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THE BETA-TO-ALPHA TRANSFORMATION CHARACTERISTICS
OF SOME DILUTE URANIUM ALLOYS

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

August 1, 1966

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TOPICAL REPORT

THE BETA-TO-ALPHA TRANSFORMATION CHARACTERISTICS
OF SOME DILUTE URANIUM ALLOYS

by

M. F. Nolan

August 1, 1966

Mallinckrodt Chemical Works
Uranium Division
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THE BETA-TO-ALPHA TRANSFORMATION CHARACTERISTICS
OF SOME DILUTE URANIUM ALLOYS

by

M. F. Nolan

ABSTRACT

Equipment is described for isothermal quenching of thin uranium alloy samples from either beta or gamma phase temperatures into a molten metal bath at selected alpha temperatures. TTT diagrams are presented for four alloys ranging from U-Si and U-Al binaries to Fe-Si-Al-Cr alloys of the French Sicral F-2 type. Two modes of transformation are reported as the general case, that in the upper temperature region being a diffusion-controlled nucleation and growth mechanism, and that at lower temperatures acting by shear. An intermediate nose is reported for a centrifugally cast high-aluminum Sicral F-2 alloy; in this region the transformation appeared to be by a combination of shear and diffusion. Quenching this same alloy from the gamma phase yields a TTT diagram with only a single nose; transformation at this nose appeared again to be by a mechanism of mixed shear and diffusion.

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M. F. Nolan*

INTRODUCTION

With the growing demand for radioisotopes, there is a need for the operation of uranium metal fueled reactors at higher power levels. This requires fuels capable of sustained performance at higher temperatures and atomic percent burn-ups. Previously, technical purity uranium was used at lower temperatures where the major problems encountered were connected with surface wrinkling, irradiation growth due to preferred orientation, and fission gas swelling. However, at higher temperatures in the range of 370° to 500°C a new problem, cavitation swelling, has been encountered which leads to large volume increases in the fuel.¹ This problem is being overcome by alloying uranium with low levels of additives such as iron, silicon, aluminum, chromium, and molybdenum usually in the range of less than 1000 ppm for any one additive.²

However, the addition of these alloying elements to uranium changes the beta-to-alpha transformation characteristics and thus its response to heat treatment for grain refinement and randomizing the grain orientation.³

These low level alloy additions stabilize the beta uranium structure as a metastable state when quenched into the alpha temperature range and the beta structure transforms to the alpha with varying kinetics and different mechanisms depending on the temperature of the quench and the cooling rate, the additives and their levels, and previous fabrication and thermal history. This effect allows greater freedom in designing heat treatments to give desired grain refinement and randomizing of the grain structure, but before heat treatment conditions may be selected the transformation characteristics of these alloys must be fully investigated.

EXPERIMENTAL WORK

Alloys Investigated

The additive chemistry of the dilute uranium alloys studied and their mode of fabrication are summarized in Table I.

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TABLE I
DILUTE URANIUM ALLOYS FOR
THE BETA-TO-ALPHA TRANSFORMATION STUDIES

<u>Alloy Code</u>	<u>Additive Chemistry, ppm</u>					<u>Fabrication Made</u>
	<u>Fe</u>	<u>Si</u>	<u>Al</u>	<u>Cr</u>	<u>C</u>	
M	-	800	-	-	~ 60	Gamma Extrusion
DD7	-	-	650	-	~ 60	Gamma Extrusion
F87 (Sicral)	250	330	670	200	~600	Alpha Extrusion
CS (Sicral)	260	330	930	190	60	Centrifugal Casting

Cursory investigations were made of the beta-to-alpha transformation behavior of alloys M and DD-7 while the equipment for this investigation was being developed. Alloy F-87, an ingot Sicral alloy, received more attention due to its good mechanical strength and creep resistance at elevated temperatures.

An intensive investigation was made of the transformation behavior of alloy CS, also a Sicral alloy but centrifugally cast and higher in aluminum content than alloy F-87. The large as-cast grain size and absence of mechanical working provided a different past history which had not been investigated previously.

Sample Preparation

Samples were machined from fuel cores for each of the alloys. The first samples (Alloy M) were $1\frac{1}{2}$ " long, $\frac{1}{8}$ " thick and $\frac{1}{8}$ " wide. Tantalum tabs with $\frac{1}{8}$ " diameter holes were spotwelded to the samples. However, it was found that the thickness of the samples did not allow fast enough heat removal in quenching and the spot-welds failed after one or two quenches.

