PHOTOGRAPH THIS SHEET

AD-A952706

DTIC ACCESSION NUMBER

LEVEL

INVENTORY

WAL TR 405.22/1

DOCUMENT IDENTIFICATION

Apr. '61

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

DISTRIBUTION STATEMENT

ACCESSION FOR	
NTIS GRA&I	☒
DTIC TAB	☐
UNANNOUNCED	☐
JUSTIFICATION	
(April 1961)	
BY	
DISTRIBUTION /	
AVAILABILITY CODES	
DIST	AVAIL AND/OR SPECIAL
A/1	

DISTRIBUTION STAMP

Released

UNANNOUNCED

DTIC
SELECTED
NOV 22 1983
D

DATE ACCESSIONED

83 09 22 091

DATE RECEIVED IN DTIC

PHOTOGRAPH THIS SHEET AND RETURN TO DTIC-DDA-2

DTIC FORM OCT 79 70A

DOCUMENT PROCESSING SHEET

#/

WAL 405.22/1

PB 156126
AD

WATERTOWN ARSENAL LABORATORIES

AD-A952706

TENSILE STRENGTH-HARDNESS CORRELATION FOR TITANIUM ALLOYS

TECHNICAL REPORT NO. WAL TR 405.22/1

AD-258684

BY

CHARLES F. HICKEY, JR.

APRIL 1961

OMS CODE 4230.1.0000.20
INDUSTRIAL PREPAREDNESS MEASURE - PRODUCT IMPROVEMENT

WATERTOWN ARSENAL
WATERTOWN 72, MASS.

PB 156126
AD

Titanium alloys

Titanium, tensile strength-hardness

TENSILE STRENGTH-HARDNESS CORRELATION FOR TITANIUM ALLOYS

Technical Report No. WAL-TR 405.22/1

By

Charles F. Hickey, Jr.

April 1961

OMS Code 4230.1.0000.20
Industrial Preparedness Measure - Product Improvement

WATERTOWN ARSENAL
WATERTOWN 72, MASS.

WATERTOWN ARSENAL LABORATORIES

TITLE

TENSILE STRENGTH-HARDNESS CORRELATION FOR TITANIUM ALLOYS

ABSTRACT

This investigation was concerned with the establishment of a correlation between tensile strength and hardness for titanium alloys. Materials of current interest were considered and tested over a fairly wide property range. Tensile and hardness properties were obtained as a function of testing temperature, heat treatment, and section size of material. Data were also obtained from a literature survey.

As a result of the findings, a correlation was established between tensile strength and hardness for stable alpha-beta alloys. It does not apply for metastable alpha-beta alloys nor does it adequately define data in all-beta alloys. In addition, a hardness correlation was established between Vickers and Rockwell C for the stable alpha-beta alloys.

Charles F. Hickey, Jr.
CHARLES F. HICKEY, JR.
Physical Metallurgist

APPROVED:

J. F. Sullivan
J. F. SULLIVAN
Director
Watertown Arsenal Laboratories

REPORT APPROVED
Date 21 June 61
WAL Board of Review
Chairman WSW

INTRODUCTION

The tensile strength-hardness relationship provides a fast, inexpensive means of approximating tensile strength from a simple hardness test. Such a relationship exists in steel[1,2], where the ultimate tensile strength is approximately 500 times the Brinell hardness number. Attempts have been made in the past to establish a workable correlation for titanium, but for the most part this has met with little success since hardness apparently varies with alloy type, directionality, prior fabrication history of the alloy, and the phases present in the alloy. Thus it appears that a strength-hardness correlation for titanium might vary considerably from one alloy to another and even with different processing variables for a given alloy.

Realizing the above, it was the author's opinion that sufficient work had not been done on the subject to completely eliminate the possibility that a correlation may exist, at least within certain alloys.

This report is a presentation of tensile strength-hardness data for numerous titanium alloys of current interest and importance. Understandably major emphasis has been placed on alpha-beta alloys. Data for the program have been accrued from tests conducted at Watertown Arsenal Laboratories, previously published work by the author[3], and from a literature survey[4,5].

