Proceedings of the Korean Nuclear Society Autumn Meeting
Seoul, Korea, October 1995

A study on the Porosity Characterization of U_3Si_2 Dispersion Fuel prepared with Atomized and Comminuted Powders

Chang-Kyu Kim, Young-Mo Ko, Hae-Dong Cho,
Don-Bae Lee, Ki-Hwan Kim, Chong-Tak Lee
and Il-Hiun Kuk
Korea Atomic Energy Research

G. L. Hofman
Argonne National Laboratory, USA

Abstract

To investigate the effects of powder shape on U loading density of fuel meat, two kinds of fuel meats were prepared with atomized and comminuted U_3Si_2 powders by extrusion or rolling process. Extruded fuel meats with atomized spherical U_3Si_2 powder appeared to have much less porosity than those with comminuted irregular U_3Si_2 powder at higher U_3Si_2 fraction. The U_3Si_2 particles with spherical shape are less fractured in extrusion than in rolling. Most of atomized particles on the whole maintained to have spherical shapes in the extrusion. It has been shown that atomized spherical particles are expected to approach similar upper loading limits comparing with comminuted particles in rolled plates, but exceed comminuted powder loading limits in extruded rods.

I. Introduction

There are basically two aspects to the development of high uranium density LEU dispersion fuels. The first challenge is the discovery of a uraium compound or alloy with the highest possible uranium density that can be fabricated in a dispersion, and has acceptable irradiation behavior. To date, the highest density qualified compound is U_3Si_2[1) used in comminuted powder form, however, recently atomized spherical powder has become developed which may possibly allow higher fuel volume loadings to be fabricated.[2) The second aspect - the maximum volume fraction of fuel particles in the core - is the main subject of this paper.

During extrusion of rod type fuel or rolling of rod type fuel, a certain amount of porosity is formed. This is primarily due to fracturing of the fuel particles in response to the extrusion or rolling force. The amount of porosity can be substaintial. For example, for a currently considered maximum commercially acceptable fuel-volume loading of 45% the porosity is 10%. This leaves only 45% matrix aluminum in the core. As the ductile aluminum provides the dispersion core with uniform flow behavior during extrusion or rolling, it appears that the maximum practical fuel loading of 45% is reached when the aluminun becomes a minor - largely discontinuous component of the dispersion. It seems reasonable to conclude that a reduction or elimination of the fabrication porosity would result in a higher practical maximum loading. A much higher loading of ~ 53 vol.% (~ 6 g-U/cm^{-3}) has indeed been achieved by a proprietary process. In this study two kinds of fuel meats were prepared with atomized and comminuted U_3Si_2 powders by extrusion or rolling process. The effects of powder shape on U loading density of fuel meat were investigated.

Ⅱ. Experimental

Both extruded rods and hot-rolled plates were prepared with comminuted irregular and atomized spherical powders. The maximum volume fraction of fuel particle was 50%. The rolling schedule consisted of nine passes of 20% reduction at 500℃. The extrusion ratio was 32.6:1 at 450℃ with maximum extrusion force of 105 kg/㎠. The final fabrication porosity measurements were obtained by the Archimedean immersion method. They are listed in Table 1. The observation of morphology was performed by scanning electron microscope.

Ⅲ. Results and discussion

The results of density measurement for U_3Si_2 fuel cores were shown in the Table 1. The difference of porosity between extrusion rod of atomized spherical powder and that of comminuted irregular powder was relatively small in the extrusion of 15 vol.% U_3Si_2 powder. It is assumed to be in error range. But the porosity of extrusion rod for atomized spherical powder was about 3.5% and much lowerer by 9.5% than that of comminuted irregular powder in the extrusion of 50 vol.% U_3Si_2 powder. The porosity of re-extruding atomized powder was somewhat decreased by 1% at the 15 vol.% U_3Si_2 powder but increased by 3.8% at the 50 vol.% U_3Si_2 powder. On the whole, extruded fuel meats with atomized spherical powder appeared to have much less porosity than those with comminuted irregular particles at higher U_3Si_2 fraction. The porosity of rolling plate for atomized spherical powder was about 9.1%, and much higher by 8.1% than that of comminuted irregular powder in the rolling of 15 vol.% U_3Si_2 powder. The porosities in rolling plate of atomized spherical powder and that of comminuted irregular powder were roughly same in the rolling of 50 vol.% U_3Si_2 powder. As shown in Fig. 1, the porosities in 50 vol.% rolled plate and extruded rod with comminuted powder were roughly same. The use of spherical powder, however, results in somewhat higher porosity in the rolled plate but drastically lower porosity in the extruded rod.

