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HIGH-STRENGTH URANIUM-0.8 WEIGHT PERCENT
TITANIUM ALLOY PENETRATORS

W. G. Northcutt

September 1978

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**HIGH-STRENGTH URANIUM-0.8 WEIGHT PERCENT
TITANIUM ALLOY PENETRATORS**

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Metallurgy Department
Y-12 Development Division

Funds for this study were provided by the US Army
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ABSTRACT

Long-rod kinetic-energy penetrators, produced from a uranium-0.8 titanium (U-0.8 Ti) alloy, are normally water quenched from the gamma phase ($\sim 800^{\circ}\text{C}$) and aged to the desired hardness and strength levels. High cooling rates from 800°C in U-0.8 Ti alloy cylindrical bodies larger than about 13 mm in diameter cause internal voids, while slower rates of cooling can produce material that is unresponsive to aging. For the present study, elimination of quenching voids was of paramount importance; therefore, a process including the quenching of plate was explored. Vacuum-induction-cast ingots were forged and rolled into plate and cut into blanks from which the penetrators were obtained. Quenched U-0.8 Ti alloy blanks were aged at 350 to 500°C to determine the treatment that would provide maximum tensile and impact strengths. Both tensile and impact strengths were maximized by aging in vacuum for six hours at 450°C .

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SUMMARY

A fabrication process was examined for producing high-strength uranium-0.8 titanium (U-0.8 Ti) alloy penetrators. Centerline-void formation was avoided by water quenching plate which had been forged and rolled from vacuum-induction-cast ingots. Strengthening of the uranium-titanium alloy was maximized by heat treating at 450° C for six hours.

INTRODUCTION

Uranium-0.8 titanium alloy penetrators were requested by the US Army Ballistic Research Laboratories (BRL) as part of the Army's long-rod kinetic-energy-penetrator development program. The Oak Ridge Y-12 Plant^(a) has provided tungsten-alloy penetrator development and hardware production support to the BRL and other Army agencies since 1973.

Initial requirements for the U-Ti alloy penetrator cores were that they have density and strength properties similar to the U-Ti alloy produced for DOE weapons programs. Centerline defects in finished rounds were to be prevented. Since the U-Ti system can be age hardened to high strength levels, Y-12 and the BRL agreed to investigate the use of higher-strength material for penetrator application. This report describes the fabrication procedure developed to prevent the centerline defects and the development of the aging heat treatment.

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

HIGH-STRENGTH URANIUM-0.8 WEIGHT PERCENT TITANIUM ALLOY PENETRATORS

EXPERIMENTAL WORK

Background

Fabrication procedures for uranium-titanium alloys have been well documented.¹ To produce the required part, forward extrusion of rod from a cast billet would be one obvious technique. However, problems with that procedure can occur due to the need to solution heat treat in the gamma (γ) phase and water quench the extruded bar. Rapid cooling of round bars [14 mm (0.56 in)] or a larger diameter causes stresses in the bar large enough to produce void formation. Anderson² has observed centerline void formation in 38-mm (1.5-in)-diameter U-0.75 Ti extrusions after gamma quenching. The stresses produced by quenching are due to the volume change associated with the $\gamma \rightarrow \alpha'$ transformation. Quenching of plates has not been observed to cause similar void formation.

An alloy of uranium-0.8 titanium, cooled rapidly from 800° C, transforms by a martensitic reaction to a supersaturated variation of α (alpha) uranium, designated as α' (alpha prime). Strengthening of the alloy then occurs by heat treatment of the quenched alloy in the 300 - 500° C range. The mechanism for strengthening is precipitation of the intermetallic compound U_2Ti .³ Slower cooling rates from the gamma phase allow diffusional decomposition of gamma to the equilibrium $\alpha + U_2Ti$ phases. Intermediate rates of cooling will allow both the martensitic and diffusional reactions to occur.

