracks at the edges of the loading plates are believed to propagate first and to connect macro-cracks in the interior while in route to disintegration of the element physically.

Acoustic emission data apparently defined a point of initial intensive cracking. The cumulative acoustic count at this point is approximately the same for all specimens.

The static fatigue strength that separates the crack arrest and propagation is at about 90 to 93% of the ultimate load.

REFERENCES

1. R. Bullock, High Temp.-High Pres., 12, 1980.
2. L. Sevier, General Atomics Report GA-A13920, April 1976.
3. B. J. S. Wilkins, J. Am. Cera. Soc., 54 (12), 1971.

TABLE 1 SUMMARY OF TEST RESULTS FOR H-451 STANDARD FUEL ELEMENTS

Section I.D.	P_u (kN)	δ_m (mm)	k (MN/mm)	P_i (kN)	N (P_i) (10^6)
1T(op)	256	0.897	0.322	187	3
1M(iddle)	241	0.777	0.327	166	1.4
1B(ottom)	260	0.701	0.396	144	1
2T	260	0.785	0.363	182	1.3
2M	265	0.841	0.35	178	1.5
2B	297	0.836	0.382	196	2.5
3T	246	0.81	0.331	166	1
3M	250	0.848	0.347	215	0.5
3B	287	0.79	0.434	218	1