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VARIABLES THAT AFFECT MECHANICAL PROPERTIES OF URANIUM-0.75 TITANIUM ALLOYS

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UNION CARBIDE

OAK RIDGE Y-12 PLANT

OAK RIDGE, TENNESSEE

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MASTER

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INTRODUCTION

Some low-level alloys of uranium can provide the metal with enhanced mechanical properties after proper heat treatment. In addition, the metallurgical processing of such alloys influences their mechanical properties. More specifically, the uranium-titanium system, with titanium as low as 0.5 wt %, can be solution treated, water quenched, and then aged to obtain high strength, good ductility, and high density, characteristics which are probably of particular interest in penetrator fabrication. This paper summarizes properties data for the U-0.75 Ti alloy as determined at the Oak Ridge Y-12 Plant of Union Carbide Corporation - Nuclear Division. Although the data reported herein were determined with the wrought alloy, similar strengths have been attained with cast metal after age hardening.

ALLOY PREPARATION

The uranium-0.75 weight percent titanium (U-0.75 Ti) is readily prepared by vacuum-induction melting of uranium with titanium sponge in refractory-washed, graphite crucibles and molds.

Some of the variables that affect the mechanical properties of the age-hardened U-0.75 Ti alloy are found in the melting practice. As is evident in Figure 1, increasing the melt temperature, time molten, and double melting, improve the strength-ductility ratio of age hardened specimens. Each slope was determined from tensile tests of specimens aged at two different temperatures. Variations of titanium level and aging temperature shift the results along the slope in each case. This technique was used to reduce the number of melts required to compare hardening response with melt practice. At a given yield strength (0.2%), the elongation is increased by double melting (DM), by 1450°C rather than 1310°C melt temperatures, and increased melt size. The larger ingots (510 x 510 x 100 mm) also represent a longer melt time than that of the small ingots (180 x 130 x 38 mm). In the melt, titanium forms a carbide which segregates to the top, so the alloy can be prepared with very low carbon levels. This process occurring during melting causes variations in titanium content depending on the carbon content in the uranium used and the pickup during melting. The tensile properties as a function of titanium content are given in Table I.

The usual low-level elements in unalloyed uranium are generally not objectionable. However, iron increases, and silicon decreases, the age hardening response of U-0.75 Ti as demonstrated in Figure 2. Tensile and yield (0.2%) strengths are plotted against silicon levels on the left and against iron levels on the right. Also, the incidental elements plus the titanium level influence the density. As prepared in the Oak Y-12 Plant, the density of the U-0.75 Ti alloy is between 18.50 and 18.56 g/cm^3.