In order to take advantage of the precipitation-hardening characteristics of the U-Ti alloy, there first must be a rapid cooling of the alloy to obtain the supersaturated alpha prime martensite. Slower rates of cooling allow increasing amounts of the diffusional $\alpha + U_2Ti$ products to form which are not amenable to age hardening. Eckelmeyer and Zanner⁴ have reported the aging response of a U-0.75 Ti alloy to be relatively unaffected if at least 50% martensite is present before aging. These authors quantitatively related experiments with Jominy end quenching with quenched plates of various thicknesses and concluded that plates thicker than 27 mm (1.06 in) would have less than 50% martensite at their centers.

For the present work, prevention of centerline voids was of prime importance, so quenching of extruded stock was not possible. To yield a blank large enough for the required penetrator part, a plate about 32 mm (1.25 in) thick would be required. Based on Eckelmeyer's⁴ results, such a plate would yield variable properties from surface to center due to differences in cooling rates at those locations. It was decided, however, to take the penetrators from plate to prevent void formation and to determine the properties of the plate through its thickness.

Tungsten-alloy-penetrator development indicated improved penetrator performance when the tungsten alloy was strengthened by cold working.⁵ Uranium-titanium alloys currently being developed for penetrator applications are strengthened by heat treatment, but

considerably increased strengths are possible with additional age hardening. Ductility decreases with further aging, but it is not known what combination of strength and ductility is required for optimum ballistic performance. It was decided to examine the room-temperature tensile and impact properties of the U-0.8 Ti alloy after aging at 350 to 500° C and select an aging treatment for the penetrators based on the mechanical-property results.

Uranium Processing^(b)

A vacuum-induction-melted-and-cast ingot [203 mm (8 in) D x 533 mm (21 in) L] was prepared. Analyses at the top and bottom of the ingot gave 0.778 and 0.792% Ti, respectively; carbon levels were 46 and 58 ppm. The cast ingot was preheated at 640° C for four hours in salt and side forged to 76 mm (3 in) in thickness. After reheating to 640° C, the forged billet was rolled in the short direction to 610 mm (24 in) long, rotated 90 degrees, and rolled to 35 mm (1.38 in) thick. The rolled plate was cut into four sections [610 mm (24 in) L x 203 mm (8 in) W x 35 mm (1.38 in) T], heated to 800° C in vacuum for eight hours, and water quenched. Care was taken to establish the best possible quenching procedure so as to minimize the amount of diffusible decomposition of gamma to $\alpha + \text{U}_2\text{Ti}$. Each section of the plate yielded four penetrator blanks which were machined to 509 mm (20 in) long by 32 mm (1.25 in) in diameter for stress leveling and aging. One penetrator blank was not stress leveled and was used to provide mechanical-property specimens. Stress-leveling and heat-treating parameters were determined from data obtained in an aging study carried out in a parallel effort to the production of the penetrators.

Aging Study

This portion of the study involved determining the effects of aging on the impact and tensile properties of quenched U-0.8 Ti. Material selected to provide blanks for aging was in the form of back-extruded hollow cylinders.^(c) Vacuum-induction castings were cut into extrusion billets and back extruded at 640° C. Cylinders [229 mm (9 in) H x 203 mm (8 in) OD x 170 mm (6.7 in) ID] were heat treated in vacuum at 800° C for four hours, water quenched, and cut into 76-mm (3-in)-high sections. One 229-mm (9-in)-high cylinder was selected after water quenching and another was upset compressively along the long axis to a 1% total strain. The compressive upset provided for stress leveling and reduced the dimensional instability of the alloy caused by residual stresses. The three sections of each cylinder were further cut into seven equal-size circular segments, each having a chord length of 76 mm (3 in). From each small segment, three tensile and three impact specimens were obtained that were oriented longitudinally in the cylinder. The segments were aged at 350 to 500° C for 6 to 15 hours in flowing argon. One segment from each cylinder was aged in each furnace run. Tensile, instrumented impact, chemical analysis, hydrogen, and metallography samples were collected from the aged segments. Standard 6.40-mm (0.252-in)-diameter tensile specimens and impact specimens [10 mm (0.394 in) x 10 mm (0.394 in) x 57 mm (2.25 in) L] were tested from each aged segment. Chemical chip samples were taken from several segments, and metallography was obtained from the specimens. Fractography was performed on tensile and impact fractures.

