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Y-2135

FABRICATION AND CHARACTERIZATION OF URANIUM-6 NIOBIUM ALLOY PLATE WITH IMPROVED HOMOGENEITY

W. B. Snyder

October 1978

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UNION CARBIDE

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OAK RIDGE, TENNESSEE

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U.S. GOVERNMENT *Contract W-7405 eng 26*

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Y-2135

FABRICATION AND CHARACTERIZATION OF URANIUM-6 NIOBIUM ALLOY PLATE WITH IMPROVED HOMOGENEITY

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Under US Government Contract W-7405-eng-26

ABSTRACT

Chemical inhomogeneities produced during arc melting of uranium-6 weight percent niobium alloy normally persist during fabrication of the ingot to a finished product. The present investigation was directed toward producing a more homogeneous product (~13.0-mm plate) by a combination of mechanical working and homogenization. Ingots were cast, forged to various reductions, homogenized under different conditions, and finally rolled to 13.0-mm-thick plate. It was concluded that increased forging reductions prior to homogenization resulted in a more homogeneous plate. Comparison of calculated and experimentally measured niobium concentration profiles indicated that the activation energy for the diffusion of niobium in uranium-niobium alloys may be lower than previously observed.

CONTENTS

SUMMARY

The purpose of this study was to determine if more chemically homogeneous plate of the uranium-6 weight percent niobium alloy could be produced by a combination of mechanical working and homogenization. Ingots were cast, forged to various reductions, homogenized under different conditions, and finally rolled to 13.0-mm-thick plate. Conclusions were that increased forging reductions prior to homogenization produced a more homogeneous plate. Comparison of calculated and experimentally measured niobium concentration profiles indicated that the activation energy for the diffusion of niobium in uranium-niobium alloys may be lower than previously observed.

INTRODUCTION

Prior analyses of arc-cast uranium-6 weight percent niobium alloy (U-6 Nb) billets have shown a considerable degree of both micro and macrosegregation present in the ingots.[1] Homogenization studies conducted on as-cast material showed that microsegregation could be adequately reduced by homogenizing the ingot for either six hours at 1100° C or ten hours at 1050° C. These treatments, however, have essentially no effect on the macrosegregation (or banding) observed in the cast ingots. A model developed during the course of the homogenization experiments predicted that forging prior to homogenization should minimize the banding effects. The present experiment, conducted at the Oak Ridge Y-12 Plant,[a] was designed to investigate the effects of forging and homogenizing treatments on the homogeneity of U-6 Nb plate.

High-temperature (> 1050° C) homogenization produces a very large grain size. Without grain growth, the ideal means of producing homogeneous plate would be to forge and roll the plate to its final thickness (obtaining maximum reduction), and then homogenize. Because of grain growth it was necessary to consider a process which allowed a grain-refining step before final heat treating of the U-6 Nb plate.

(a) Operated by the Union Carbide Corporation's Nuclear Division for the Department of Energy.

FABRICATION AND CHARACTERIZATION OF URANIUM-6 NIOBIUM ALLOY PLATE WITH IMPROVED HOMOGENEITY

EXPERIMENTAL WORK

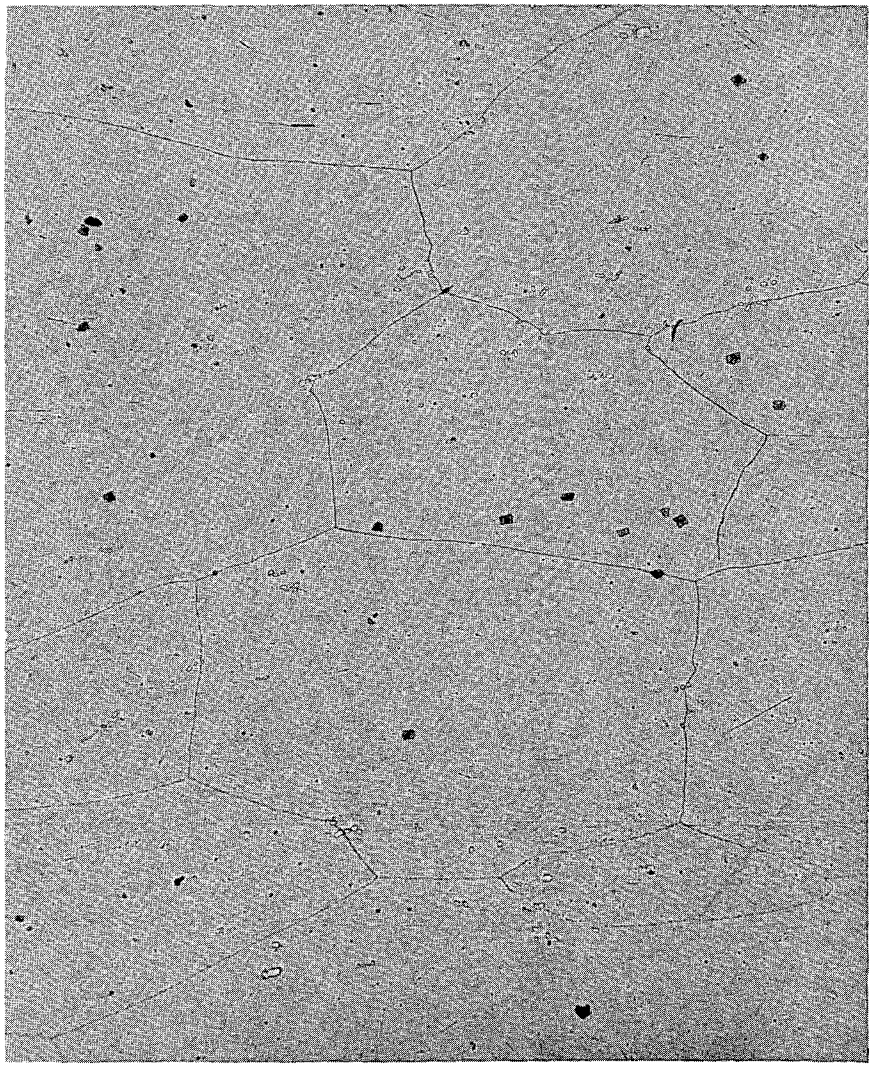
A preliminary set of experiments determined the extent of cold rolling, warm rolling, or hot rolling necessary for subsequent recrystallization of large-grained, homogenized plate. Plate for this experiment was produced by vacuum arc melting, forging, and round rolling a 150-mm-long by 150-mm-diameter recycle billet according to standard Oak Ridge Y-12 Plant practices. Specimens (50.0 x 62.5 mm), cut from this 14.4-mm-thick plate, were homogenized for twelve hours at 1175° C in a vacuum of $< 7 \times 10^{-3}$ Pa. After homogenizing, all specimens were heat treated for one hour at 800° C in a vacuum of $< 7 \times 10^{-3}$ Pa and water quenched. Specimens were cross rolled to various reductions at room temperature, 200° C, and 800° C, and subsequently annealed for one hour at 800° C in a vacuum of $< 7 \times 10^{-3}$ Pa and water quenched. The extent of recrystallization of each rolled specimen was determined by optical metallography of a mounted-specimen cross section.