The samples for the other alloys were machined to $1\frac{1}{2}$ " length, $\frac{1}{32}$ " thickness, and $\frac{1}{4}$ " width. Two $\frac{1}{8}$ " diameter holes, centered $\frac{1}{8}$ " from each end, were drilled in each sample.

During work on the 650 ppm Al alloy (DD-7) the samples were given a coating of Molykote to protect them from attack by the solder of the quench bath. However, it was found that the Molykote acted as a thermal barrier and effectively insulated the sample on quenching. Oxide on the samples also acted as a barrier to heat conduction. The remainder of the samples were therefore pickled in concentrated nitric acid before each test to remove any oxide layer and used bare. This procedure gave excellent quenching rates so long as the furnace atmosphere was adequately inert. No trouble from attack by the solder was experienced for the immersion times involved.

Equipment

The density increase uranium undergoes in transforming from the beta-to-alpha phases yields a linear contraction of approximately 0.3% for total transformation. As this length change progresses it provides a convenient means of detecting the degree of transformation. For this reason, the heart of the equipment design for these studies was the dilatometer as shown in Figure 1.

The sample was suspended between two hooks, one an extension of a quartz tube and the other on the end of a quartz rod that slid within the tube. A slight tensile load held the sample in place through a compressive spring located between the top of the tube and a rubber collar on the sliding rod.

This assembly was centered in the pick-up platform by two rubber "O" rings mounted in two vacuum feed-through connections, silver soldered end-to-end. Tightening the vacuum feed-through tightened the "O" rings around the quartz tube holding it rigidly in place.

A tripod of invar studs supported a Philips PR-9310 inductive pick-up above the polished end of the quartz rod. The pick-up measured the linear contraction or expansion of the sample by the detection of relative displacement between the upper ends of the rod and tube.

The signal from the inductive pick-up was fed into a Philips 9300 measuring bridge from where it could be displayed either by the instrument read-out page or by a Honeywell Electronik 19 multirange-multispeed recorder.

A Cromel-Alumel 0.040" diameter stainless steel sheathed thermocouple attached to the dilatometer with fiberglass tape was used to detect the sample temperature. The thermocouple bead was welded to the sheath in order to increase the thermal response of the couple. The thermocouple tip was held against the sample surface during testing. A check of the thermocouple response during heating of the sample against a Cromel-Alumel 20 gage wire thermocouple spot welded to the sample agreed to within $\pm 2^\circ\text{F}$ as measured on a Leeds and Northrup millivolt potentiometer. The calibration of the wire used in both thermocouples was $\pm 4^\circ\text{F}$ up to 400°F and $\pm \frac{3}{4}\%$ of the temperature above 400°F .

In the first phases of design of the equipment, the dilatometer was suspended from pulleys on a Flex-a-frame support but vibration in the system and the lack of rigid guides for dilatometer motion prevented satisfactory interpretation of results. The first heating furnace was 5" long with an inside diameter of $1\frac{1}{4}$ ". This short length resulted in a thermal gradient along the length of the sample. The resistance-heated quench bath was only 4" deep with a 2" diameter and the introduction of the sample and lower part of the dilatometer raised the temperature of the bath. Temperature measurements were first made with Cromel-Alumel thermocouples in the heating furnace and quench bath without actually measuring sample

temperature. Data for the M alloy and some data for alloy F-87 were compiled using this initial design of equipment.

The final equipment developed for determining the isothermal beta-to-alpha transformation kinetics is shown in Figure 2. In this final version, the dilatometer was mounted on a traveling carriage with rubber shock absorbers to insulate it from any vibration in the system. A wire-rope and pulley arrangement connected this carriage to a traversing handle which was used to raise or lower the dilatometer rapidly. The carriage's ball bushings rode on hardened steel guide rods which reduced friction and vibration during movement.

Protection of the specimen from oxidation during heating and quenching was provided by a $1\frac{1}{4}$ " diameter quartz tube in which the dilatometer was centered, which passed down through the heating furnace with its lower end immersed in the liquid metal quenching bath. A sliding seal around the dilatometer at the upper end of the tube closed the system to contain an argon atmosphere which flowed continually through the tube during the experimental runs.

