PROPERTIES OF EXTRUDED FUEL RODS FOR HTGR APPLICATIONS*

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Until recently, a small program existed at ORNL and at LASL investigating extrusion as a process for fabricating fuel rods or elements for High Temperature Gas-Cooled Reactors. This work was undertaken because of the relative simplicity of the extrusion process over injection molding techniques. Also, in looking ahead to process heat reactors where the outlet gas temperatures of 1000°C or greater are desirable, the fuel would operate at temperatures no higher than steam-cycle reactors if in direct contact with the helium coolant. Hollow extruded rods with a strong continuous matrix offer such a configuration.

Fabrication of extruded elements has been discussed at a previous Carbon Conference[1], and is based on NERVA technology. The principle differences are that the curing and corbonizing times were decreased from a 40-hr cycle to five hours, and extrusion rates were increased to ten feet per minute. At this rate, the small table-top extrusion press utilized at ORNL could easily fabricate fuel rods for three to four reactor cores per year. Matrix densities of greater than 1.4 Mg/m^3 could easily be maintained and varied only about 6% from no fuel particle loading up to a maximum of 40 volume-% particle loading. Above 45 volume-% mechanical degradation of the matrix became obvious due to shrinkage relative to the particles.

The two obvious advantages of extrusion are its simplicity and its ability to yield high thermal conductivities even after irradiation damage. These conductivity measurements are reported elsewhere in this conference[2]; the importance of high matrix conductivity is to reduce the thermal gradient across particles by about a factor of three, thus significantly reducing the uranium migration due to oxygen transport or thermal diffusion.

The most significant disadvantage of extruded elements is the limitation on fuel particle volume loading. The injection-molded elements have a maximum loading of about 59 volume-% whereas extruded rods can probably attain only 45—50 volume-%. The higher loadings become increasingly important as one attempts to reach conversion factors above 0.66 in the General Atomic prismatic core design. Hence extruded rods would be impractical in the GA core configuration without significant redesign.

A number of other questions have been raised as to the practicality of fabrication by extrusion, and the purpose of this paper is to dispose of these insofar as possible. It must be pointed out most of the data on extrusion quoted here arise from a single semi-production run of 630 lineal feet of nominal 0.5-inch diameter fuel rods at 30 volume-% loading with very little attempt to optimize the system.

Ojection: Diameters will very significantly more than for molded rods. Standard deviation on diameters from rod-to-rod and within-a-rod were

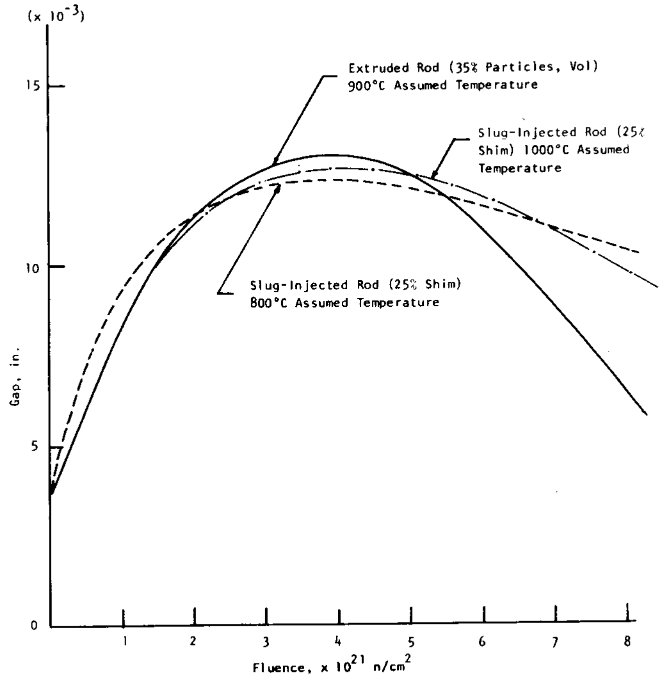

Fig. 1. Gap Thickness as a Function of Fluence Between Injected Molded Rods and Extruded Rods and the Graphite Block Making Up the Entire Fuel Element.

0.0007 inches (0.12%). Batch-to-batch variations were statistically insignificant. The total range in diameter was 0.0023 inches. These numbers are comparable to those observed for molded rods.

Radiation damage will induce increased shrinkage of the continuous matrix leading to an increased temperature drop across the gas gap between fuel rod and graphite block. All available data on dimensional changes in typical injection molded and extruded rods under comparable conditions has been smoothed and is given in the accompanying figure. During at least the early part of the fuel rod life when uranium is still present in significant quantities, there are no differences in the gas gap between the two types of rods.

Densities of the matrix will vary considerably making weight a poor means of determining fuel homogeneity. Matrix density for these rods was calculated at 1.75 Mg/m^3. The lineal rod densities within the batch examined determined to be 2.763 g/cm with a standard deviation of 0.0026 g/cm (0.09%) and a total range of 0.0071 g/cm (0.26%). These are quite within the range required for accountability. A random sample of 80 of the 30-inch rods were weighed and a variance analysis performed. The within-a-batch standard deviation was 0.0177 g/cm (0.7%) but includes errors in length and broken edges on end cutting. The batch-to-batch variation was quite large (approximately 2.1%), but this was

*Research sponsored by the U.S. Energy Research and Development Administration under Contract with Union Carbide Corporation.

traced to the variability of the coated particle densities. The particles were reject BISO-coated thorium carbide and not only exhibited poor coatings, but were cracked as well. Finally, one rod was cut into samples 1.90 cm long and alternate samples oxidized and the residue weighed. The oxide mean value was 39.99 wt-% with a standard deviation of 0.79%. This is statistically consistent with a 0.09% deviation from rod-to-rod. In all, we conclude rod weight is acceptable as both a process control and accountability measure.

X-radiography can only be used as a qualitative tool since the rods are essentially opaque to x-rays along the centerline three-fourths of the rod volume.

The 30-inch rods will bow and be difficult to insert into the graphite fuel block. Only a single Fort St. Vrain fuel block was filled from this rod run, representing about 130 randomly selected rods. All inserted easily, with only one having to be pushed gently into the block. Clearance between rod and hole diameters was approximately 0.010 inch on the average. These rods were extruded into and heat-treated on graphite pallets containing 3/4-inch face-to-face hexagonal grooves rather than nominal 1/2-inch diameter semi-circular grooves, and hence bowing could be expected to be larger than normal. To determine the point at which a rod would break, a single surplus rod was supported on a 27-inch span and broken in flexure. The mid-point tranverse distortion was 0.435 inches. Hence there should be no difficulty in inserting 30-inch rods into a block.

In summary, it is our considered opinion extrusion offers a very viable alternative form of fuel rod fabrication in core designs less restrictive than the General Atomic prismatic block configuration. Although not investigated here, continuous auger extrustion, hollow shaped cylindrical shapes, and concentric coextrusion of several types of material are accepted techniques in graphite technology.

(1) R. L. Hammer, J M Robbins, J. H. Coobs, *Development of Continuous-Matrix Fuel Rods for Advanced High Temperature Gas-Cooled Reactors*, Paper NF-11, 11th Biennial Conference on Carbon, June 1973.

(2) J. P. Moore, R. S. Graves, W. P. Eatherly, *Thermal Conductivity and Electrical Resistivity of Simulated Fuel Elements*, this conference.