Based on the results obtained on the specimens, a second set of large plates was produced by forging 150 by 150-mm-diameter billets (from recycle ingots) to various reductions, homogenizing, and round rolling either hot at 850° C from a molten salt bath or warm at 200° C from an argon furnace. After final heat treating of these plates for one hour at 800° C and water quenching, metallographic specimens were cut from the edge and center of each plate and mounted in epoxy such that a surface normal to the rolling direction was exposed. Electron microprobe scans were made along the thickness dimension of all plate specimens at intervals of 10 μm (1500 μm, total scan) and 50 μm (7500 μm, total scan). At each data point, the niobium L_α radiation was counted for thirty seconds. Calculations and plots of theoretical-concentration profiles were made by using a Hewlett Packard 9821A computer and 9862 plotter. Grain-size estimates were made by using the untwinned ASTM grain-size charts.

RESULTS

Preliminary Study

A summary of the results that were obtained from rolling the small (14.4 x 50.0 x 62.5-mm) homogenized specimens will be given first, then the data from the processing of full-sized plates will be presented later. A view of the microstructure of a small specimen after homogenizing for 12 hours at 1175° C, followed by solution heat treating for one hour at 800° C and water quenching, is given in Figure 1. The large grain size (ASTM 00) illustrates the need for a grain-refining step prior to final heat treatment. Three of the specimens were cold rolled on the Metallurgical Development two-high mill. Data from these rolling tests are recorded in Table 1. Using small reductions per pass, it was possible to roll the material to a total of 17% thickness reduction. Larger reductions per pass resulted in extensive cracking of the homogenized specimens. Samples were cut from the 17% cold-worked specimen and annealed for one hour at 800° C, followed by a water quench. As seen in Figure 2, the



M287-1

Figure 1. MICROSTRUCTURE OF A 12.5-mm SPECIMEN AFTER HOMOGENIZING FOR 12 HOURS AT 1175° C, VACUUM HEAT TREATING FOR ONE HOUR AT 800° C, AND WATER QUENCHING. (Bright Field Illumination; 100X)

Table 1

SUMMARY OF THE ROOM-TEMPERATURE ROLLING OF SMALL, HOMOGENIZED SPECIMENS

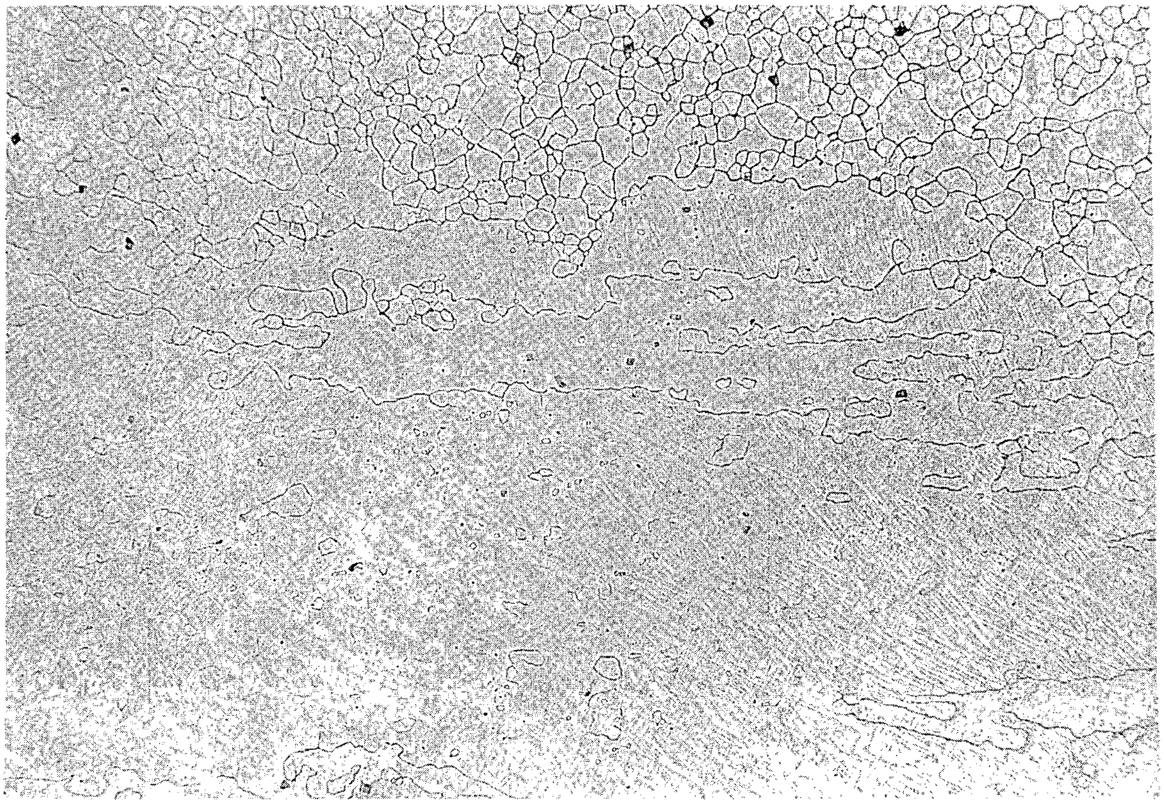
	Specimen(1)		
	1(2)	2(3)	3(4)
	Pass 1		
Reduction (%)	5.8	13.0	15.3
	Pass 2		
Reduction (%)	7.2	12.3	
	Pass 3		
Reduction (%)	4.9		
Total Reduction (%)	17.0	21.0	15.3

(1) All specimens had an initial thickness of 14.4 mm and were homogenized at 1175° C for 12 hours, heat treated one hour at 800° C, and water quenched.

(2) Slightly edge cracking on the last pass.

(3) Cracked on the second pass.

(4) Cracked on the first pass.



MS-77-0409-1

Figure 2. MICROSTRUCTURE OF A URANIUM-6 NIOBIUM SPECIMEN THAT HAS BEEN HOMOGENIZED FOR 12 HOURS AT 1175° C, HEAT TREATED FOR ONE HOUR AT 800° C, WATER QUENCHED, COLD WORKED 17 PERCENT, VACUUM HEAT TREATED FOR ONE HOUR AT 800° C, AND WATER QUENCHED. (Bright Field Illumination; 100X)

material was only partially recrystallized by this cold working-and-annealing treatment. Since the limit of cold working prior to cracking appeared to be approximately 20% for the homogenized plates, additional plates were rolled at 200 and 700° C. [It should be mentioned that U-6 Nb plate which has a moderate grain size (ASTM 5 - 6) can be cold worked to a total of 50% reduction at room temperature; therefore, the room-temperature ductility of the alloy appeared to be sensitive to grain size at reasonably high strain rates.]

Data for three small specimens which were rolled at 200° C from an argon furnace are listed in Table 2. The limit of warm working appears to be between 30 and 46% reduction, which was a factor of 2 to 3 greater than that achievable at room temperature. Samples of each of the rolled specimens were heat treated at 800° C for one hour and water quenched. The microstructures of the specimens can be seen in Figure 3. There was a duplex grain size present in all specimens; however, the material which received only 30% work contained several large areas which were unrecrystallized. Since the plates which were worked 46 and 48% were fully recrystallized, a reduction of 40% (between 30 and 46%), followed by heat treating at 800° C for one hour, was conjectured to be adequate to recrystallize the homogenized material. It also seemed that a longer heat treatment at 800° C would tend to give the final recrystallized plate a more uniform grain size.