MATERIALS AND PROCEDURE

Materials selected for investigation were Department of Defense titanium alloys and others of commercial and current interest. The alloys and all available compositions are as follows:

COMPOSITION (WEIGHT PERCENT)

Ti Alloy	Al	Mo	V	Cr	H	O	C	N	Fe
7Al-4Mo	7.16	4.19	-	-	0.0036	0.02-0.13	0.065	0.007	-
7Al-3Mo	7.15	3.00	-	-	0.0126	0.09	0.040	0.009	0.20
6Al-4V	5.90	-	4.25	-	0.0012	0.09	0.030	0.010	-
4Al-3Mo-1V	3.85	3.07	0.96	-	0.0024	0.02-0.09	0.045	0.009	-
16V-2.5Al	2.79	-	15.80	-	0.0018	0.02-0.13	0.025	0.025	-
13V-11Cr-3Al	3.18	-	13.15	10.96	0.0069	0.02-0.10	0.028	0.013	-
6Al-4V[3]	5.85	-	4.07	-	0.0042	0.108	0.026	0.018	0.162
6.5Al-3Mo-1V[3]	6.39	2.92	1.00	-	0.0044	0.110	0.028	0.015	0.02
6Mo-3Al[3]	2.77	6.00	-	-	0.0024	0.132	0.024	0.018	0.02
4Al-3Mo-1V[4]									
6Al-4V[5]									

Hardness data obtained from literature were reported in Rockwell C (R_c) units for some alloys and Vickers Hardness Number (VHN) for others. Thus, for the alloys which were to be investigated at Watertown Arsenal Laboratories, it was decided to utilize both hardness methods in hopes of also establishing a relationship between R_c and VHN. This would allow greater utilization of literature data and would also allow a tensile strength-hardness relationship to be expressed in terms of either R_c or VHN.

Tensile and hardness properties were obtained as a function of testing temperature, heat treatment, and section size of the material. Standard 0.252" tensile specimens were used in all cases. R_c data were obtained from Charpy bars while VHN data were from polished disks. The R_c data are from a plane perpendicular to the tensile direction while VHN data are parallel to the tensile direction. Hardness direction was not stipulated in the literature data.

The least mean square method was used for fitting equations to the various curves. It was assumed that a linear relationship would define each plot.

RESULTS AND DISCUSSION

Effect of Testing Temperature on Hardness

Figure 1 is a plot of VHN versus testing temperature for Ti-7Al-4Mo, Ti-7Al-3Mo, Ti-6Al-4V, Ti-4Al-3Mo-1V, Ti-16V-2.5Al, and the all-beta alloy Ti-13V-11Cr-3Al in the annealed condition. All-beta Ti-13V-11Cr-3Al shows the greatest increase in hardness over the investigated temperature span. It ranges from approximately 269 VHN at +200° to 544 VHN at -319°F, a difference of 275. The five remaining alloys follow the same general trend with an increase of between 180 and 220 VHN. Ti-16V-2.5Al is of a much lower hardness level than any of the other materials, however its increase with a decrease in temperature is within the above stated range.

Hardness Correlation

Figure 2 is a plot of R_c versus VHN for the alloys in Figure 1, utilizing testing temperatures of room temperature, -240°, and -319°F. An examination of the data shows the hardness level of Ti-16V-2.5Al and all-beta Ti-13V-11Cr-3Al to be higher and lower, respectively, than that of the other alloys; thus they were not included in the relationship which is defined by the following equation:

$$R_c = 0.078 \text{ VHN} + 8.1$$

$$\sigma = 2.4 \ R_c$$

A standard deviation of 2.4 R_c means that 68% of the cases (data points) were included within the range of ± 2.4 R_c about the line of regression which is defined by the equation

$$R_c = 0.078 \text{ VHN} + 8.1.$$

In reference to the higher hardness level of Ti-16V-2.5Al, a possible explanation may lie in the fact that it is a metastable alpha-beta alloy and transforms to martensite upon straining. Thus the R_c values tend to be higher than the corresponding VHN due to its 150 kg load versus the 10 kg load which was used in the VHN determination. Verification of this is shown in Figure 3, for as the Vickers load is increased to 50 kg the resulting hardness becomes greater for the metastable alloy. It is also shown, utilizing Ti-7Al-4Mo, that hardness is independent of load for stable alpha-beta alloys.

For reasons to be discussed later, all-beta Ti-13V-11Cr-3Al data were not included in the hardness equation.

Tensile Strength Versus Hardness Relationships

Figures 4 and 5 are plots of tensile strength versus hardness, VHN and R_c respectively, of the above-mentioned materials with data being obtained at room temperature, -105°, -240°, and -319°F for most of the alloys. In both figures the four stable alpha-beta alloys exhibit a similar trend which can be defined as follows:

$$\text{UTS} = 435 \text{ VHN} + 9,200$$

$$\sigma = 8,300 \text{ psi}$$

$$\text{UTS} = 5,200 R_c - 24,000$$

$$\sigma = 8,600 \text{ psi.}$$

Again, as in the hardness correlation, the Ti-16V-2.5Al data fell above that of other alloys. Strain-induced martensitic transformation once more appears to be the answer. The strain produced by the tensile test is considerably higher than that of either hardness method, accounting for the high corresponding tensile values.