The evidence to this widely different behavior can be found in metallographic sections shown in Fig. 2 and Fig. 3. The atomized powder on the whole have maintained spherical shape in the extrusion rod of 50 vol.% atomized U_3Si_2 powder. The fuel meat showed small amount of U_3Si_2 fragments broken up during extrusion. Also some cracks were observed some cracks to occur inside atomized particles. Atomized U_3Si_2 particles with internal closed pores were not found frequently in all fuel meats. The fuel meat with 50 vol.% comminuted U_3Si_2 powder showed so many U_3Si_2 fragments that were considered to be produced during extrusion. But a large fraction of atomized particles have been broken up during rolling in the plate of 50 vol.% atomized U_3Si_2 powder. The fuel meat with 50 vol.% atomized U_3Si_2 powder showed many U_3Si_2 fragments that were considered to be broken up during rolling. Also many cracks were observed to occur inside atomized particles.

The comminuted particles predominately fracture perpendicular to the rolling or extrusion direction. This is particularly clear in cross-section of an irradiated U_3Si_2 plate made with depleted uranium. Because negligible swelling took place in the depleted fuel, the crack patterns in the fuel particles are preserved and consolidated by radiation enhanced sintering. The reason for this is that the rhombic shaped U_3Si_2 particles align themselves during compacting of the core so that during the rolling deformation stage the preferred fracture planes tend to be aligned as well. This alignment, or preferred orientation, is clearly evident from X-ray diffraction patterns shown in Fig. 4. It is also clear that no such alignment takes place with spherical particles. Indeed, spherical particles fracture randomly under the planar stress imposed by rolls, evidently causing more porosity. The force on spherical particles in a circular extrusion die is more uniform leaving the particles largely intact, thus generating less porosity.

Ⅵ. *Conclusion*

The fabrication porosity generated in the core of dispersion fuel plates and rods is an indicator of uniform plastic flow during fabrication. As such fabrication porosity can be used as a measured parameter in optimizing highly loaded dispersion fuel.

Most of atomized particles on the whole maintained to have spherical shapes in the extrusion. The U_3Si_2 particles with spherical shape are less fractured in extrusion than in rolling. Extruded fuel meats with atomized spherical U_3Si_2 powder appeared to have much less porosity than those with comminuted irregular U_3Si_2 powder at higher U_3Si_2 fraction. It has been shown that atomized spherical particles are expected to approach similar upper loading limits comparing with comminted particles in rolled plates, but exceed comminuted powder loading limits in extruded rods.

References

1. Hofman, G. L., and Rest, J., "Correlation of Irradiation Induced Microstructral Changes and Fission Gas Swelling in Uranium Compounds," ANL/RERTR/TM-18.
2. C.K. Kim et. al., " Characterization of Atomized U_3Si_2 Powder for Research Reactor", International Meeting on Reduced Enrichment for Research and Test Reactors, Roskilde, Denmark (Sept.,27-Oct.,1,1992).

Table 1. Porosity of U_3Si_2 dispersion fuel core using Archimedean immersion method.