In addition to the warm-rolling treatment, four specimens were also hot rolled from a salt bath at 700° C. Table 3 reports the results of the rolling experience for these four specimens. Specimen 1 was the first one to be rolled and did not receive a reheat. Because of the time consumed during measurement of thickness during rolling, Specimen 1 cooled to a black heat range and cracked on the last pass. Subsequent plates were given more substantial incremental reductions (up to 46.8%) in order to keep the billet at least above a dark red heat. There appeared, from these tests, to be no limit to the amount of rolling reduction the homogenized material would accommodate if it were kept above 700° C. Samples from each of the specimens were heat treated for one hour at 800° C and water quenched. The microstructure of each of the specimens is shown in Figure 4. Hot rolling 50% at 700° C, followed by 800° C for one hour, appeared to be inadequate to fully recrystallize the homogenized specimens. Specimens which received 60% hot working exhibited a few isolated areas showing incomplete recrystallization. At 69 and 74% reduction, recrystallization was complete and reasonably uniform.

Table 2

SUMMARY OF 200° C ROLLING OF SMALL, HOMOGENIZED SPECIMENS

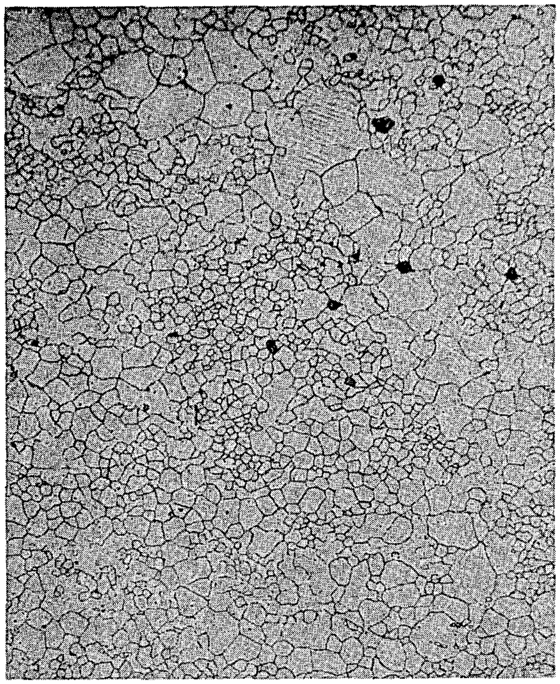
	Specimen(1)		
	1(2)	2(3)	3(4)
	Pass 1		
Reduction (%)	3.5	7.1	8.7
	Pass 2		
Reduction (%)	7.2	10.5	12.8
	Pass 3		
Reduction (%)	9.7	9.6	14.8
	Pass 4		
Reduction (%)	13.6	13.9	13.1
	Pass 5		
Reduction (%)		16.1	11.8
Total Reduction (%)	30.1	45.7	48.0

(1) All specimens were homogenized at 1175° C for 12 hours, heat treated for one hour at 800° C, water quenched, and had a starting thickness of 14.6 mm. Specimens were heated for one half hour at 200° C prior to rolling.
(2) Rolled successfully.
(3) Cracked on the last pass.
(4) Began cracking on the third pass.

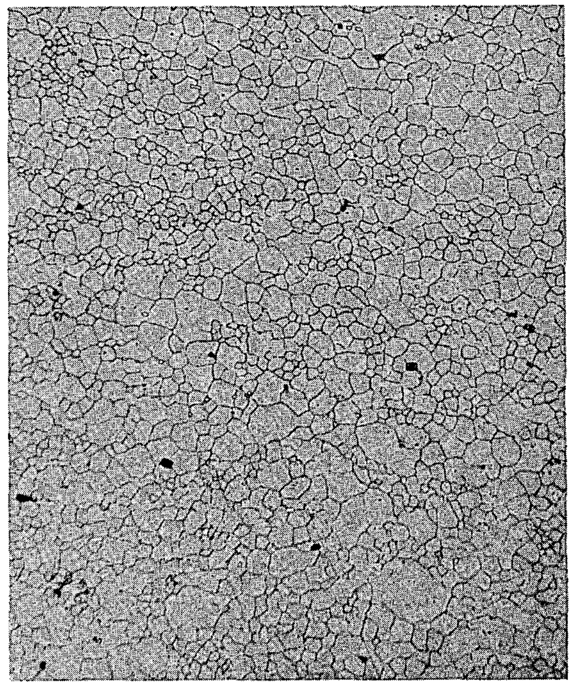
Large-Scale Study

Based on the results of the small-scale experiments, a final experiment utilizing production equipment was performed to compare the effects of different forging and homogenization treatments on the chemical homogeneity of rolled plate (Table 4). Plates of the first three processes received a 3.14:1 forging reduction, homogenization, and hot rolling to approximately 70% reduction. The only difference among the three processes was the homogenization treatment. Plates of Process 4 received a 6.25:1 forging reduction, prior to homogenization, and a final warm rolling of approximately 40%. Processes 3 and 4 utilized the same homogenization, but included different reductions prior to the homogenization treatment.

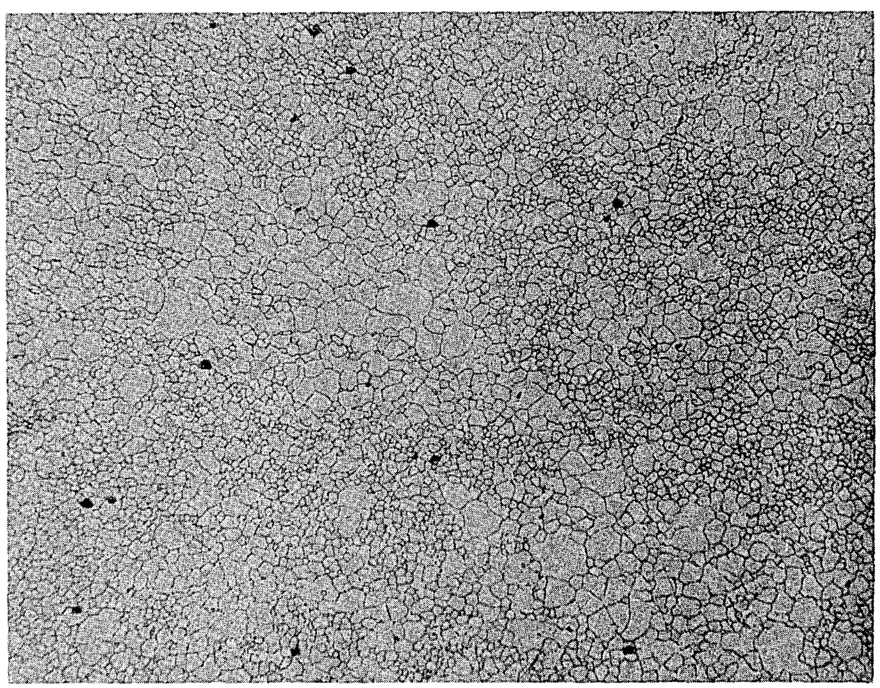
Prior experiments on as-cast ingots have shown that the inadvertent homogenization of billets in Processes 3 and 4 should have had essentially no effect on the chemical homogeneity of the rolled plate.[1] During forging of billets in Processes 3 and 4, edge cracking occurred which was most likely due to severe forging reductions between reheats. Subsequent billets have been processed in a similar manner by using less severe reductions, and no edge cracking has been observed.[2] Before homogenizing and rolling, billets of