(b) Directed by J. M. Jones of the Y-12 Metal Preparation Division.

(c) Provided by P. S. Lewis of the Y-12 Development Division.

Figure 1. TENSILE-YIELD-STRENGTH VARIATION WITH AGING TEMPERATURE FOR URANIUM-0.8 TITANIUM ALLOY. (Aging was for Six Hours, Except as Noted by the Number Next to the Appropriate Symbols)

strong dependence on stress leveling, but it was believed that it was necessary to prevent dimensional instability during machining. Table 2 lists the Rockwell C hardness values for the aged samples. Again, the hardness increased to a maximum for material aged at 450°C for six hours.

Mechanical-property differences due to aging conditions were examined by scanning electron microscopy^(d) of tensile and impact-fracture surfaces. A tensile fracture of the alloy underaged at 365°C for six

Figure 3. EFFECT OF AGING TEMPERATURE ON THE TENSILE ELONGATION OF STRESS-LEVELLED AND NOT-STRESS-LEVELLED URANIUM-0.8 TITANIUM ALLOY. (Aging was for Six Hours, Except as Noted by the Numbers Next to the Appropriate Symbols)

3. Specimens from the center of the plate thickness, both at the edge and in the middle of the plate, showed lower tensile and impact strengths than specimens near the surface. This behavior would be expected if cooling rates on quenching were too slow to obtain a high fraction of alpha prime at the center of the plate.

Hardness values across the quenched-and-aged plate thickness are reported in Figure 7. The center of the plate is seen to be harder when quenched, but softer after aging. These data agree very well with the Jominy results of Eckelmeyer and Zanner.⁴ Their estimate of the amount of alpha prime at the center of a 35-mm (1.38-in)-thick plate was about 30%. Quantitative metallography^(e) of specimens from the edge and center of the quenched plate

(d) Scanning electron microscopy performed by R. K. Bennett of the Y-12 Development Division.

(e) Performed by J. G. Greene of the Y-12 Product Certification Division.

Figure 2. VARIATION OF IMPACT YIELD STRENGTH WITH AGING TEMPERATURE FOR URANIUM-0.8 TITANIUM ALLOY. (Aging was for Six Hours, Except as Noted by the Numbers Next to the Appropriate Symbols)

hours had the ductile-dimple appearance shown in Figure 4. Aging at 450°C for six hours to maximum strength led to the fracture surfaces seen in Figures 5 and 6 for tensile and impact fractures, respectively. The brittle fracture is characterized by nearly complete absence of dimples and the appearance of cleavage-like fracture regions along the alpha-prime plates.

Specimen blanks from the water-quenched plate were obtained near the plate edge and center, and both were aged at 450°C for six hours with the first batch of round penetrator bars. Tensile, instrumented impact, hardness, and metallography data were obtained.

Tensile and impact data are reported in Table

in this study gave 30-40% alpha prime at the center and 95-100% alpha prime at the edge. Microstructures^(f) from the edge and center of the plate are shown in Figure 8. The metallography results (optical and quantitative) point out the reason for the low yield strengths (impact and tensile) at the center of the plate. The relatively large amounts (60-70%) of $\alpha + \text{U}_2\text{Ti}$ in the microstructure at the middle of the 35-mm (1.38-in)-thick plate limited the response of the alloy to precipitation hardening. No voids were present in the metallography samples from quenched plate. Round penetrator bars were examined by radiography, and no centerline voids were observed in any of the bars. Sections of several bars, up to 150 mm (~6 in) long, were heated to 800°C and water quenched. Samples across the diameters of the quenched bars were examined, and centerline voids were seen.