The resistance furnace for heating the specimen was 9" long and $1\frac{1}{4}$ " ID split vertically with the two halves hinged. During the heating portion of the cycle the furnace halves were closed around the quartz tube with the dilatometer in the raised position. At the moment of quenching, the catch locking the furnace was released and the halves swung open by springs attached to its base, permitting lowering of the dilatometer into the quench bath without interference.

The liquid metal quench bath was 5" in diameter and 6" deep. For temperatures above 500°F a lead-tin solder was used. For lower temperatures a bath of molten Wood's metal was employed.

Temperature control of the upper heating furnace was maintained by a West SCR Power unit and a JYSCR set point unit. A Chromel-Alumel sensing thermocouple was positioned on the inside wall of the quartz tube at the center of the furnace.

The resistance heated quench bath was controlled by a Honeywell Electronik 18 recorder and Electr-O-Pulse controller unit. The Chromel-Alumel sensing thermocouple was positioned between the outer wall of the quench bath and the surrounding heater elements.

The actual temperature of the sample during the heating cycle was displayed on a 2" per minute chart speed Honeywell Electronik 16 recorder and, on quenching, on a modified Honeywell Electronik 16 recorder with a chart speed of 1" per second and full scale pen response time of $\frac{1}{4}$ second. Checks of the temperature were made on a Leeds and Northrup millivolt potentiometer.

Experimental Procedure

The test procedure was to position a sample in the dilatometer and adjust the pick-up to within its measuring limit of ± 1 mm. The dilatometer was then attached to the traveling carriage and the measuring bridge zeroed and the recorder set to a range of 0.3 mm full scale.

The test cycle began by heating the sample to temperature and holding at the test temperature for 15 minutes. The usual heating time to 1350°F was one-half hour and for 1472°F three-quarters of an hour. A temperature record and an elongation record were both made at a chart speed of 2"/minute. The temperature of the sample was checked on the potentiometer and adjustments of the controller were made to bring the sample temperature to within $\pm 1^\circ\text{F}$ of the desired level.

After 15 minutes at temperature the furnace was opened and the sample quenched into the liquid metal bath which was being agitated by a mechanical stirrer. A temperature record and a contraction record were both made at a chart speed of 1"/second. Within three seconds after the quench, the sample had reached the bath temperature and the mechanical stirrer was turned off to prevent perturbations in the dilatometer record. The temperature recorder was then turned off and a check made of the sample temperature.

After 30 seconds the chart speed of the contraction recorder was decreased to 1"/20 seconds. For long transformation times the chart speed was periodically decreased as appropriate.

Treatment of Data

The record of the contraction of the sample against time was replotted on a graph of contractions in mm versus the logarithm of time. The effective "zero" time was taken as the movement when the sample entered the quench bath. The start of transformation was interpreted as the time at which renewed contraction began after thermal contraction due to the quench into the alpha region had ceased. The finish of transformation was defined as the time at which all further contraction ceased. The assumption was made that the change in length was directly proportional to the fraction of beta phase transformed. Thus the time for 50% transformation was defined as the time at which one-half of the total observed contraction had taken place.

The start, 50%, and finish times for various temperatures were plotted on a temperature versus logarithm of time graph to obtain an isothermal time-temperature-transformation (TTT) diagram for each alloy. In cases where transformation initiated during the actual quench, only the end of transformation could be determined.

Metallography

Specimens of the CS alloy quenched from both 1350°F and 1472°F were sectioned for metallographic examination. The samples were mounted and ground through 600 grit silicon carbide paper. Attack polishes consisting of Linde A and then Linde B alumina suspended in dilute chromic acid followed. A final electrolytic etch consisted of 5 to 6 seconds exposure at 20 volts to an etchant of 5 parts of orthophosphoric acid, 5 parts ethylene glycol and 8 parts ethyl alcohol.

EXPERIMENTAL RESULTS

Isothermal Transformation Diagrams

The isothermal beta-to-alpha TTT diagrams for alloys M, DD7, F87, and CS are shown in Figures 3 through 6. All specimens were soaked 15 minutes at 1350°F before quenching. Figures 3, 4, and 5 show that alloys M, DD7, and F87 possessed two modes of transformation as quench temperature decreased as indicated by the two "C's" or "noses" of the TTT curves. Alloy DD7's transformation was so rapid at lower temperatures that the lower part of the diagram could not be determined. Figure 6 shows a difference in the kinetics of transformation for Alloy CS as three "C's" or modes of transformation were discovered.