(a) Rolled to 30.0% Total Reduction. M290-1



(b) Rolled to 45.7% Total Reduction. M290-2



(c) Rolled to 48.0% Total Reduction. M290-3

Figure 3. MICROSTRUCTURE OF 14.4-mm SPECIMENS THAT WERE HOMOGENIZED FOR 12 HOURS AT 1175° C, HEAT TREATED FOR ONE HOUR AT 800° C AND WATER QUENCHED, ROLLED TO VARIOUS REDUCTIONS AT 200° C, THEN GIVEN A FINAL VACUUM HEAT TREATMENT FOR ONE HOUR AT 800° C AND WATER QUENCHED. (Bright Field Illumination; 100X)

Table 3

SUMMARY OF 700° C OF SMALL, HOMOGENIZED SPECIMENS

	Specimen(1)			
	1(2)	2	3	4
Pass 1				
Reduction (%)	14.8	24.0	23.5	32.2
Pass 2				
Reduction (%)	17.8	16.5	46.8	35.4
Pass 3				
Reduction (%)	13.2	20.6		39.7
Pass 4				
Reduction (%)	5.8			
Total Reduction (%)	68.9	49.6	60.0	73.5

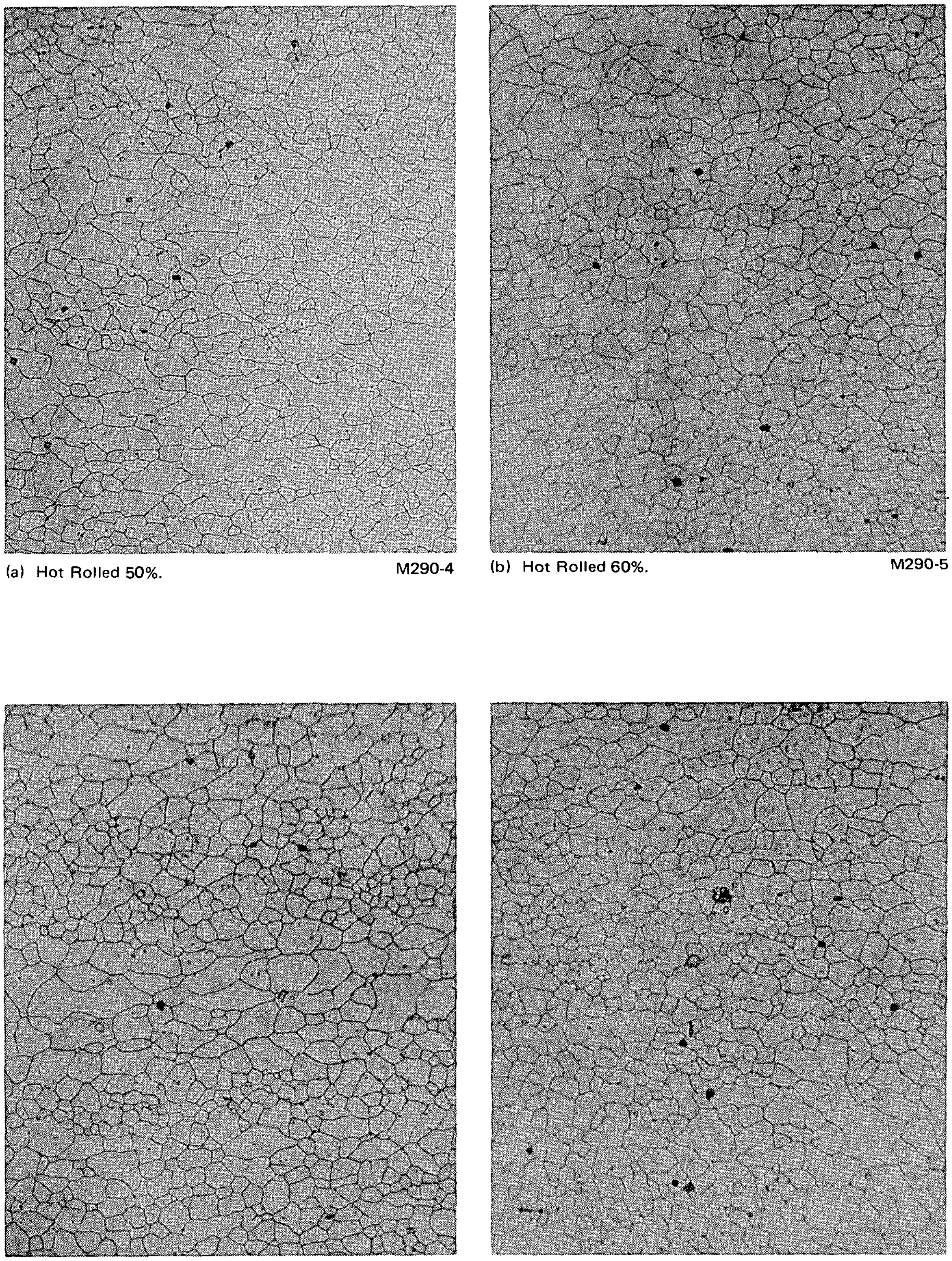
(1) All specimens were homogenized at 1175° C for 12 hours and heated in the salt bath for one half hour prior to rolling. Starting thickness, 14.6 mm.
(2) Cracked on the last pass.

Table 4

PROCESSING SCHEDULE FOR 12.5-mm PLATE

Process 1(1)	Process 2	Process 3	Process 4
Arc Melt Ingot	Arc Melt Ingot	Arc Melt Ingot	Arc Melt Ingot
Cut Billet (140 mm ϕ x 140 mm)	Cut Billet (140 mm ϕ x 140 mm)	Cut Billet(2) (140 mm ϕ x 140 mm)	Cut Billet(2) (140 mm ϕ x 140 mm)
Forge to 44.5 mm at 850° C	Forge to 44.5 mm at 850° C	Forge to 44.5 mm at 850° C	Forge to 22.4 mm at 850° C
Homogenize for 4 hrs at 1000° C	Homogenize for 10 hrs at 1050° C	Homogenize for 18 hrs at 1175° C	Homogenize for 18 hrs at 1175° C
Round Roll at 850° C to 12.5 mm(3)	Round Roll at 850° C to 12.5 mm	Round Roll at 850° C to 12.5 mm	Round Roll at 200° C to 12.5 mm

(1) Two plates were produced by each process.
(2) Homogenization of 10 hours at 1050° C inadvertently given to this billet.
(3) All plates were heat treated (immediately after rolling) for one hour at 800° C in an argon furnace and water quenched. Plates were subsequently flattened by forging between two platens and given a final vacuum heat treatment for one hour at 800° C, followed by a water quench.



(a) Hot Rolled 50%. M290-4

(b) Hot Rolled 60%. M290-5

(c) Hot Rolled 69%. M290-6

(d) Hot Rolled 74%. M290-7

Figure 4. MICROSTRUCTURE OF 14.4-mm SPECIMENS THAT WERE HOMOGENIZED FOR 12 HOURS AT 1175° C, ROLLED AT 700° C TO VARIOUS REDUCTIONS, HEAT TREATED FOR ONE HOUR AT 800° C, AND WATER QUENCHED. (Bright Field Illumination; 100X)

Processes 3 and 4 were machined to remove any edge cracking. Plates in Processes 1 through 3 were hot rolled according to the schedule shown in the left-hand column of Table 5, while plates of Process 4 were warm rolled according to the schedule given in the right-hand column. Plates in Processes 1 and 2 were rolled successfully. However, because of the small size and difficulty in handling, the first plate of Process 3 cooled to too low a temperature and cracked. The second plate of Process 3 was reheated before Step 5 and rolled successfully. Both plates in Process 4 cracked on the last pass due to excessive working. However, an average total reduction of 36% was achieved prior to the last pass. Thus, it would be possible to design a warm-rolling schedule to produce a total reduction of 36% in sound plate. Such a reduction would produce full recrystallization in plate processed from homogenized billets.

