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History and Current Status of the Development of the U_3Si_2 Atomization Process at KAERI

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1. Introduction

KAERI has been developing atomization technology, which is a key technology for achieving high-density low-enriched uranium (LEU) fuel. With the atomization technology presented in Fig. 1, KAERI can fabricate a spherical type of powder via a process much simpler than that used to make the conventional comminuted type. Atomized powder is known for its high purity with fewer defects, excellent irradiation performance, and high production yield rates.

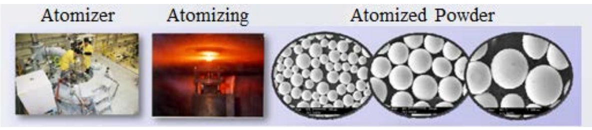

Fig. 1. KAERI centrifugal atomization technology [1]

For U_3Si_2 atomization, U_3Si_2 molten alloy should be heated to more than 1800℃, though such high temperatures can damage the parts used in the atomization process and can cause chemical reactions with the U_3Si_2 molten alloy. These problems cause production failures or low production yield rates, meaning that the U_3Si_2 atomization process must be optimized to achieve high production yield rates. From 2013 to 2023, there were five important steps in the development of U_3Si_2 atomization.

2. History of the Development of the U_3Si_2 Atomization Process from 2013 to 2023

2.1 U_3Si_2 powder fabricated from 2013 to 2014

In 2013 and 2014, KAERI conducted six batches of U_3Si_2 atomization. The main purpose of the first round of the experiments was to check the yield rate and durability of the atomizer and the parts used in the atomization process

The results of these six batches are presented in Table I, which indicates that the total yield rate was 63.25%. Accordingly, the basic parameters of the U_3Si_2 atomization process were set.

Table I: Results of U_3Si_2 Atomization from 2013 to 2014

Batch	Composition (U-wt.%Si)	Loading (g)	Powder (g)	Yield Rate (%)
B1301	U-7.4Si	1,194.38	1,164.30	97.48
B1330	U-7.4Si	1,610.15	-	-
A1309	U-7.4Si	1,766.42	1,416.10	80.17
A1310	U-7.4Si	1,642.80	1,553.00	94.53
A1415	U-7.4Si	756.37	-	-
A1416	U-7.4Si	911.82	851.70	93.41
Total		7,881.94	4,985.10	63.25
Average		1,313.66	830.85	-

2.2 U_3Si_2 powder fabricated from 2018 to 2020

From 2018 to 2020, KAERI conducted 14 batches of U_3Si_2 atomization. During that period, KAERI needed to prepare for fabricating plate-type U_3Si_2 fuel assemblies and exporting U_3Si_2 atomized powder using a new atomizer built in 2014. The main purpose of the second round of the experiments was to assess the improvement in the U_3Si_2 atomization yield rate and verify the U_3Si_2 atomization process parameters with the new atomizer.

The results for the 14 batches are presented in Table II, which shows that the total yield rate and the average loading weight were improved to 77.46% and 2.4kg, respectively. It was also shown that the new atomizer could produce U_3Si_2 powder.

Table II: Results of U_3Si_2 Atomization from 2018 to 2020

Batch	Composition (U-wt.%Si)	Loading (g)	Powder (g)	Yield Rate (%)
C1803	U-7.4Si	1,948.94	1,873.28	96.12
C1804	U-7.4Si	1,939.92	1,845.50	95.13
C1805	U-7.4Si	2,004.13	1,914.28	95.52
C1806	U-7.4Si	1,982.13	1,909.37	96.33
C1807	U-7.4Si	2,357.34	2,267.48	96.19
C1808	U-7.6Si	2,989.24	2,758.28	92.27
C1809	U-7.6Si	3,026.67	2,352.38	77.72
C1810	U-7.6Si	2,968.55	1,965.29	66.20
C1811	U-7.6Si	3,038.98	2,921.75	96.14
C1812	U-7.6Si	3,032.36	-	-
C1813	U-7.6Si	2,470.35	2,348.97	95.09
C1916	U-7.8Si	2,330.27	2,256.34	96.83
C2009	U-7.6Si	1,900.12	16.27	0.86
C2011	U-7.6Si	1,912.64	1,830.18	95.69
Total		33,901.64	26,259.37	77.46
Average		2,421.55	1,875.67	

2.3 U_3Si_2 powder fabricated in 2021

In 2021, KAERI had to produce qualified LEU_3Si_2 atomized powder to fabricate the plate-type LEU_3Si_2 fuel assemblies. To do this, we had to choose the most optimized U_3Si_2 atomization process parameters including the loading weight based on the past experiments' results from 2013 to 2020. The main purpose of the third round of experiments was to produce 1.2kg of LEU$_3$Si$_2$ powder per batch with total yield rate better than the 77.46%.

The results for 12 batches are presented in Table III, which indicates that the total yield rate was improved once more, this time to 84.46%, due to the minimization of the overall batch failure rate with the loading levels of 1.2kg and due to the training of workers with the process parameters.