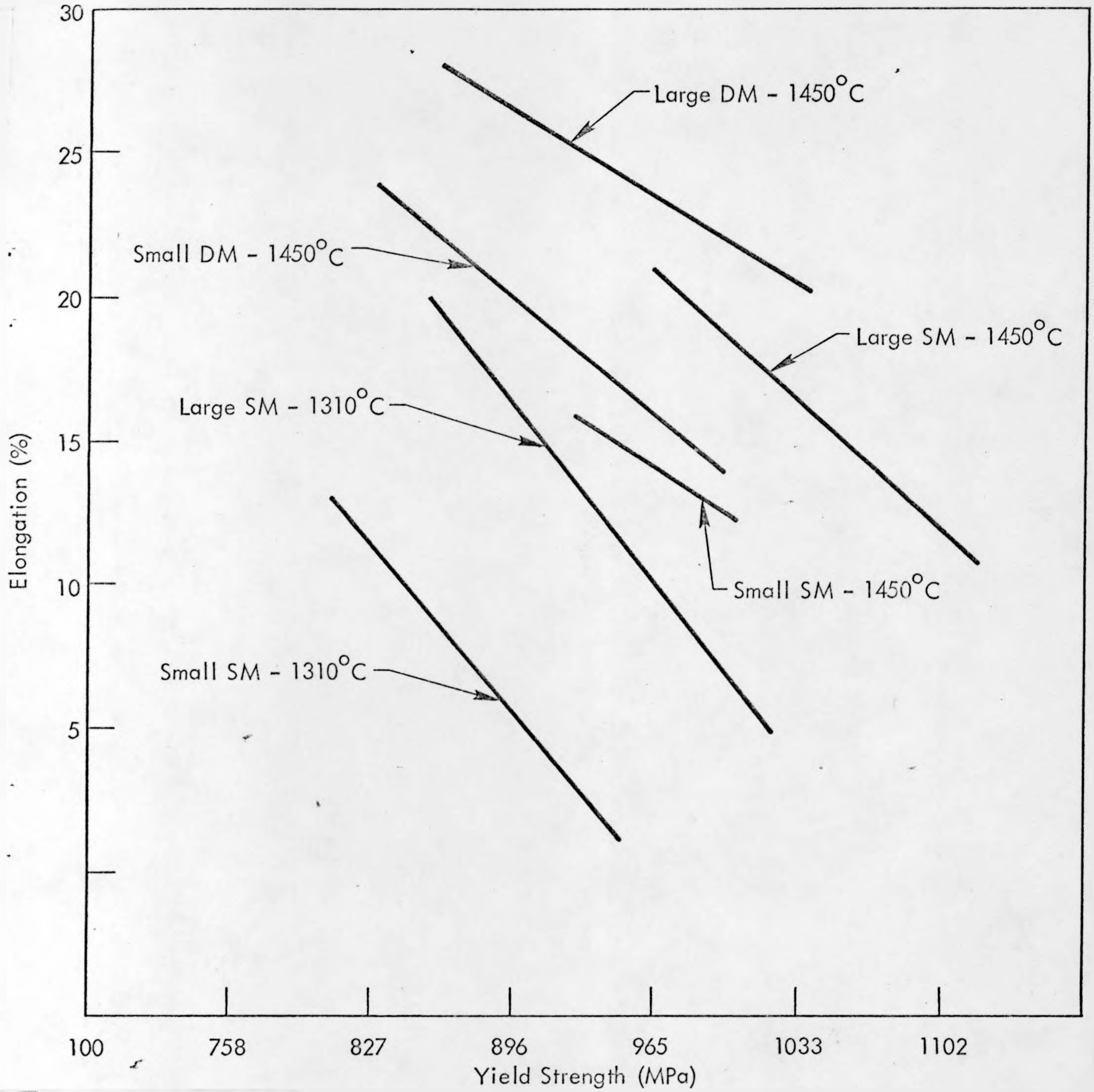
Table I

TENSILE PROPERTIES OF URANIUM-0.75 PERCENT TITANIUM
ALLOY AT SEVEN LEVELS OF TITANIUM
(Vacuum-Water Quenched and Aged at 400°C for 6 hrs.)

Titanium Level (wt %)	Yield Strength (MPa) 0.2% Offset	Yield Strength (MPa) 0.85% Extension(1)	Tensile Strength (MPa)	Elongation(2) (%)	Reduction in Area (%)
0.646-0.642	742	792	1253	14.5	14.3
0.703-0.696	820	861	1335	16.0	16.4
0.720-0.730	883	916	1381	9.0	7.8
0.755-0.765	884	923	1390	8.8	18.3
0.760-0.768	958	985	1500	6.7	6.7
0.781-0.779	925	930	1443	8.7	8.8
0.824-0.818	961	978	1457	5.2	4.0