Table 5

ROLLING SCHEDULE FOR FULL-SIZE PLATE

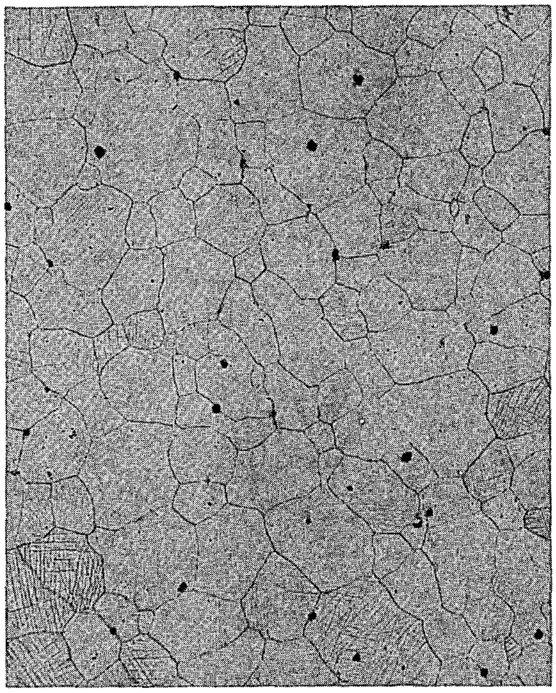
	Processes 1 through 3[1]	Process 4[2]
	Pass 1	
Reduction (%)	Nominal 10.0[3]	9.0 ↑
	Pass 2	
Reduction (%)	Nominal 10.0	14.0 →
	Pass 3	
Reduction (%)	Nominal 10.0	14.0 ↘
	Pass 4	
Reduction (%)	Nominal 10.0	11.0 ↙
	Passes 5 - 10	
Reduction (%)	Nominal 10.0	
Total Reduction (%)	71.0	41.0[4]

(1) Rolling temperature, 850° C; starting thickness, ~44 mm.
(2) Rolling temperature, 200° C; starting thickness, ~22 mm.
(3) All percent reductions are nominal reductions.
(4) Both plates cracked on the last pass.

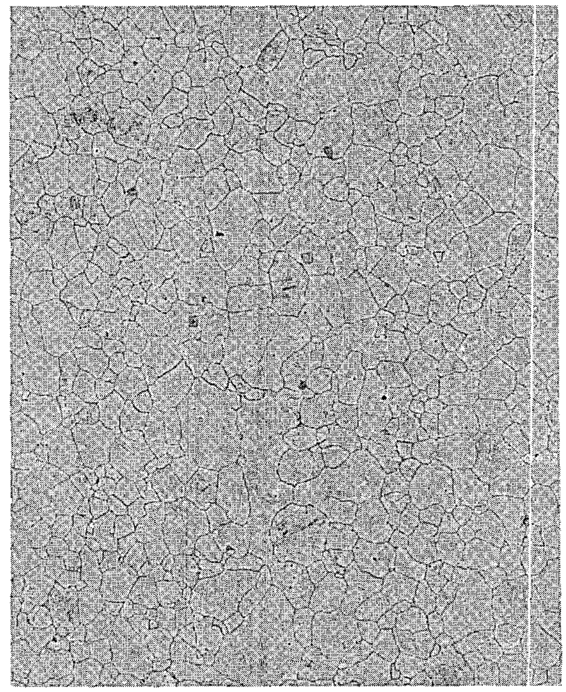
Optical microstructures taken from the center of representative plates of all four processes are shown in Figure 5. Plate produced by Process 1 had the largest grain size (ASTM 4 - 5), whereas plates from Process 4 had the smallest grain size (ASTM 8 - 8½). Plates from Processes 2 and 3 had an intermediate grain size (ASTM 6½ - 7½).

In a prior study,[3] it was discovered that chemical inhomogeneities in plates of U-6 Nb could be accentuated by heat treating for one half hour at 600° C and water quenching. Because the rate of decomposition of the gamma phase was very sensitive to niobium concentration, pearlite formed first in the niobium-rich areas, thus outlining regions of high niobium content. Specimens from the center region of plates produced in the four processes were heat treated isothermally for one half hour at 600° C in vacuum and water quenched. Polarized-light microstructures of these plates are included (Figure 6). As a more complete check on the chemical homogeneity of the plates, microprobe traces for niobium were made on the specimens of Figure 4. These traces (shown in Figures 7 and 8) were made at increments of 10 and 50 μm over distances of 1500 and 7500 μm, respectively.

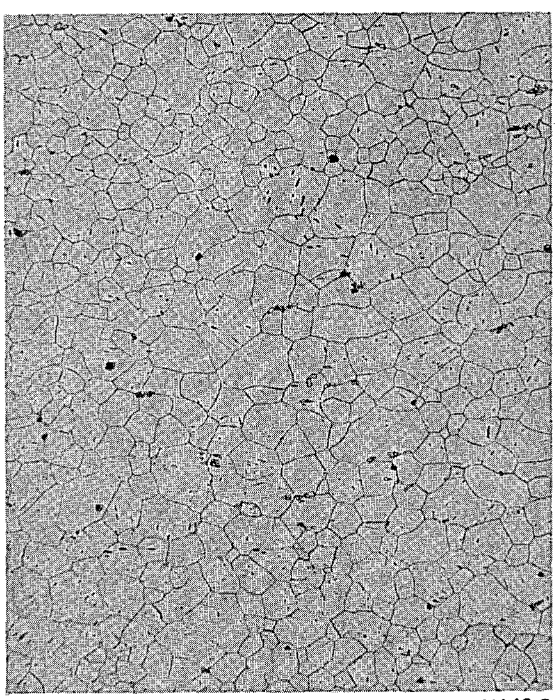
Theoretical calculations of niobium-concentration profiles for forged, homogenized, and rolled plate were performed by using the following equation:[1]