Table III: Results of U_3Si_2 Atomization in 2021

Batch	Composition (U-wt.%Si)	Loading (g)	Powder (g)	Yield Rate (%)
C2108	U-7.6Si	1,205.90	1,141.46	94.66
C2109	U-7.6Si	1,206.27	1,086.32	90.06
C2110	U-7.6Si	1,143.64	1,082.99	94.70
C2111	U-7.6Si	1,238.01	1,191.79	96.27
C2112	U-7.6Si	1,234.92	1,176.99	95.31
C2113	U-7.6Si	1,198.49	1,142.93	95.36
C2117	U-7.6Si	1,130.95	1,059.55	93.69
C2118	U-7.6Si	1,127.45	1,066.54	94.60
C2125	U-7.6Si	1,240.09	915.80	73.85
C2126	U-7.6Si	1,209.61	1,133.13	93.68
C2127	U-7.6Si	1,218.51	-	-
C2128	U-7.6Si	1,251.94	1,169.10	93.38
Total		14,405.78	12,166.60	84.46
Average		1,200.48	1,013.88	-

2.4 U_3Si_2 powder fabricated in 2022

In 2022, KAERI focused on improving the U$_3$Si$_2$ atomization process by, for instance, increasing the loading weight and improving the yield rate. Through 22 batches, as presented in Table IV, we optimized the coating thickness applied to the surfaces of the carbon parts used in the atomization process and set the maximum loading weight such that cracks did not appear on the coated parts or ceramic crucibles. The maximum loading weight was determined to be 2.7kg after a loading test, as presented in Fig. 2.

Fig. 2. Loading test with uranium and coated parts

Table IV: Results of U_3Si_2 Atomization in 2022

Batch	Composition (U-wt.%Si)	Loading (g)	Powder (g)	Yield Rate (%)
C2201	U-7.6Si	1,224.22	1,118.05	91.33
C2202	U-7.6Si	1,251.37	1,160.37	92.73
C2203	U-7.6Si	1,067.07	555.52	52.06
C2204	U-7.6Si	1,148.28	1,060.65	92.37
C2205	U-7.6Si	1,135.54	1,009.05	88.86
C2206	U-7.6Si	1,103.51	1,042.26	94.45
C2207	U-7.4Si	1,098.76	1,036.13	94.30
C2208	U-7.6Si	2,267.13	1,595.78	70.39
C2209	U-7.4Si	1,109.92	974.23	87.77
C2210	U-7.6Si	1,089.06	1,018.20	93.49
C2211	U-7.6Si	2,207.92	2,122.96	96.15
C2212	U-7.6Si	3,288.66	-	-
C2213	U-7.6Si	3,260.80	2,857.65	87.64
C2214	U-7.6Si	3,303.79	3,157.02	95.56
C2215	U-7.6Si	2,287.03	2,224.00	97.24
C2216	U-7.6Si	2,010.14	-	-
C2217	U-7.6Si	3,337.69	3,211.42	96.22
C2218	U-7.6Si	3,290.57	3,172.23	96.40
C2219	U-7.6Si	3,312.64	-	-
C2220	U-7.6Si	3,301.27	1,778.71	53.88
C2221	U-7.6Si	3,295.12	3,112.06	94.44
C2222	U-7.6Si	3,324.64	459.84	13.83
Total		48,715.13	32,666.13	67.06
Average		2,214.32	1,484.82	-

The results for the 22 batches show that the average loading weight was 2.2kg and the total yield rate was decreased to 67.06% due to the more severe atomization process conditions. During this fourth round of experiments, we finalized the U$_3$Si$_2$ atomization process parameters and established documents of the atomization process operating procedures.

2.5 U_3Si_2 powder fabricated in 2023

In 2023, KAERI conducted seven batches of U$_3$Si$_2$ atomization, as presented in Table V. The main purpose of the fifth round of experiments was to verify the new optimized process conditions established in 2022. As a result, the total yield rate was increased to 90.99% and the average yield rate for the last two batches with a 2.7kg loading level was improved once more, to 96.83%.

Table V: Results of U_3Si_2 Atomization in 2023

Batch	Composition (U-wt.%Si)	Loading (g)	Powder (g)	Yield Rate (%)
C2301	U-7.6Si	2,777.20	1,898.51	68.36
C2302	U-7.6Si	2,784.59	2,716.05	97.54
C2303	U-7.6Si	2,746.79	2,641.90	96.18
C2309	U-7.6Si	1,867.42	1,606.20	86.01
C2310	U-7.6Si	1,875.10	1,776.89	94.76
C2311	U-7.6Si	2,790.58	2,705.98	96.97
C2312	U-7.6Si	2,791.11	2,698.72	96.69
Total		17,632.79	16,044.25	90.99
Average		2,518.97	2,292.04	-

3. Conclusion

Through five rounds of experiments to fabricate 61 batches from 2013 to 2023, KAERI achieved an improved yield rate of more than 90% with 2.7kg loading for U_3Si_2 atomization. The results of this study will contribute to the stable fabrication of plate-type U_3Si_2 fuel assemblies and to the export of U_3Si_2 atomized powder.

REFERENCES

[1] S.C. Park, et al., Microstructural Characterization of Atomized UAl_x Powder for High-Density LEU Dispersion Target Fabrication, Transaction of KNS Spring Meeting, Korea, 2018

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