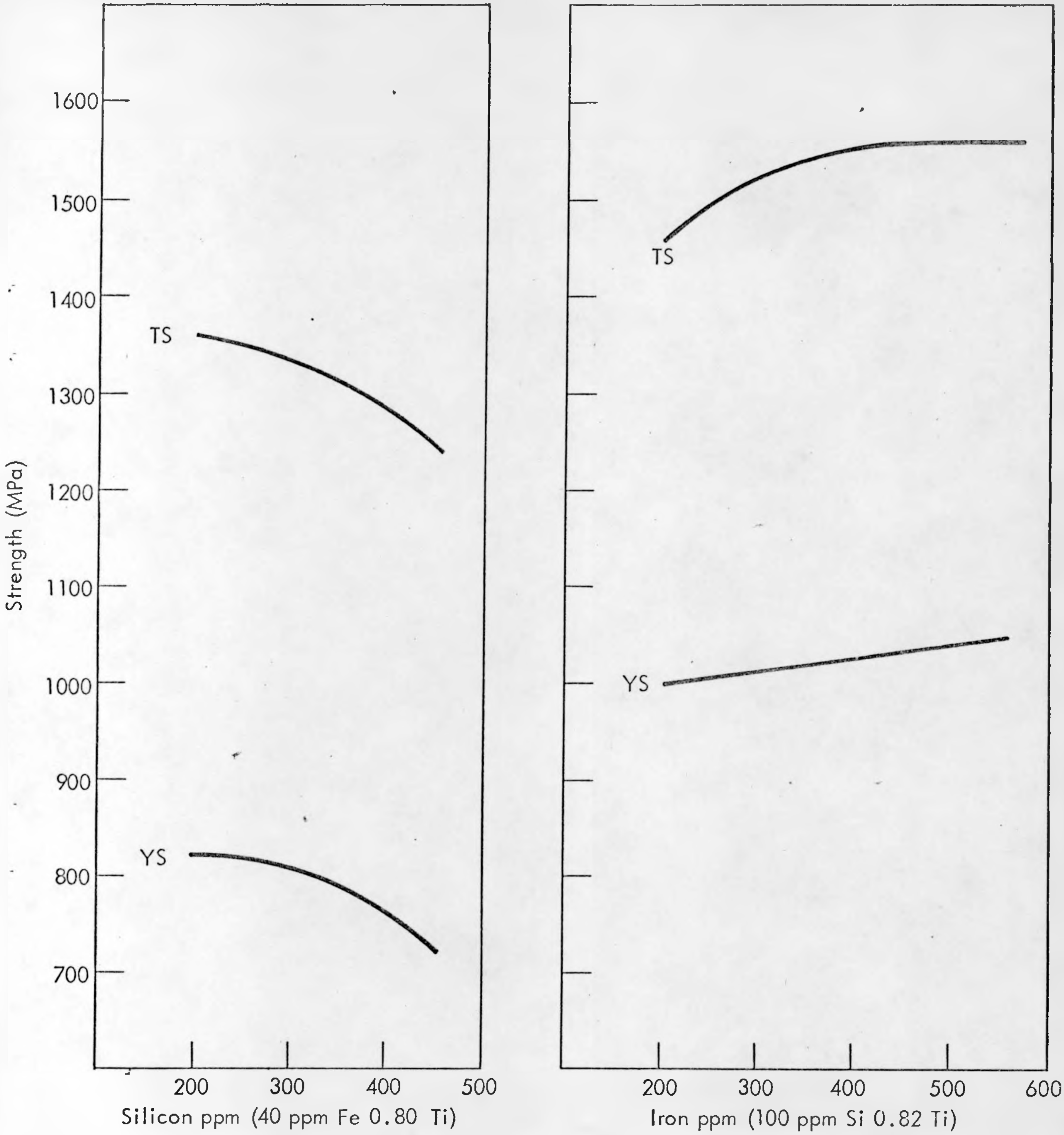
(1) Stress at 0.85 percent extension under load.

(2) In one inch.



YIELD STRENGTH AND ELONGATION (AVERAGE) OF AN AGE-HARDENED PLATE FROM URANIUM-0.75 TITANIUM ALLOY. (SM - Single Melt; DM - Double Melt)

Figure 1.



INFLUENCE OF IRON AND SILICON AT PPM LEVELS UPON AGE HARDENING RESPONSE OF THE U-0.75 WT % TI ALLOY

Figure 2.

A study was undertaken to determine the heat treatment needed to promote uniform distribution of the titanium in the U-0.75 Ti alloy. Mechanical property data from a cast ingot was used as a basis for evaluation. The tensile test results appear in Table II. Except for ductility, superior properties were produced in the unhomogenized alloy; however, the best combination of properties was shown by specimens which had been subjected to the 1000°C 24-hour homogenization treatment. An attempt was made to optimize the holding time for the 1000°C homogenization. Nothing was gained by extending the holding time beyond about 16 hours.

Table II

MECHANICAL PROPERTIES OF CAST URANIUM-0.75 PERCENT TITANIUM
AFTER VARIOUS HOMOGENIZATION TREATMENTS
(All specimens except "As Cast", heated at 800°C 1 hr., water quenched, aged at 380°C for 6 hrs.)

	Tensile Strength (MPa)	Yield Strength (0.2%)	Yield Strength (0.85% Strain)	Elongation in 1 inch (%)	Reduction in Area (%)
As Cast	799 ± 19	497 ± 10	577 ± 9	2.8 ± 0.3	1.8 ± 0.4
Not Homogenized	1421 ± 29	981 ± 36	991 ± 24	4.7 ± 1.7	4.6 ± 1.0
Homogenized 2 hr at 800°C	1277 ± 37	794 ± 28	847 ± 22	8.8 ± 2.1	8.6 ± 1.2
Homogenized 24 hr at 800°C	1358 ± 23	884 ± 30	906 ± 23	8.4 ± 1.4	8.7 ± 1.8
Homogenized 2 hr at 1000°C	1429 ± 23	911 ± 19	923 ± 15	13.3 ± 1.6	13.7 ± 2.5
Homogenized 24 hr at 1000°C	1410 ± 23	871 ± 25	903 ± 21	16.7 ± 2.0	18.0 ± 4.2

When worked in the gamma or in the high alpha regions, the grain size of the alloy is very large after solution treating at 800°C. When worked at slightly lower temperatures, 575°C instead of 630°C for example, the grain size after solution treatment is much smaller. The comparison is shown in Figure 3. The grain matrix is alpha prime with a lenticular metallographic structure, and there is some alpha uranium nucleated at the grain boundaries. The smaller grain size alloy does not develop as much strength on aging at a particular temperature as does the larger grain size alloy. However, the difference can be compensated for by higher aging temperatures or by increased titanium level. In some applications, the smaller grain size may be useful, even though the strength-ductility ratio is relatively unaffected.