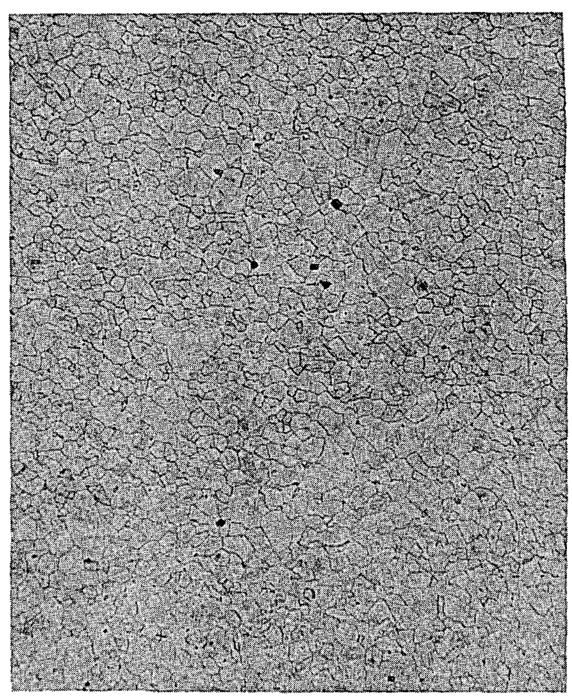
(a) Process 1. (ASTM 4 - 5) M423-1



(b) Process 2. (ASTM 7 - 7 1/2) M374

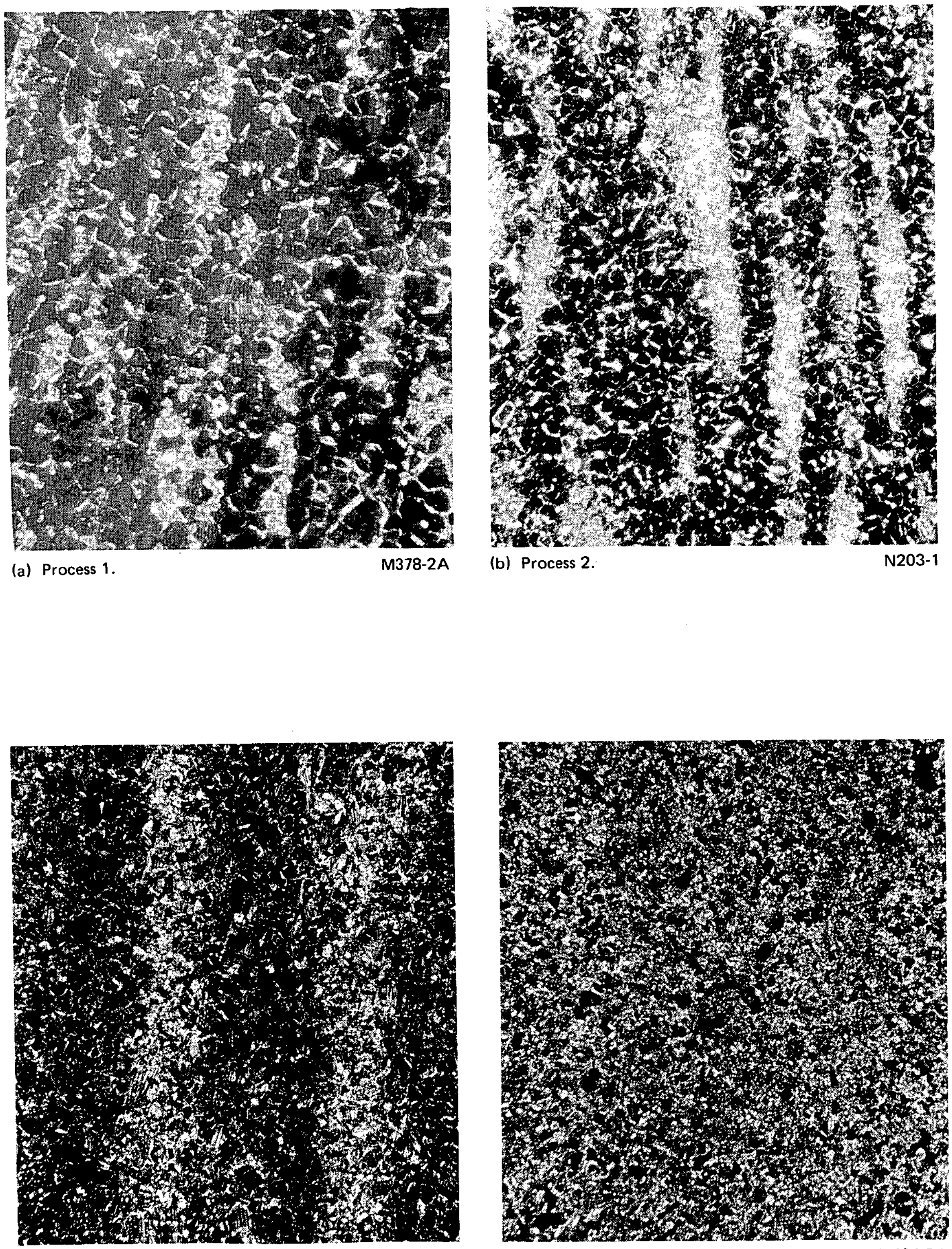


(c) Process 3. (ASTM 6 1/2 - 7) N146-2



(d) Process 4. (ASTM 8 - 8 1/2) M404-1A

Figure 5. OPTICAL MICROSTRUCTURE OF PLATES THAT WERE PRODUCED BY THE FOUR PROCESSES. (Bright Field Illumination; 100X)



(a) Process 1. M378-2A (b) Process 2. N203-1

(c) Process 3. M377 (d) Process 4. M404-3A

Figure 6. MICROSTRUCTURE OF THE CENTER PORTION OF PLATES THAT WERE FABRICATED BY THE FOUR PROCESSES, ISOTHERMALLY HEAT TREATED AT 600° C FOR ONE HALF HOUR, AND WATER QUENCHED. (Polarized Light; 50X)