Volume Fraction of U_3Si_2(%)	Powdering Method	Fabrication Method	Porosity(%)
15	Comminuted	Extruding	1.0
		Rolling	1.0
	Atomized	Extruding	1.2
		Re-extruding	0.2
		Rolling	9.1
50	Comminuted	Extruding	13.0
		Rolling	17.3
	Atomized	Extruding	3.5
		Re-extruding	7.3
		Rolling	16.5

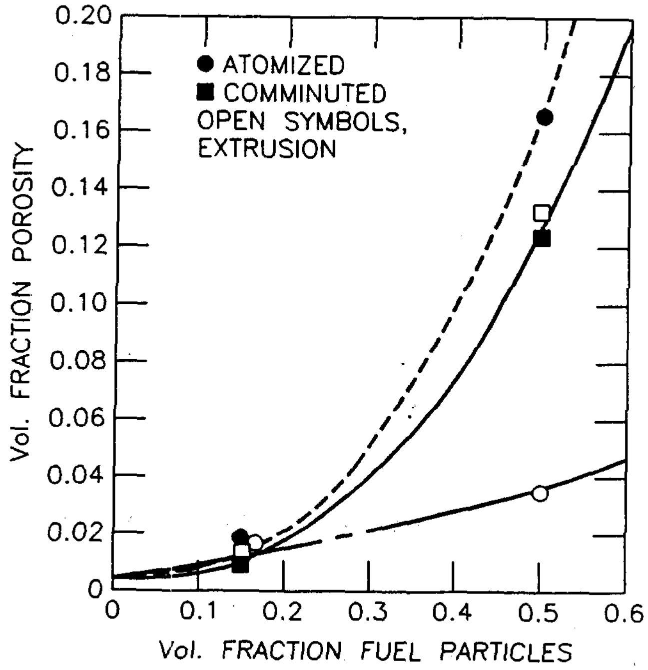
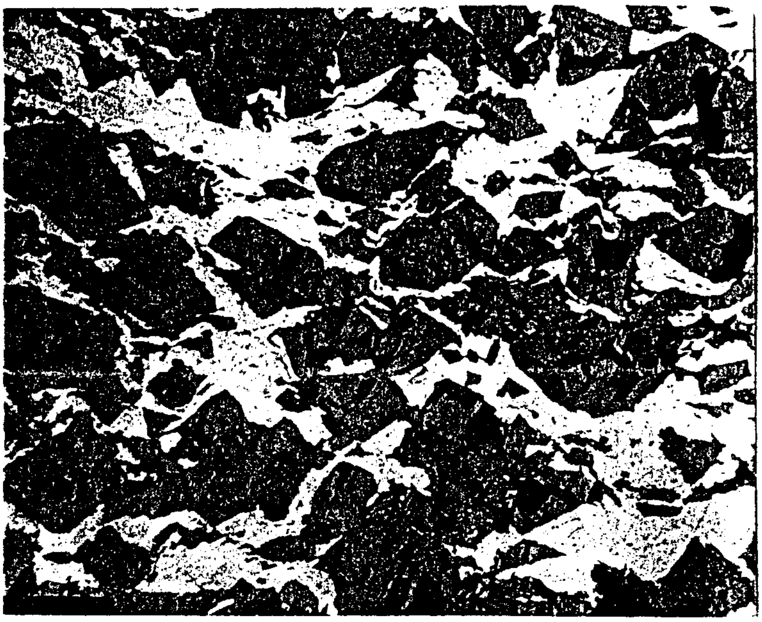
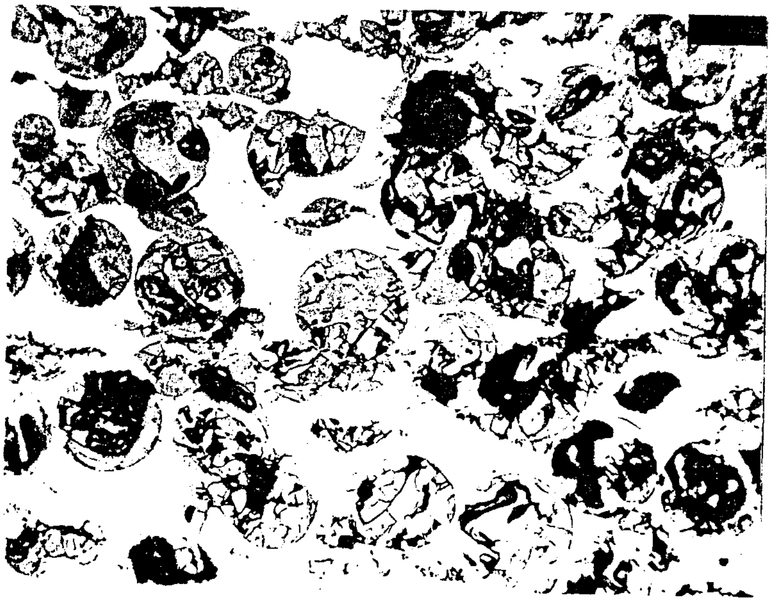