To look at the effect of coarse grain sizes on the tensile results, two different size tensile bars, 6.4 mm and 12.7 mm diameter, were tested. The small gage diameter specimens were superior to the large specimens particularly with respect to elongation and reduction in area, but for the small specimens the confidence limits on the mean were greater for all properties except tensile strength.

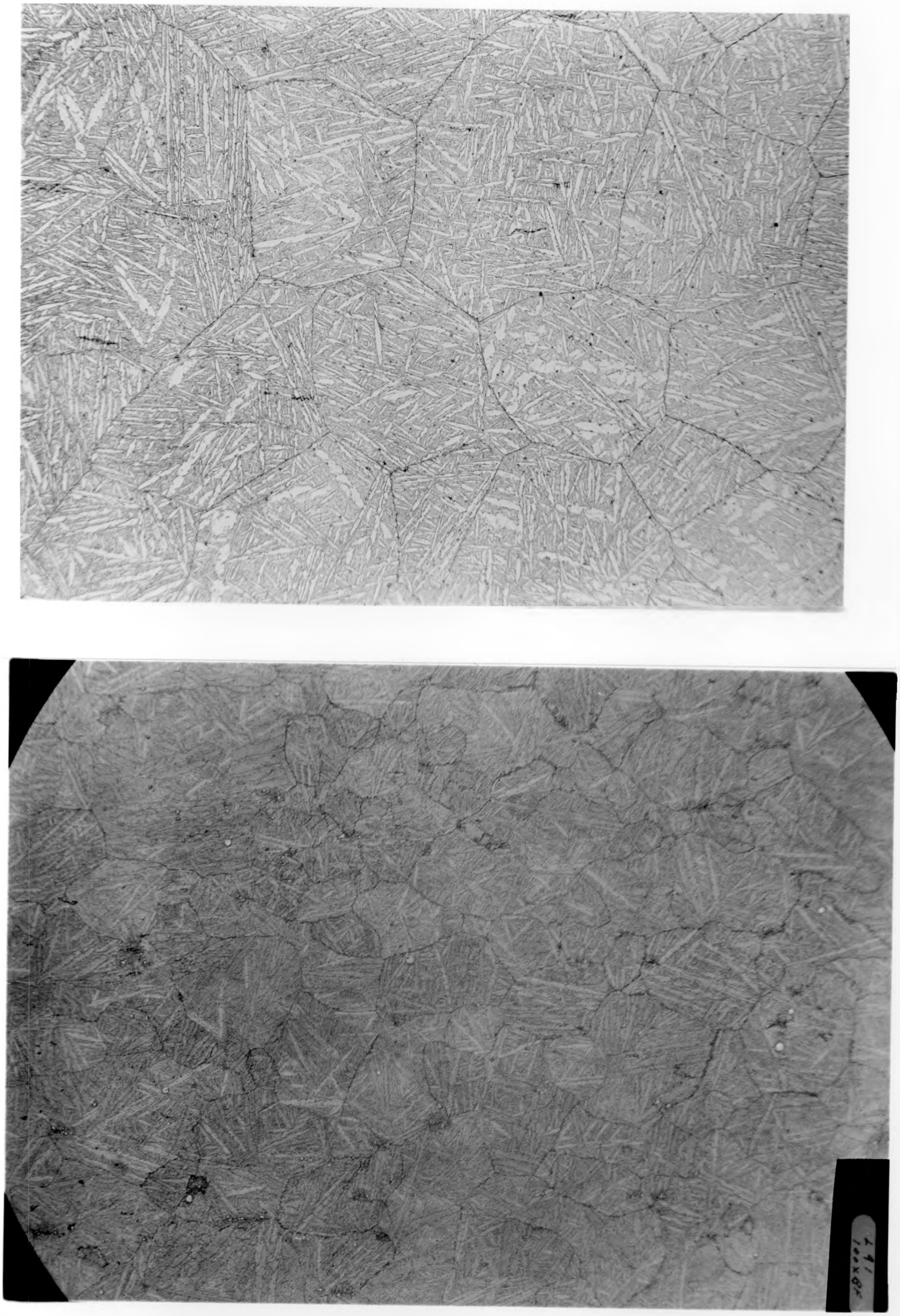


Figure 3. URANIUM-0.75 WEIGHT PERCENT TITANIUM WORKED AT 575°C (SMALL GRAINS) AND 630°C (LARGE GRAINS) AND SOLUTION TREATED AT 800°C

Tensile specimens, 6.4 mm in diameter, taken from 12.7 mm thick stock provided lower yield stress and greater ductility than specimens taken from 25.4 mm thick stock. Hardness and strength variations through a thickness due to quenching rates are responsible for these effects.