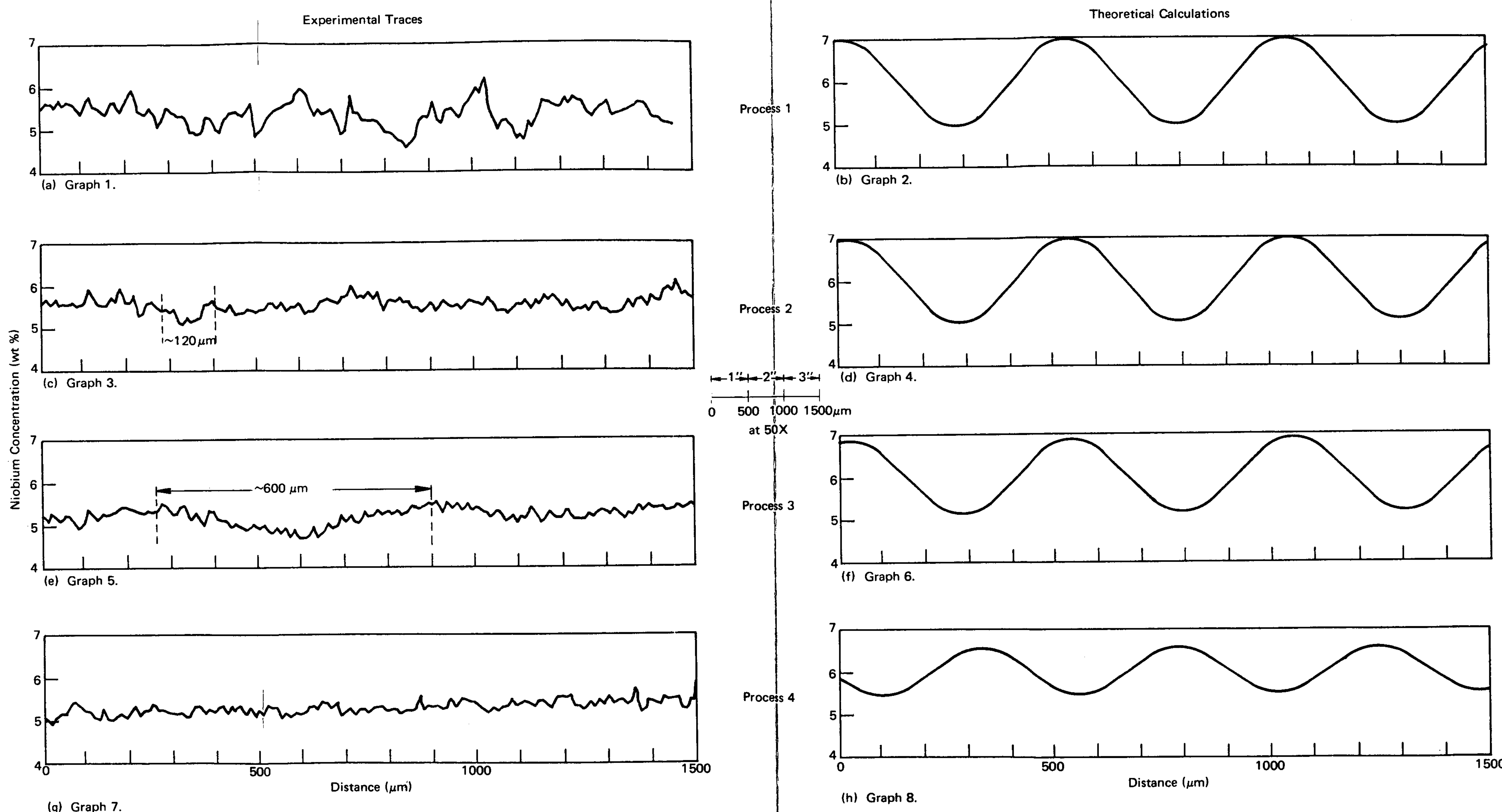


Figure 7. MICROPROBE TRACES AND THEORETICAL CALCULATIONS OF THE NIOBIUM DISTRIBUTION THROUGH THE THICKNESS OF 12.5-mm URANIUM-6 NIOBIUM PLATE. (Process 1 - 3.14:1 Forging Reduction, 4-Hour Homogenization at 1000° C; Process 2 - 3.14:1 Forging Reduction, 10-Hour Homogenization at 1050° C; Process 3 - 3.14:1 Forging Reduction, 18-Hour Homogenization at 1175° C; Process 4 - 6.25:1 Forging Reduction, 18-Hour Homogenization at 1175° C; Each Data Point was Taken at a 10-μm Interval)

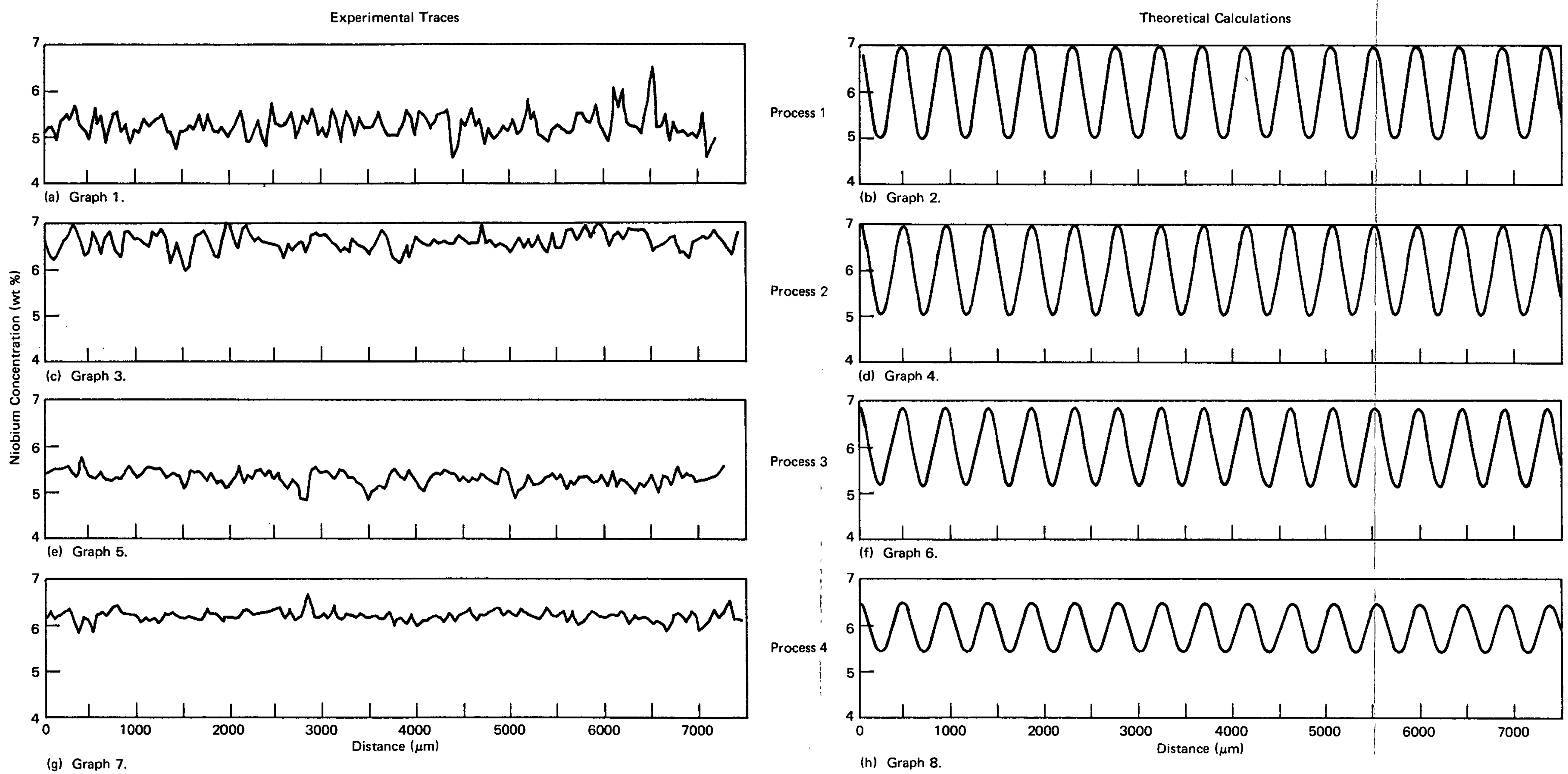


Figure 8. MICROPROBE TRACES AND THEORETICAL CALCULATIONS OF THE NIOBIUM DISTRIBUTION THROUGH THE THICKNESS OF A 12.5-mm URANIUM-6 NIOBIUM PLATE. (See Title to Figure 18 for Descriptions of the Four Processes; Each Data Point was Taken at a 50-μm Interval)

$$C(x,t) = C_o + A_c \left[\cos\left(\frac{\pi x}{W_c}\right)\right]\left[\exp\left(\frac{-\pi^2 Dt}{(W_c)^2\, 10^{-8}}\right)\right] + A_b \left[\cos\left(\frac{\pi x}{W_b}\right)\right]\left[\exp\left(\frac{-\pi^2 Dt}{(W_b)^2\, 10^{-8}}\right)\right] . \quad (1)$$

This equation gives the niobium concentration at any distance, x, after a given diffusion time, t. The diffusion coefficient is given as $D = 1.4 \times 10^{-4} \exp(-36{,}200/RT)$ $cm^2/sec.$[4] In Equation 1, A_c is the amplitude of the interdendritic (short-wavelength) segregation (in wt %), which has been measured on as-cast material to be 2.5 wt %; A_b is the amplitude of banding (long-wavelength) segregation (in wt %), which has also been measured on as-cast material to be 1.0%; W_c is half the interdendritic spacing (in μm), which has been measured on as-cast material to be ~75 μm; W_b is half the banding spacing (in μm), measured to be ~2500 μm for as-cast material, and C_o was taken to be 6.0, which is the nominal composition of the alloy.

