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ScienceDirect

Ceramics International 42 (2016) 705–710

CERAMICS INTERNATIONAL

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Effect of sintering aids on the grain growth of simulated dupic fuel pellets using the simfuel technique

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Received 25 July 2015; received in revised form 26 August 2015; accepted 31 August 2015
Available online 6 September 2015

Abstract

The effect of sintering aids on the grain growth of simulated DUPIC fuel pellets with burn-ups was investigated using SIMFUEL pellets as a surrogate for actual spent PWR fuel avoiding the high radioactivity of spent fuel. In this study, titania and niobia were used as sintering aids, and SIMFUEL pellets with burn-ups of 35 GWd/tU and 60 GWd/tU were used. The sintering aids significantly improved the grain sizes of the sintered pellets. Moreover, metallic precipitates, which inhibit the movement of the grain boundary, were included even at the interior of grains due to an increase of grain boundary mobility caused by the addition of sintering aids. Titania is more effective than niobia in grain growth, while niobia is more effective than titania in densification.

Keywords: Simulated DUPIC fuel pellet; SIMFUEL pellet; Metallic precipitates; Sintering aids; Grain growth

1. Introduction

The DUPIC (Direct Use of spent PWR fuel In CANDU reactor) fuel pellets for CANDU (CANada Deuterium Uranium) reactor are directly refabricated from spent PWR fuel materials using a dry process that consists of mechanical decladding, OREOX (Oxidation and REduction of OXide fuels) process, milling, and sintering [1]. The sintered density and microstructure of DUPIC pellets could be affected by the content and composition of fission products depending on the burn-ups of the spent fuel. An improvement of DUPIC fuel powder and pellet has been investigated using SIMFUEL (SIMulated FUEL) pellets due to the high radioactivity of spent fuel [2–4]. In particular, SIMFUEL is a surrogate that can mostly replicate the composition and phase of fission products, which is composed of the dissolved elements in the UO_2 matrix to form a solid solution of (U,SS)O_2 (SS: soluble solids), metallic precipitates, and oxide precipitates in spent fuel [4,5].

The fuel pellet with large grain is generally required to decrease the amount of fission gas release and the fuel swelling rate during irradiation of UO_2 [6,7]. However, the grain size of the simulated DUPIC fuel pellets is governed by the content of the metallic and oxide precipitates, which are primarily formed at the grain boundary and inhibit the movement of the grain boundary of (U,SS)O_2 [4].

Various methods have been investigated, for achieving a large grain size of UO_2, including techniques of a combination of the high sintering temperature and long sintering times [8,9], the addition of sintering aids [7,10–16], and control of the sintering atmosphere [15,16]. One simple method for obtaining fuel pellets with a large grain size without requiring additional pulverization of the fuel materials is to add sintering aids. Among the available sintering aids, titania (TiO_2) [10–13] and niobia (Nb_2O_5) [7,14–16] are known to greatly increase the rate of UO_2 grain growth.

In the present work, the effect of sintering aids on the grain growth and densification of simulated DUPIC fuel pellets with burn-ups was investigated using SIMFUEL pellets with

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http://dx.doi.org/10.1016/j.ceramint.2015.08.168
0272-8842/

Table 1
Chemical composition and surrogate oxides added to UO_2 as fission products in SIMFUEL.

Fission product groups	Uranium and fission products	Surrogate oxides	Element composition (wt%)	
			35 GWd/tU[a]	60 GWd/tU[b]
	U	UO_2	96.768	94.505
Dissolved oxides (SS)	Y	Y_2O_3	0.048	0.086
	La	La_2O_3	0.172	0.227
	Ce (Pu, Np)[c]	CeO_2	0.814	1.405
	Nd (Pr, Sm)[c]	Nd_2O_3	0.630	1.054
	SUM		1.664	2.772
Dissolved oxides (SS)/oxide precipitates (OP)	Sr	SrO	0.078	0.164
	Zr	ZrO_2	0.388	0.659
	Ba	$BaCO_3$	0.193	0.278
	SUM		0.659	1.101
Metallic precipitates (MP)	Mo	MoO_3	0.350	0.613
	Ru(Tc)[c]	RuO_2	0.317	0.595
	Rh	Rh_2O_3	0.047	0.058
	Pd	PdO	0.145	0.266
	SUM		0.859	1.532
Oxide/metallic precipitates (OP/MP)	Te	TeO_2	0.049	0.09

[a]Cooling time: 15 years.
[b]Cooling time: discharge.
[c]Surrogate elements in SIMFUEL for the fission products in parenthesis.