The alloy is solution treated at 800°C, in vacuo to reduce hydrogen to an acceptable level, water quenched, and then age hardened to the desired strength level. As with non-uranium age hardening alloys, the uranium-titanium alloys show both upper and lower level hardening, but only the lower level is used because it provides the better strength-ductility ratios. Figure 4 shows hardness versus the aging temperature. The times were 24 hours at each temperature. Figure 5 is a graph of the tensile test properties that exemplifies, in part, the mechanical properties which can be developed by variation of the aging temperature and/or time. The mechanical properties here are plotted against aging temperature. The solid curves are results after aging for 12 hours, while the dashed curves are results after aging for 6 hours.

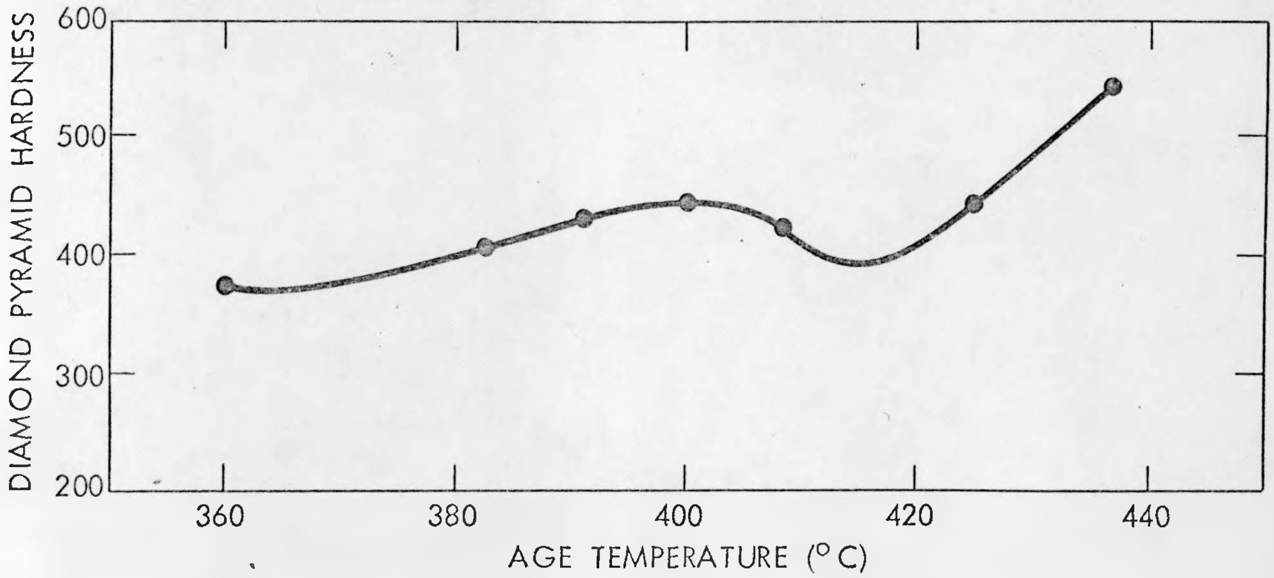
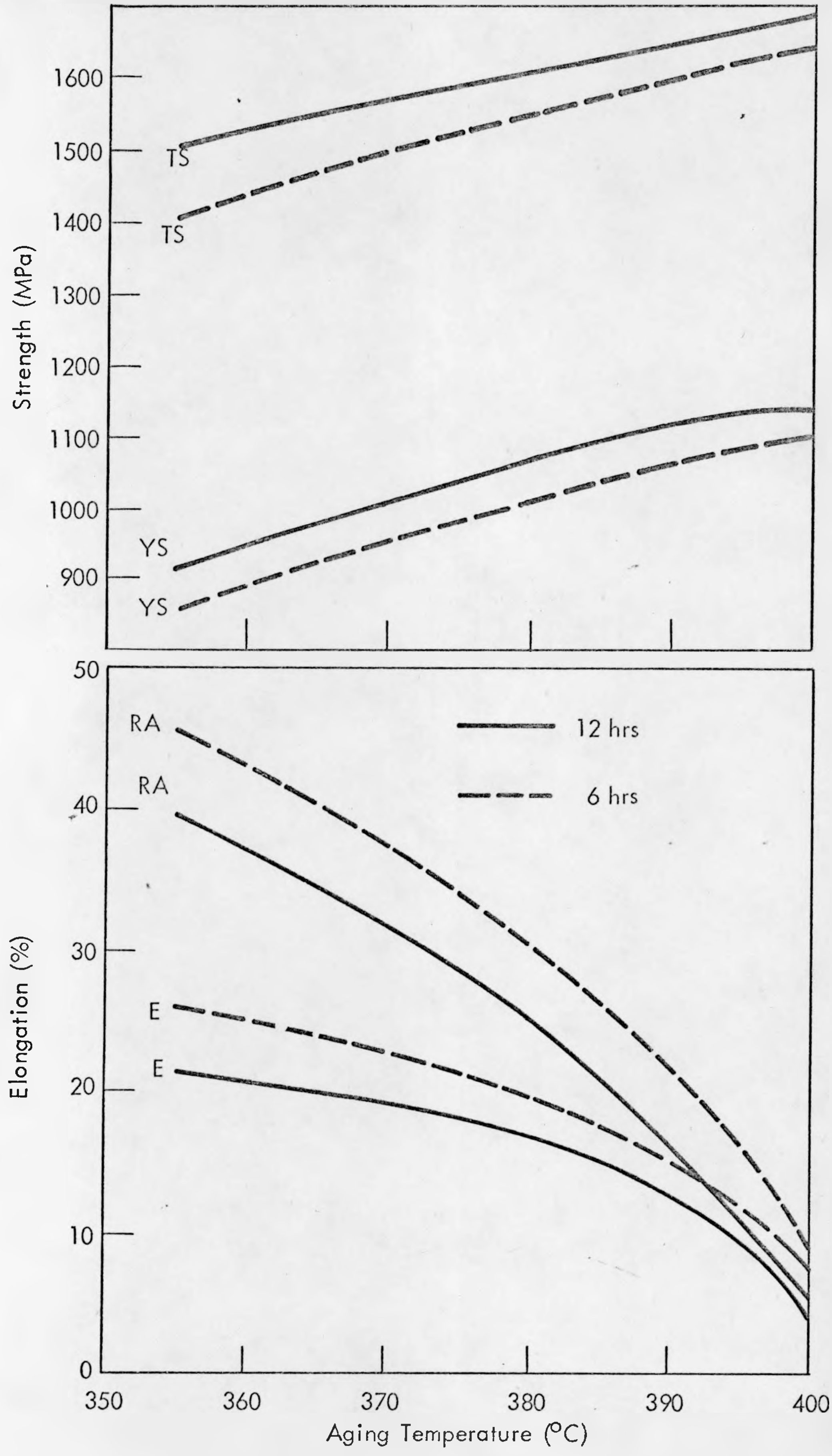