It should be mentioned that data for the all-beta alloy Ti-13V-11Cr-3Al were not included in either equation even though at some temperatures they agree fairly well with the stable alpha-beta alloys. In Figure 4 there is some evidence that the alloy may undergo a certain amount of martensitic transformation due to straining. Also, it is known that this material exhibits excessive embrittlement at cryogenic temperatures.

Figure 6 is a plot of tensile strength versus hardness (R_c) utilizing previously published tensile data[3] and the corresponding hardness values. The materials, Ti-6Al-4V, Ti-6.5Al-3Mo-1V and Ti-6Mo-3Al are stable alloys.

Each material was of several section diameters (2, 3, 4, and 6 inches) and tested in both the annealed and heat-treated conditions, thus providing a range of conditions and properties.

The data fell into a fairly consistent pattern and can be described as follows:

$$UTS = 5{,}170\ R_c - 38{,}600$$

$$\sigma = 8{,}150 \text{ psi}$$

Figure 7 is a plot of UTS versus VHN for Ti-4Al-3Mo-1V(4) and Ti-6Al-4V(5), with the data being obtained from Battelle Memorial Institute. The first alloy was tested in the heat-treated condition and the latter is cast material which presumably was annealed prior to testing. Their data may be defined as follows:

$$UTS = 225\ VHN + 73{,}000$$

$$\sigma = 4{,}500 \text{ psi}$$

As can be seen in Figure 7, the property range is very limited. Due to this fact, and lacking complete fabrication history, only limited emphasis can be placed upon these data. However, it can be said that in the area of 300 VHN fairly good agreement equation-wise does exist between these data and those presented in Figure 4.

Figures 4 through 7 present tensile strength versus hardness data for numerous titanium alloys in various conditions. In an effort to arrive at the equation which best defined all the data, it was decided to analyze all the results on an R_c versus UTS basis. The VHN in Figure 7 were converted to R_c utilizing the hardness relationship established in Figure 2. Also included in this bulk analysis were limited results from Ti-5.5Al-5.5V-2Sn, Ti-155A, and Ti-7Al-4V.

The equation and resulting deviation which best describe all of the data is

$$UTS = 5{,}050\ R_c - 27{,}000$$

$$\sigma = 8{,}250 \text{ psi}$$

Utilizing the hardness conversion between R_c and VHN, the hardness versus tensile strength relationship can now be expressed in terms of VHN, as follows:

$$UTS = 395\ VHN + 14{,}000$$

Figure 8 is a plot of the equation which best defines the presented data. In addition there are also equation plots of the data presented in Figures 5 and 6. It is of interest to note that the data from these two figures parallel each other, even though a difference of approximately 15,000 psi exists between them.

After the statistical analysis had been completed for this report, additional data on tensile strength and Vickers hardness for Ti-4Al-3Mo-1V and Ti-6Al-4V by Rice, Campbell, and Simmons[6] were discovered. Thus, these results could not be included; however it can be said that their findings fall within the scope of the correlation.

CONCLUSIONS

The results of this investigation to establish a correlation between tensile strength and hardness for titanium are as follows:

1. A hardness correlation (R_c versus VHN) was established for stable alpha-beta alloys, based upon the data from Ti-7Al-4Mo, Ti-7Al-3Mo, Ti-6Al-4V, and Ti-4Al-3Mo-1V. The equation and standard deviation are as follows:

$$R_c = 0.078\ VHN + 8.1$$

$$\sigma = 2.4\ R_c$$

2. A relationship does exist for stable alpha-beta alloys over the investigated hardness range of 30-50 R_c and corresponding tensile strengths of 130,000 to 240,000 psi. This relationship and standard deviation can be expressed as follows:

$$UTS = 5{,}050\ R_c - 27{,}000$$

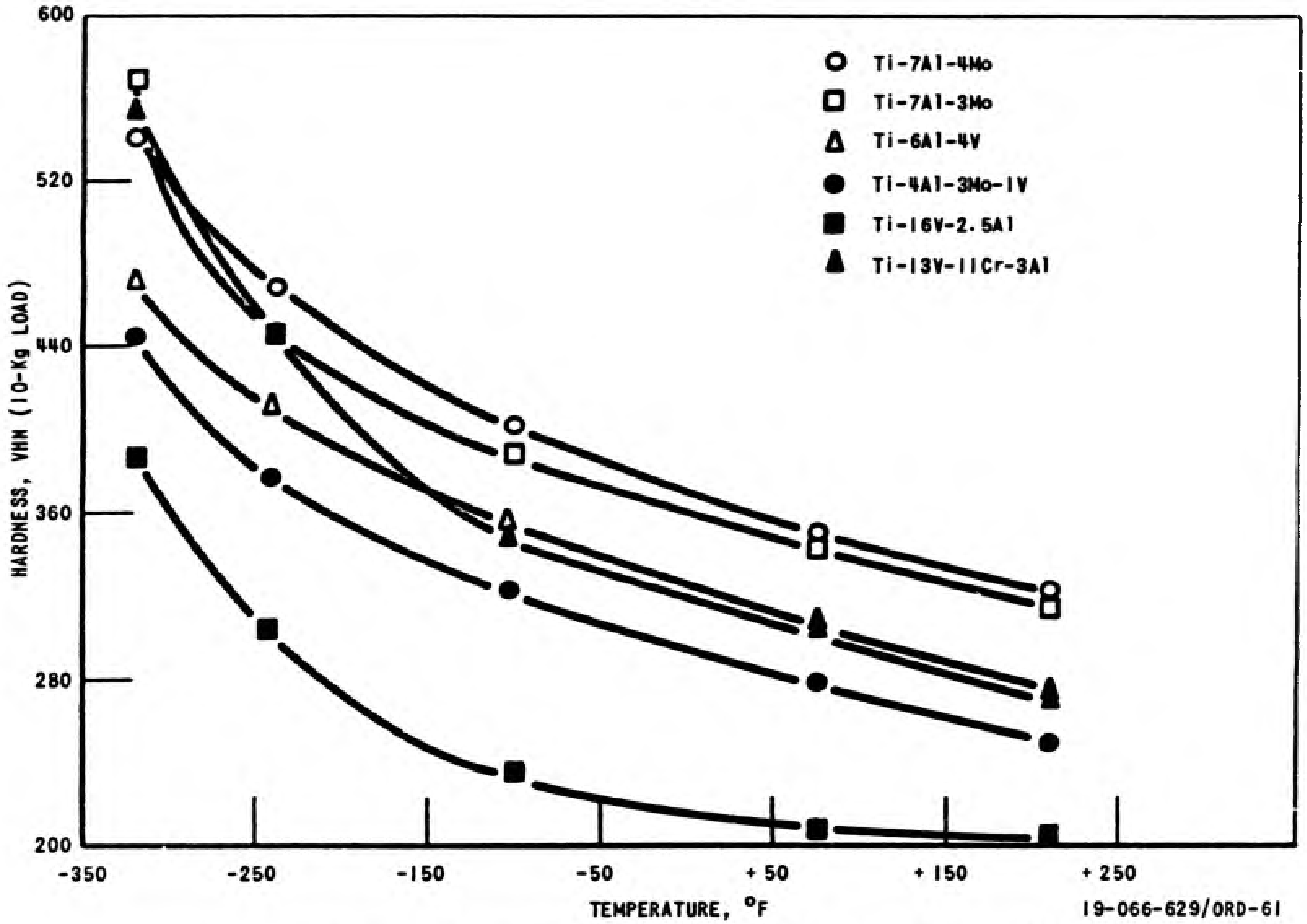
$$\sigma = 8{,}250\ psi$$

3. The above relationships can be combined, resulting in the following expression for UTS in terms of VHN:

$$UTS = 395\ VHN + 14{,}000$$

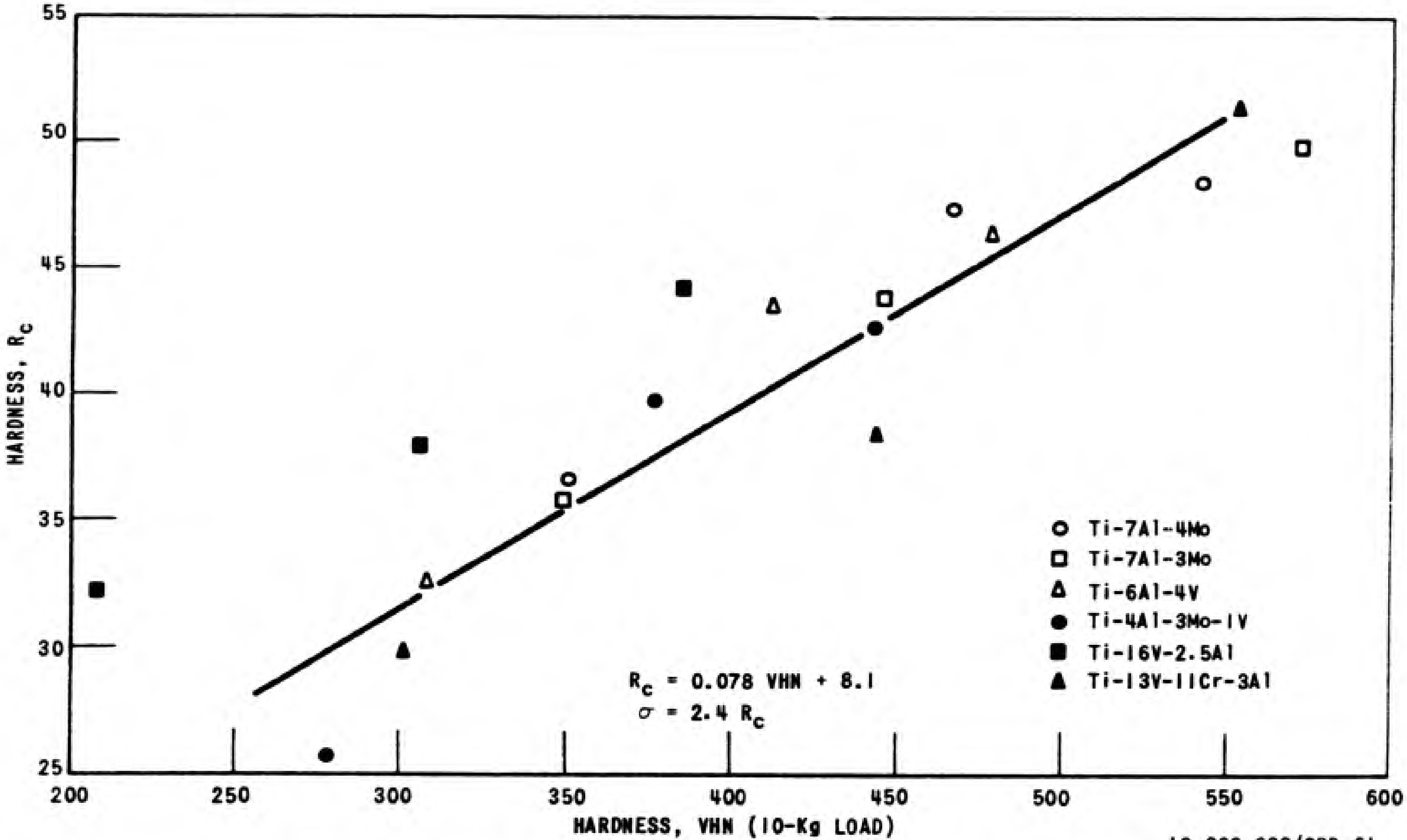
This study shows that the tensile strength-hardness relationships for the alpha-beta materials do not define Ti-16V-2.5Al, a metastable alpha-beta alloy. A likely explanation appears to lie in the fact that this alloy transforms to martensite upon straining.

Even though the data for all-beta Ti-13V-11Cr-3Al agrees fairly well with the stable alpha-beta results, especially at lower strength and hardness levels, it was not included in the above equations. This decision was based on the possibility that the alloy may undergo a certain amount of martensitic transformation due to straining, plus the known fact that it exhibits excessive embrittlement at cryogenic temperatures.