Table 2
HARDNESS OF AGED URANIUM-0.8
TITANIUM ALLOY

Part Number ⁽¹⁾	Aging Conditions		Rockwell C Hardness ⁽²⁾
	Temperature (°C)	Time (hr)	
1-4	350	15	42
5-12 ⁽³⁾	350	15	42
3-18	365	6	41
4-1*	365	6	42
3-17	370	8	42
6-18*	370	8	43
1-3 ⁽⁴⁾	370	8	43
5-18 ⁽⁴⁾	370	8	42
3-16	380	6	43
4-2*	380	6	42
2-13	400	6	45
4-4*	400	6	43
3-19	425	6	49
6-17*	425	6	47
1-6	450	6	50
5-13*	450	6	50
2-8	500	6	50
6-20*	500	6	48

(1) Parts marked with an asterisk were stress leveled.

(2) Average of five readings.

(3) One percent total strain in compression.

(4) Production cycle—others in the laboratory furnace.

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Figure 4. SCANNING ELECTRON FRACTOGRAPH OF A URANIUM-0.8 WEIGHT PERCENT TITANIUM ALLOY TENSILE FRACTURE. (Aged for Six Hours at 365°C; 1000X)

(f) Photomicrographs by H. C. East of the Y-12 Product Certification Division.

SM-66969

Figure 5. SCANNING ELECTRON FRACTOGRAPH OF A URANIUM-0.8 WEIGHT PERCENT TITANIUM ALLOY TENSILE SPECIMEN. (Aged for Six Hours at 450° C; 1000X)

SM-66693

Figure 6. SCANNING ELECTRON FRACTOGRAPH OF A URANIUM-0.8 WEIGHT PERCENT TITANIUM ALLOY IMPACT FRACTURE. (Aged for Six Hours at 450° C; 1000X)

The two cylinders used for the aging study to determine the aging treatment for the penetrators were found to have different titanium levels. Chemical analysis of the two parts is given in Table 4. The water-quenched part had an average titanium content of 0.817%, and the quenched-and-stressed part had 0.743% Ti. Carbon levels for the two parts were 31 and 30 ppm, respectively. These differences in chemical content do not appear, from the data obtained, to have greatly influenced the tensile or impact results. Higher titanium alloys have been found to be stronger and less ductile than lower titanium alloys when given the same processing treatment.⁷ Elongation results in Figure 3 do show higher values for the stress-leveled part, and the difference in titanium content could contribute to that difference. Microstructures of aged specimens from the two cylinders are shown in Figures 9 and 10. Initial decomposition of the alpha prime to $\alpha + \text{U}_2\text{Ti}$ is noted at the former gamma grain boundaries of Figure 9, View a. Aging at 365° C for six hours has not created large

Table 3
TENSILE AND IMPACT PROPERTIES OF URANIUM-0.8 TITANIUM ALLOY PLATE THAT WAS AGED AT 450° C FOR SIX HOURS

Specimen Location	Impact Properties ⁽¹⁾		Tensile Properties ⁽¹⁾			
	Dial Energy (J/ft lb)	Dynamic Yield Strength (MPa/ksi)	Ultimate Tensile Strength (MPa/ksi)	Yield Strength ⁽²⁾ (MPa/ksi)	Elongation ⁽³⁾ (%)	Reduction in Area (%)
Plate Edge						
Surface	43/32	2592/376.4	1751/254	1248/181	3.0	1.2
Center	35/26	2317/335.8	1579/229.4	1027/149.2	3.5	2.0
Surface	45/33	2648/384.1	1737/252.1	1213/175.9	2.0	1.2
Plate Mid						
Surface	46/34	2549/373.5	1806/261.9	1282/186.0	3.0	2.0
Center	52/38	2468/358.4	1531/221.5 ⁽⁴⁾	1069/154.9	1.5	<1
Surface	43/32	2696/390.8	1324/191.9 ⁽⁴⁾	1200/174.1	1.0	1.2

(1) Data are from single tests.

(2) At 0.2% offset.

(3) In 25.4 mm gage length.

(4) Specimen broke in the threads.

Table 4
COMPOSITIONS OF EXPERIMENTAL CYLINDERS

Element	Quenched (ppm)	Quenched and Stress Leveled (ppm)
Al	10	10
C	31	30
Cu	3	3
Fe	40	50
H	0.16	0.03
Si	70	80
Ti	0.817%	0.743%

Figure 7. VARIATION OF HARDNESS THROUGH THE THICKNESS OF WATER-QUENCHED-AND-AGED URANIUM-0.8 TITANIUM ALLOY PLATE.