Figure 4. DIAMOND PYRAMID HARDNESS FOR URANIUM-0.75 PERCENT TITANIUM ALLOY AS A FUNCTION OF THE AGE HARDENING. (Average of 20 DPH Specimens)

As with other age hardening alloys, excessive time at temperature overages the U-0.75 Ti alloy, as demonstrated in Figure 6. Although this particular curve was derived from a 0.5 wt % titanium alloy, the general shape showing overaging is the same as that for the 0.75 wt % alloy. It was included here to demonstrate that the alloy can be age hardened at a titanium level as low as 0.5 wt %. Figure 7 shows the Charpy Impact values as a function of test temperature for the age hardened alloy. A transition is noted at about -46°C.

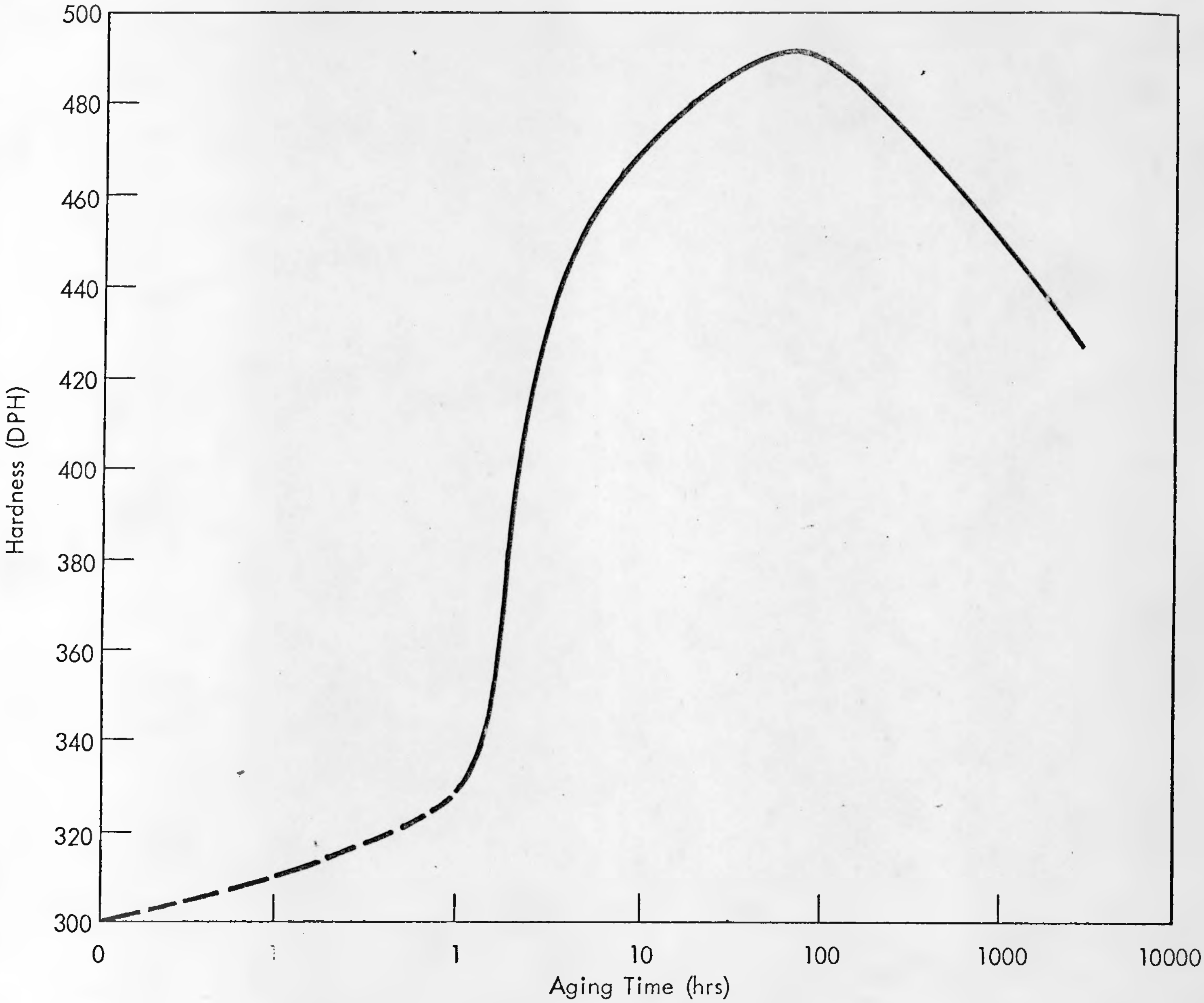
Different humidities and atmospheres can affect the tensile properties of the aged U-0.75 Ti alloy. Table III gives results of tests in argon and air of varying humidities. Changes are noted in air with 55% RH and above.

Plating is often used to protect the alloy and many tests have been run, particularly with nickel-plated specimens, to determine the effect of plating. The etching treatment, prior to plating, has proven to be most important as to whether the tensile properties will be degraded.



COMPARISON OF AGING TIME AND TEMPERATURE ON MECHANICAL PROPERTIES OF 0.75 WT % TI ALLOY.

Figure 5



AGING TIME VS HARDNESS OF U-0.5 WT % TI
ALLOY AGED AT 400 °C.