EFFECT OF TESTING TEMPERATURE ON HARDNESS OF TITANIUM ALLOYS

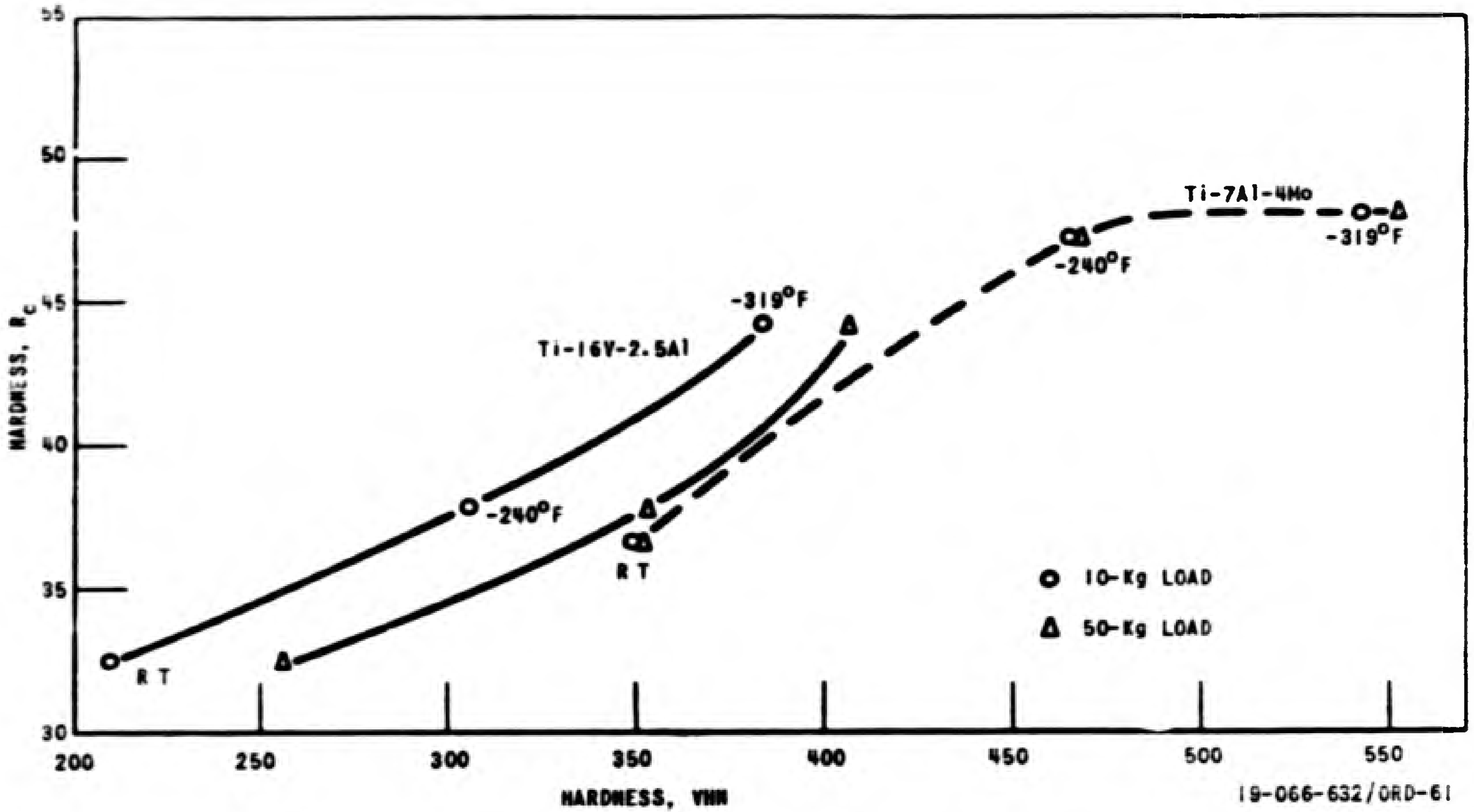
FIGURE 1



19-066-633/ORD-61

EFFECT OF TESTING TEMPERATURE (ROOM TEMPERATURE TO -319°F) ON HARDNESS CORRELATION (R_c VERSUS VHN) FOR TITANIUM ALLOYS

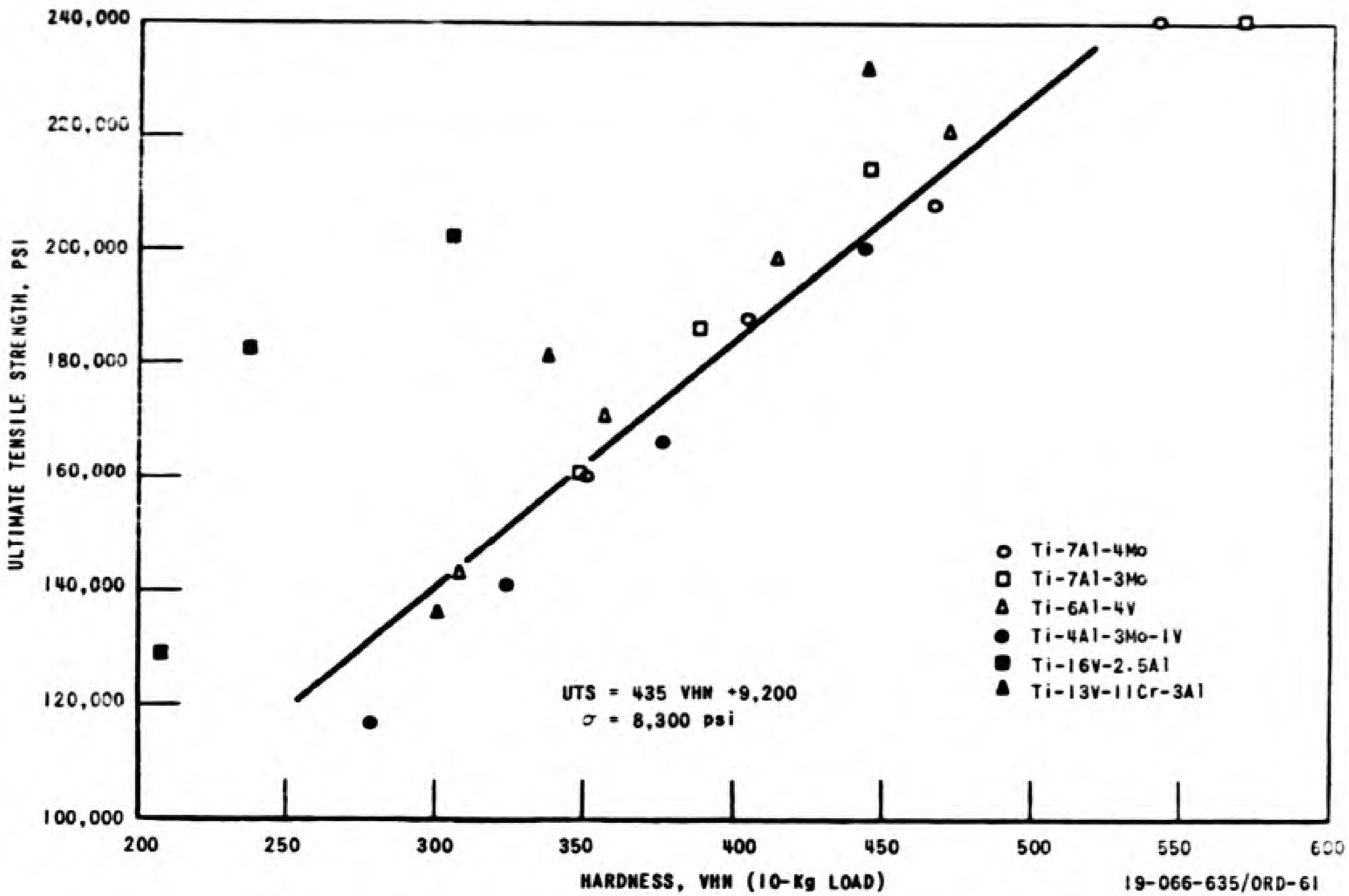
FIGURE 2



19-066-632/ORD-61

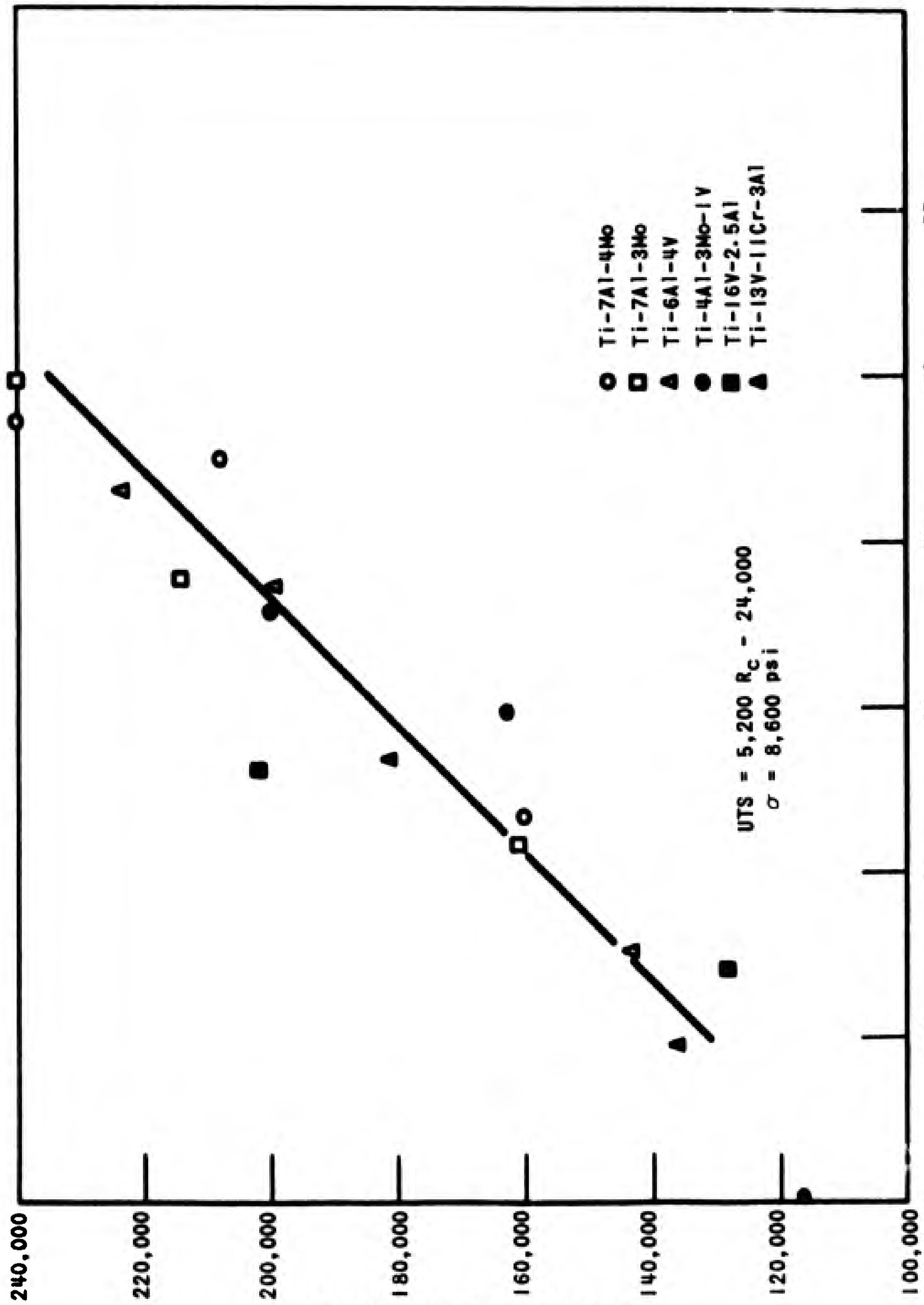
EFFECT OF LOAD ON HARDNESS RELATIONSHIP (VHN VERSUS R_c) FOR TITANIUM ALLOYS