For all individual quenches of all alloys, the plot of contraction due to transformation versus time formed a sigmoidal curve except for alloys M and F87 at temperatures just below the intersection of the two "C's"; and at the temperature for alloy CS at which the middle and lower "C's" intersected. In these regions the initial portion of the curves was sigmoidal followed by a linear portion. Alloy CS at the temperature of the lower portion of the middle "C" showed erratic transformation rates, the contraction appearing to occur in steps after the initial sigmoidal section of the curve. Due to this erratic behavior, observation of the completion of transformation was uncertain for this region.

The effect of quenching alloy CS from 1472°F in the gamma phase on the TTT diagram is shown in Figure 7. Although the alpha transformation temperatures investigated were the same as those explored in quenching from the beta phase (Figure 6), the behavior was very different with only one "C" exhibited. The diagram shows two sets of curves, one for as-cast samples given their initial quench and the other set for samples that had had previous successive quenches. The as-cast samples began transformation and were 50% transformed at times appreciably shorter than those shown for previously gamma-quenched specimens. The completion of transformation was at about the same time for both conditions. This effect was most marked at the nose of the "C". This same comparison was made for samples of alloy CS quenched from the beta but there was no discernable difference between the two conditions as can be seen in Figure 6.

A comparison between Figures 6 and 7 shows that even in the as-cast sample quenched from the gamma, the beta phase was stabilized for a longer period than when the quench was from the beta phase. This can be attributed to the difference in the solubility limits for aluminum in the beta and gamma phases. In the beta phase at 1350°F the solubility limit for aluminum is 400 ppm while at 1472° in the gamma, all 970 ppm of aluminum were soluble. The larger amount of aluminum in solution during the gamma soak therefore retarded the beta-to-alpha transformation more.

Three types of transformation kinetics were observed in these studies. In the first, the contraction-time plot was sigmoidal in form but the initial portion of the curve had a much larger radius of curvature than the final section. In the second type, the plot was also sigmoidal but the radii of curvature were essentially equal at both ends of the curve. In the third type, as has been described, the plot showed a sigmoidal portion similar to that for Type 2 described above but followed by a linear portion.

The Type 1 curve was observed for all the alloys at the temperatures of the upper "C" from just below the nose on up. Type 2 was observed from below the nose of the upper "C" to the intersection with the lower "C" for all the alloys except for alloy CS when beta quenched. In this case Type 2 curves were observed in the entire upper "C" and Type 2 curves in the middle "C".

For the temperatures of the lower "C", Type 1 curves were obtained for alloys M and F87 below the nose and Type 2 just above the nose. Type 3 curves were observed just below the intersection of the upper and lower "C's" for alloys M and F87 and just below the intersection between the middle and lower "C" for beta-treated alloy CS. No Type 3 curves were observed for the gamma-treated CS alloy. White⁴, in his investigation of the beta-to-alpha transformation kinetics of uranium-chromium alloys, observed this same type of behavior. He attributed the kinetics of the Type 1 curves to diffusion-controlled nucleation and growth transformation with kinetics similar to an autocatalytic chemical reaction. For Type 2 curves he found the kinetics similar to those for the bainitic transformations in steel for which the transformation mechanism is a mixture of shear and diffusion. Other investigations⁵ have found the lower "C" to represent time-dependent shear or martensitic type mechanism.

Metallography

In Figure 8 the as-cast microstructure is shown for alloy CS. The polarized light photograph shows large grains and the dark field photograph reveals a fairly light network of precipitate. Figure 9 shows polarized light and dark field photographs of alloy CS structures after transformation at various alpha phase temperatures. By comparison with Figure 6 it can be seen that in samples transformed at temperatures in the upper "C", the grains were equiaxed and a heavy precipitate network was present. At temperatures in the upper "C" well above the nose, a very large grain size resulted which decreased to a minimum at the nose temperature. Below the nose, the grain size was again slightly larger.

In the middle "C" the grain boundaries became feathery due to shear and grew heavier and more feathery below the middle "C" nose temperature. The precipitate network was still heavy indicating diffusion was still a controlling factor.

At 700°C in the lower "C" the grain size was quite large but the precipitate network was greatly decreased indicating shear to be the important transformation mechanism.

In the microstructures of the gamma-treated CS alloy (Figure 10), a large grain size was again formed at temperatures above the nose of the single "C" in Figure 7. However, there were no precipitates visible in any of the microstructures of the samples quenched from the gamma phase. This is attributed to the complete solution of the aluminum at 1472°F, eliminating the particles that are not dissolved in beta treatment.