Figure 6

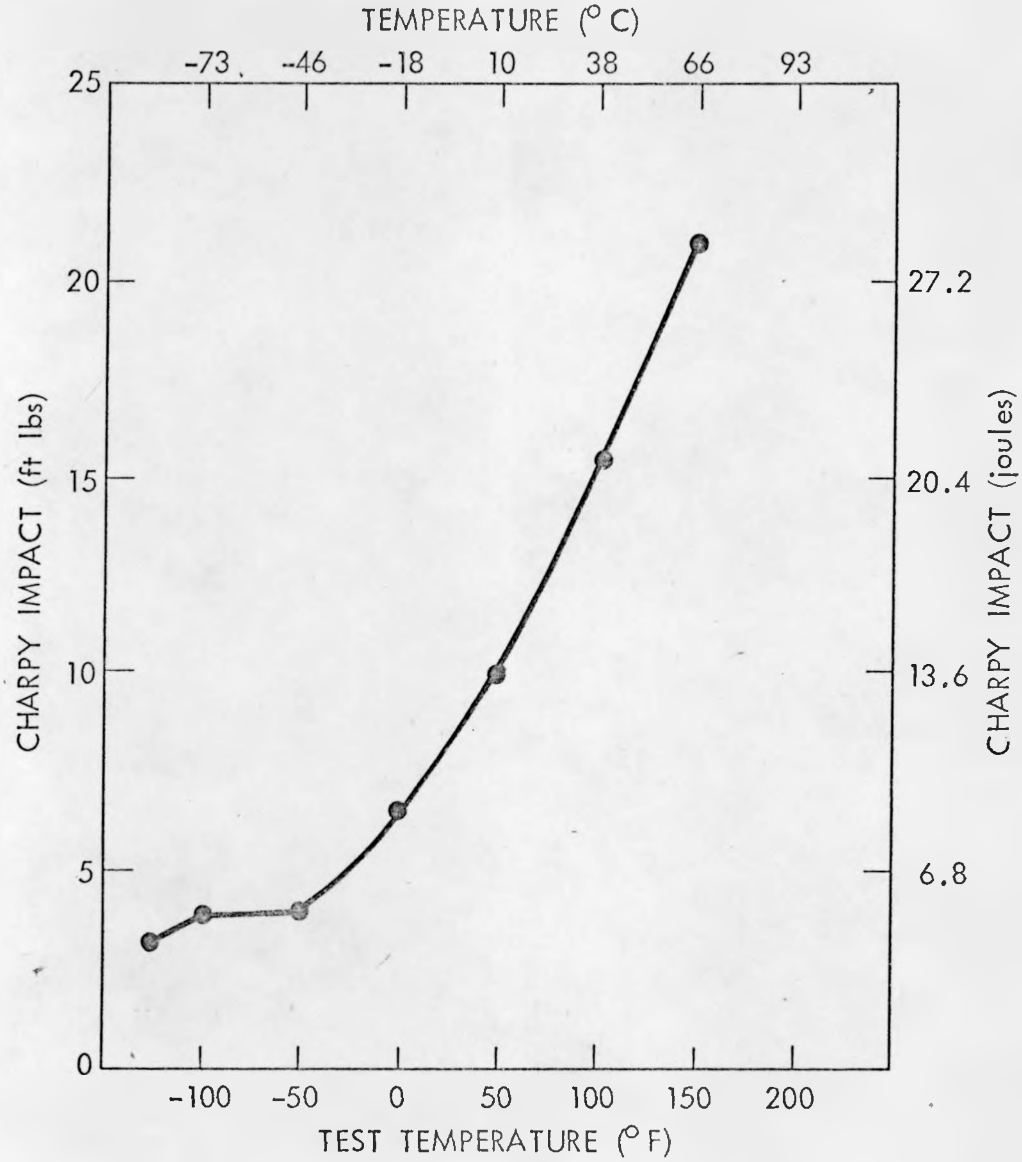


Figure 7. CHARPY IMPACT AS A FUNCTION OF THE TEST TEMPERATURE FOR AGE-HARDENED (380° C, 6 HOURS) URANIUM-0.75 PERCENT TITANIUM ALLOY. (Average of 2 Specimens)

Table III

TENSILE TESTS OF THE URANIUM-3/4 PERCENT TITANIUM ALLOY
VACUUM WATER QUENCHED FROM 800°C AND AGED AT 380°C FOR 6 HOURS
AT DIFFERENT ATMOSPHERE AND HUMIDITY LEVELS

Atmosphere	Yield Strength(1) (MPa)	Elongation(2) (%)	Reduction in Area (%)
Argon	982	19.8	21.5
Air-12% RH	981	19.4	23.0
Air-50% RH	961	18.9	18.7
Air-55% RH	993	17.8	14.4
Air-60% RH	958	8.0	7.7
Air-80% RH	974	6.3	6.3
100% RH	954	3.8	4.0

(1) At 0.2 percent offset.

(2) In one inch.

The U-0.75 Ti alloy has been successfully electrochemically machined (ECM) recently. There is still some question as to whether there is a detrimental effect on mechanical properties as a result of such material removal. The data have been conflicting and confusing. The general opinion is that there is not detrimental effect but it is yet to be proven.

Electrical discharge machining (EDM) has been used on U-0.75 Ti alloys and the strength of nickel-plated EDM specimens were compared to nickel plated conventional machined alloys. The average ultimate tensile strength (UTS) for the conventional machined specimen was 1472.7 MPa while the average UTS of the EDM specimens was 1432.7 MPa. After the EDMing of the specimens, a "recast" layer containing cracks was observed on the surface. It was shown that nickel plating was instrumental in propagating these cracks into the substrate. Thus the EDM surfaces were wire brushed prior to nickel plating.

SUMMARY

Mechanical properties of the U-0.75 Ti alloy are affected by variables of aging temperature, aging time, melt temperature, melt time, double melting, working temperature, homogenization time and temperature, test atmosphere, humidity, plating, machining method, and the chemical levels of titanium, silicon, and iron in the alloy.

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