(a) Surface of the Plate; 95 - 100% α' .

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(b) Center of the 1.38-Inch-Thick Plate; 30 - 40% α' .

MS-77-0533-2

Figure 8. MICROSTRUCTURES OF WATER-QUENCHED PLATE AT TWO LOCATIONS. (Light, Lenticular Phase is α' Martensite, Darker Areas are $\alpha + U_2Ti$; Bright Field Illumination; 100X)

(a) Aged at 365° C for Six Hours.

MS-77-0593-1

(b) Aged at 450° C for Six Hours

MS-77-0593-4

Figure 9. MICROSTRUCTURES OF QUENCHED-AND-AGED SPECIMENS FROM A NOT-STRESS-LEVELLED CYLINDER. (Bright Field Illumination; 100X)

(a) Aged at 425° C for Six Hours.

MS-77-0593-2

(b) Aged at 500° C for Six Hours.

MS-77-0593-5

Figure 10. MICROSTRUCTURES OF QUENCHED-AND-AGED SPECIMENS FROM A STRESS-LEVELLED CYLINDER.
(Bright Field Illumination; 100X)

amounts of the equilibrium phases, and maximum strengths are not yet attained (Figures 1 and 2). Further aging at higher temperatures [425° C (Figure 10, View a), 450° C (Figure 9, View b), and 500° C (Figure 10, View b)] reveal considerable decomposition of the martensitic phase at the grain boundaries and along the alpha-prime platelets within the grains.

Some grain-size differences are apparent between Figures 9 and 10. Stress-leveling and titanium-content differences between the two cylinders would not be expected to influence the gamma grain size. Rather, differences in location of specimens within the back extrusion are likely to be responsible for these grain-size variations. Different amounts of work are received during extrusion, depending on the location within the cylinder. Another possible reason for the grain-size difference is the gamma solution temperature. Beck⁸ showed that an increase in gamma grain size can occur at 830 to 870° C, compared to an 800° C treatment. After aging at 370° C for eight hours, his tensile data were not affected by the different gamma treatments.

CONCLUSIONS

Three conclusions can be stated as a result of this study:

1. Long-rod penetrators of U-0.8 Ti alloy were produced in the solution-water-quenched-and-aged condition without centerline voids.
2. Impact strengths of aged U-0.8 Ti alloy exhibit similar behavior to tensile yield strength, maximizing at 450° C.
3. Uranium-0.8 titanium plate, 35 mm thick and quenched from 800° C, had a variable microstructure with the amount of alpha prime decreasing from edge to center in agreement with other work.⁴

REFERENCES

1. Cadden, J. L., Jessen, N. C., and Lewis, P. S.; "Melting and Casting of Uranium Alloys", *Physical Metallurgy of Uranium Alloys*, p 3; J. J. Burke, et al, Editors, Brook Hill (1976).
2. Ammons, A. M.; "Precipitation Hardening in Uranium-Rich Uranium-Titanium Alloys", *Physical Metallurgy of Uranium Alloys*, p 511; J. J. Burke, et al, Editors, Brook Hill (1976).
3. *Ibid*, p 525.
4. Eckelmeyer, K. H. and Zanner, F. J.; *J Nuc Matls*, **67**, p 33 (1977).
5. Northcutt, W. G.; "Fabrication Development of Tungsten Alloy Penetrators", *Proceedings of the High-Density Alloy Penetrator Materials Conference*, AMMRC-SP-77-3, p 37; April 1977.
6. Eckelmeyer, K. H. and Zanner, F. J.; *J Nuc Matls*, **62**, p 37 (1976).
7. Koger, J. W. and Hemperly, V. C.; "Variables that Affect Mechanical Properties of Uranium-0.75 Titanium Alloys", *Proceedings of the High-Density Alloy Penetrator Materials Conference*, AMMRC-SP-77-3; April 1977.
8. Beck, D. E.; *Unpublished Research*; Oak Ridge Y-12 Plant.

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