Fig. 1. Fabrication Porosity in Hot-Rolled and Extruded Dispersion Cores with comminuted and atomized U_3Si_2 particles.

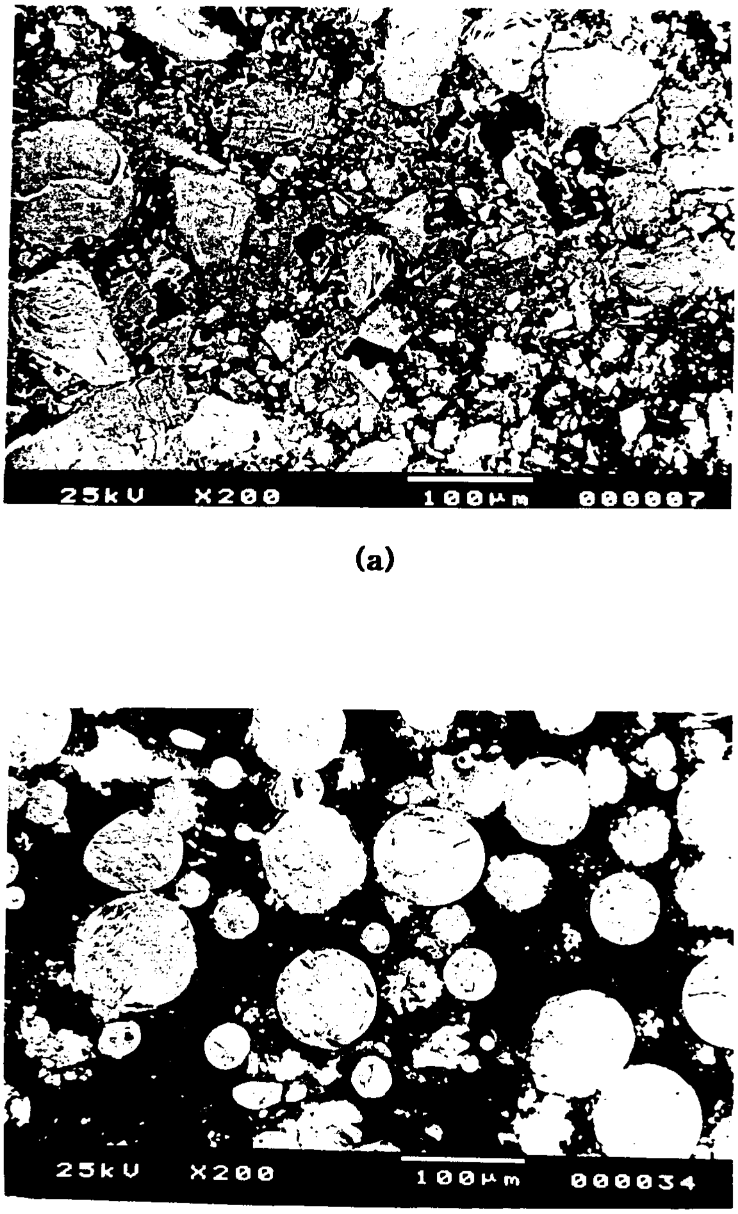


(a) Comminuted 250 X



(b) Atomized 250 X

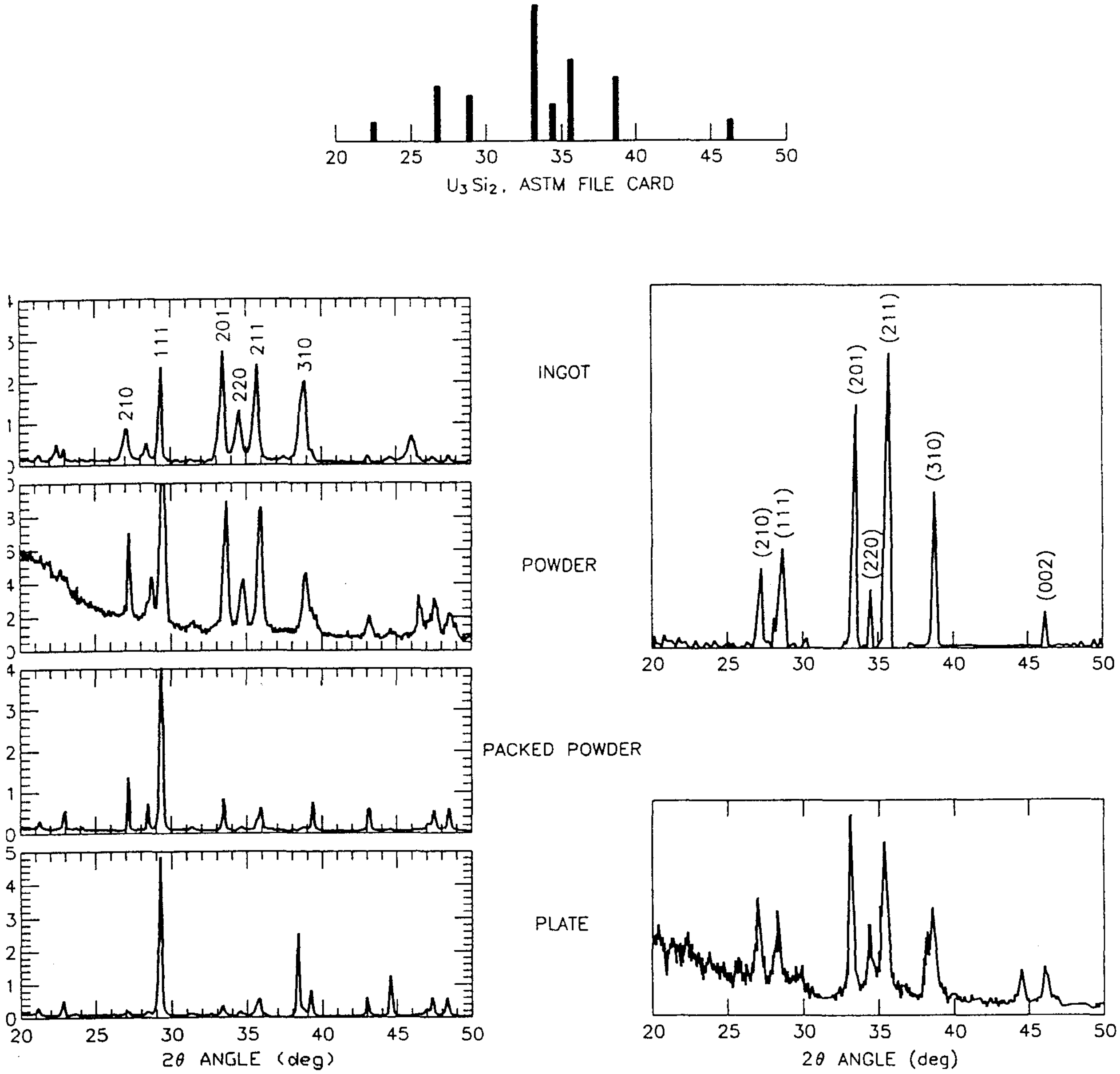
Fig. 2. Scanning electron photographs of hot-rolled cores containing 50 vol.% comminuted (a) and atomized (b) U_3Si_2 powder.



(a)

(b)

Fig. 3. Scanning electron photographs of extruded cores containing 50 vol.% comminuted (a) and atomized (b) U_3Si_2 powder.



(a)

(b)

Fig. 4. X-ray diffraction of comminuted (a) and atomized (b) powder plates.