Concentration profiles for 12.5-mm-thick plate were produced by assuming that interdendritic spacing, W_c, and interband spacing, W_b, were reduced from those of the cast ingot by the appropriate forging ratios. For instance, if the billet was reduced from 137.7 mm in height to 44.5 mm (a ratio of 3.14:1) before homogenizing, W_c and W_b were reduced by the same ratio before the effects of homogenizing were calculated. It was also assumed that no further homogenization occurred during rolling and final heat treatment. The final profiles were plotted on a scale which accounted for a total reduction from ingot to plate of 11:1.

DISCUSSION OF RESULTS

Observed Microstructure

The sensitivity of large-grained (ASTM 00) U-6 Nb to cracking during cold rolling was somewhat surprising and required an examination of alternate methods of grain refinement. A review of available literature on the uranium-rich, uranium-niobium alloys indicates that no systematic study of the effects of either strain rate or grain size on the mechanical properties of the U-6 Nb alloy has been performed. Such a study should be undertaken to more clearly define the working range of homogenized ingots and billets.

A wide variation in grain size was noted in plates produced from all four processes (Figure 5). Warm rolling would normally be expected to produce a finer-grained material; and, in this instance, plate of Process 4 had a very fine grain size (ASTM 8 - 8½). However, the variation of grain size in the plates of Processes 1 through 3 was unexpected. It would be anticipated that the extensive homogenization given the billets of Process 3 would result in the largest-grained material. However, Process 1, which included the lowest-temperature homogenization treatment, yielded the largest grain size. There appears to be no suitable explanation for this effect.

Clearly, the most homogeneous plates produced were those from Process 4. Microprobe traces of these plates at both 10 and 50-μm increments show the most consistent uniformity in niobium content (Figures 7 and 8). The microstructure of this plate (Figure 6, View d) was also the most uniform. Of the four processes, Process 1, which represents the current Y-12 Plant standard practice, produced the poorest plates from the standpoint of niobium uniformity. Microprobe traces of these plates showed a variation in niobium content of from 4.6 to 6.2%. Microprobe traces of plates from Processes 2, and 3 appeared to be very similar. A closer examination of these traces revealed that the plate of Process 2 contained more short-range homogeneities (Figure 7, Graph c), while plate from Process 3 contained longer-range inhomogeneities, Graph e. The microstructures of these two plates also exhibited similar differences. Plate 2 showed many shorter, more closely spaced bright areas, which correspond to regions of higher niobium content. On the other hand, Plate 3 showed very regularly spaced regions of high niobium content (brighter bands) which extend for long distances parallel to the plane of the plate. The measured wavelength of banding segregation in Graph e (Figure 7), 600 μm, corresponds to a banding spacing of 6600 μm in the as-cast ingot (using an 11:1 reduction from ingot to plate). Considering the variation which exists in band spacing, the 6600 μm is in reasonable agreement with the 5000 μm estimated in previous studies.[1] A comparison of Graphs c, e, and g of Figure 7 shows that increased forging reduction, prior to homogenization (Graphs e and g), was more important than higher temperatures and longer soak times during homogenization (Graphs c and e).

Comparison to the Model

Predictions of plate inhomogeneities from the model used were quite inaccurate. For instance, the maximum variation in niobium content calculated for Graph f (Figure 7) was ± 0.8 wt %, while the measured variation was ± 0.3 wt %. In examining the model, it appeared reasonable to assume a reduction in interband spacing equivalent to the forging reduction. Measurements such as those of Graph e substantiated the assumption. However, it seemed that the activation energy for the diffusion of niobium in uranium might be lower than that of Peterson and Ogilvie,[4] used in the model. It was noted by Peterson and Ogilvie that the activation energy was perhaps a function of composition. However, they did not determine the compositional dependence and it, therefore, was not included in the model. Figure 9 illustrates the effect of lowering the activation energy of 32,600 cal/mole by 10% (29,340 cal/mole) and 15% (27,710 cal/mole). The conditions of forging and homogenization

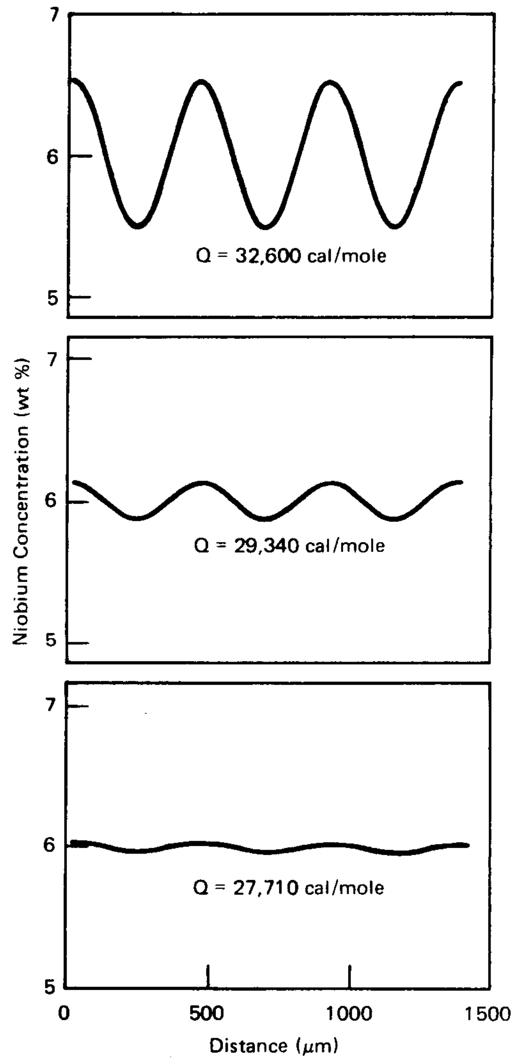


Figure 9. EFFECT OF LOWERING THE DIFFUSION ACTIVATION ENERGY FOR NIOBIUM IN URANIUM (BY 10 AND 15%) ON THE COMPUTED CONCENTRATION PROFILES. (Compared these Curves with Graphs g and h of Figure 8)

for Figure 9 are identical to those of Graphs g and h of Figure 8; ie, 6.25:1 forging reduction and 18 hours at a 1175^{o} C homogenization treatment. Note that the experimental data of Graph g are in very good agreement with the activation energy between 27,710 and 29,340 cal/mole. These results would thus suggest that the activation energy for niobium diffusion in the U-6 Nb alloy may be lower than that measured previously by diffusion couples. Though the model, as used, did not predict the exact niobium profile in the plate, prior calculations had successfully predicted an improvement in homogeneity due to increased forging prior to homogenization.[1]

CONCLUSIONS

The following conclusions have been reached as a result of this study:

1. Plates of the U-6 Nb alloy can be produced with a very uniform chemical homogeneity and a fine grain size.

2. U-6 Nb alloy exhibits a reduction in ductility at room temperature with increasing grain size.

3. Increased forging reductions, prior to homogenization, produces better chemical homogeneity than increasing time and temperature of the homogenization treatment.

4. Calculations of the effect of forging on homogeneity of rolled plate suggests that the activation energy for the diffusion of niobium may be lower in uranium-niobium alloys than previously measured.

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