The grains formed above the nose were equiaxed but polygonization of the grains was visible. The grain size decreased as the transformation temperatures were lowered to the nose and increased below the nose. Also, below the nose the grain boundaries took on the feathery appearance of alloys transformed by a mechanism of mixed shear and diffusion. All samples examined were of centrifugally cast origin without mechanical working either prior to or succeeding heat treatment.

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REFERENCES

1. Angerman, C. L., and Caskey, G. R. Jr., "Swelling of Uranium by Mechanical Cavitation." J. of Nucl. Mat., Vol. 13, No. 2, p. 182-196 (1964)
2. McDonell, W. R., and Angerman, C. L., "Effect of Microstructure on Cavitation Swelling of Dilute Uranium Alloys." USAEC Report CONF-650904-4 (July 1965)
3. Jepson, M. D., et al, "Transformation Behavior of Some Dilute Uranium Alloys." UKAEA Report P/27.
4. White, D. W. Jr., "Transformation Kinetics in Uranium-Chromium Alloys." USAEC Report KAPL-595 (1951)
5. Townsend, R. D., and Burke, J., "The M_s Temperature for Pure Uranium." J. of Nucl. Mat., Vol. 17, p. 279-281 (1965)

Figure 1. Dilatometer Design to Register Contraction during Isothermal Beta-to-Alpha Transformations.

Figure 2. Heating and Quenching Apparatus for Determination of Beta-to-Alpha TTT Diagrams.

Figure 3. TTT Diagram for Isothermal Beta-to-Alpha Transformation of Alloy M (800 PPM Si).

The solution temperature was 1350°F. The dashed lines are indicative of the uncertainty as to the absolute location and shape of the lines.

Figure 4. TTT Diagrams for Isothermal Beta-to-Alpha Transformation of Alloy DD7 (650 PPM Al). The solution temperature was 1350°F. Only the upper portion of the diagram could be determined.

Figure 5. TTT Diagram for Isothermal Beta-to-Alpha Transformation of Alloy F87 (250 PPM Fe, 330 PPM Si, 670 PPM Al, 200 PPM Cr, 600 PPM C). The solution temperature was 1350°F.

Dashed portions of the lines indicate uncertainty as to proper position.

Figure 6. TTT Diagram for Isothermal Beta-to-Alpha Transformation of Alloy CS (Centrifugally Cast, 260 PPM Fe, 330 PPM Si, 930 PPM Al, 190 PPM Cr, 60 PPM C). Solution temperature was 1350°F. Dashed portions of lines indicate uncertainty as to absolute position.

Figure 7. TTT Diagram for Isothermal Transformation of Alloy CS (Centrifugally Cast, 260 PPM Fe, 330 PPM Si, 930 PPM Al, 190 PPM Cr, 60 PPM C) Quenched from the Gamma Phase at 1472°F. Dashed lines refer to behavior during initial quenches of the samples in question. Solid lines represent transformation behavior in subsequent quenches.

Figure 8. As-Cast Microstructure of Alloy CS.
Upper picture with polarized light, lower
with dark field illumination. 100X.

Figure 9. Isothermal Transformation Structures of Alloy CS.

Upper picture of each pair with polarized light, lower with dark field illumination. All quenched from 1350°F. All at 100X.

The pair shown above: (a) Transformed at 1154°F.

Figure 9 (Continued).

(b) Transformed at 1053°F.

Figure 9. (Continued).

(c) Transformed at 980°F.

Figure 9 (Continued).

(d) Transformed at 930°F.

Figure 9 (Continued).

(e) Transformed at 858°F.

Figure 9 (Continued).

(f) Transformed at 836°F.

Figure 9 (Continued).

(g) Transformed at 821°F.

Figure 9 (Continued).

(h) Transformed at 700°F.

Figure 10. Isothermal Transformation Structures of Alloy CS when Quenched from the Gamma Phase at 1472°F. Upper picture of each pair with polarized light, lower with dark field illumination. All at 100X.

The pair shown above: (a) Transformed at 1154°F.

Figure 10 (Continued).

(b) Transformed at 1053°F.

Figure 10 (Continued).
(c) Transformed at 922°F.

Figure 10 (Continued).

(d) Transformed at 860°F.