FIGURE 3



TENSILE STRENGTH-HARDNESS RELATIONSHIP AS A FUNCTION OF TESTING TEMPERATURE (ROOM TEMPERATURE TO -319°F) FOR TITANIUM ALLOYS

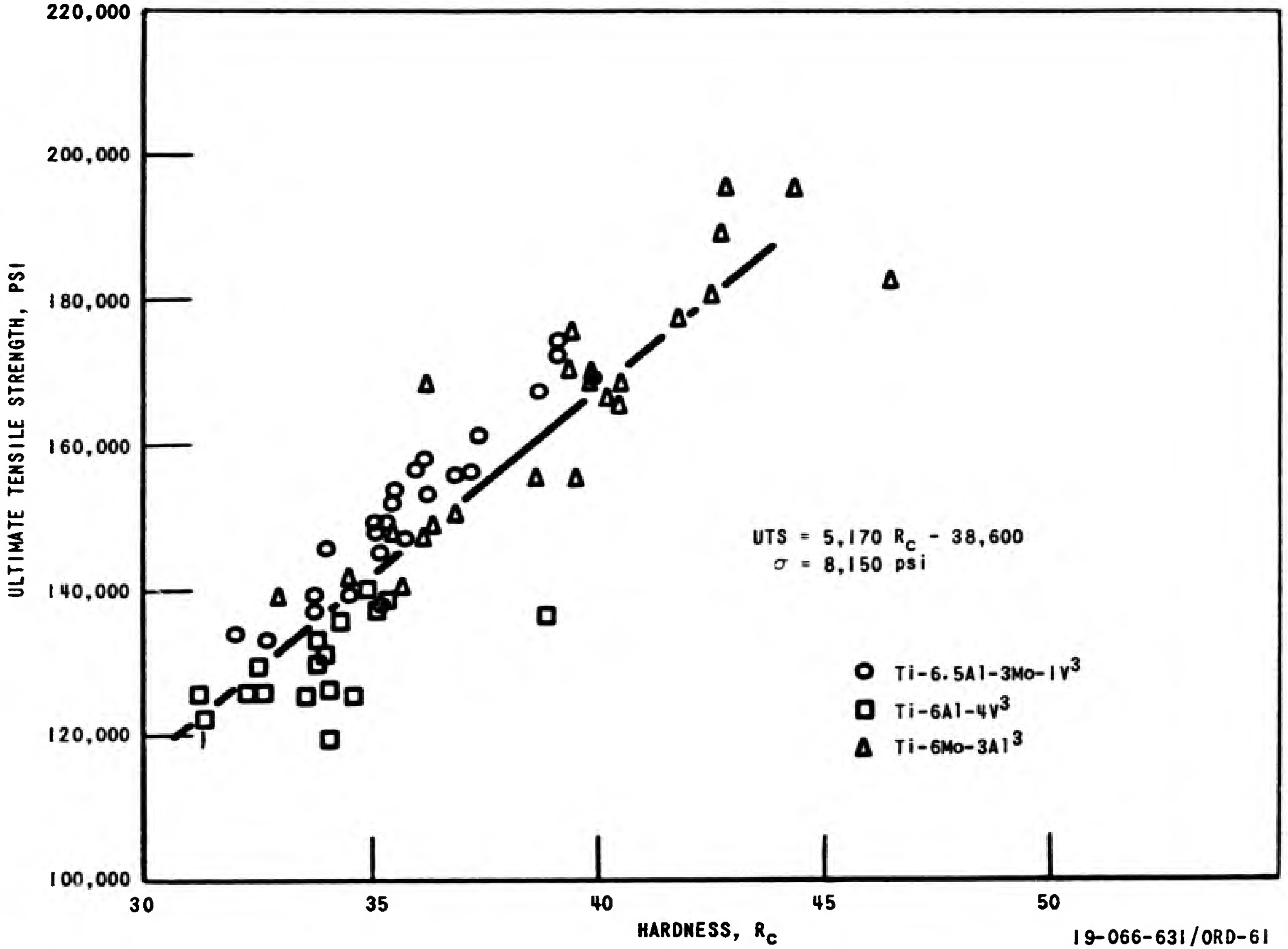
FIGURE 4



19-066-628/ORD-61

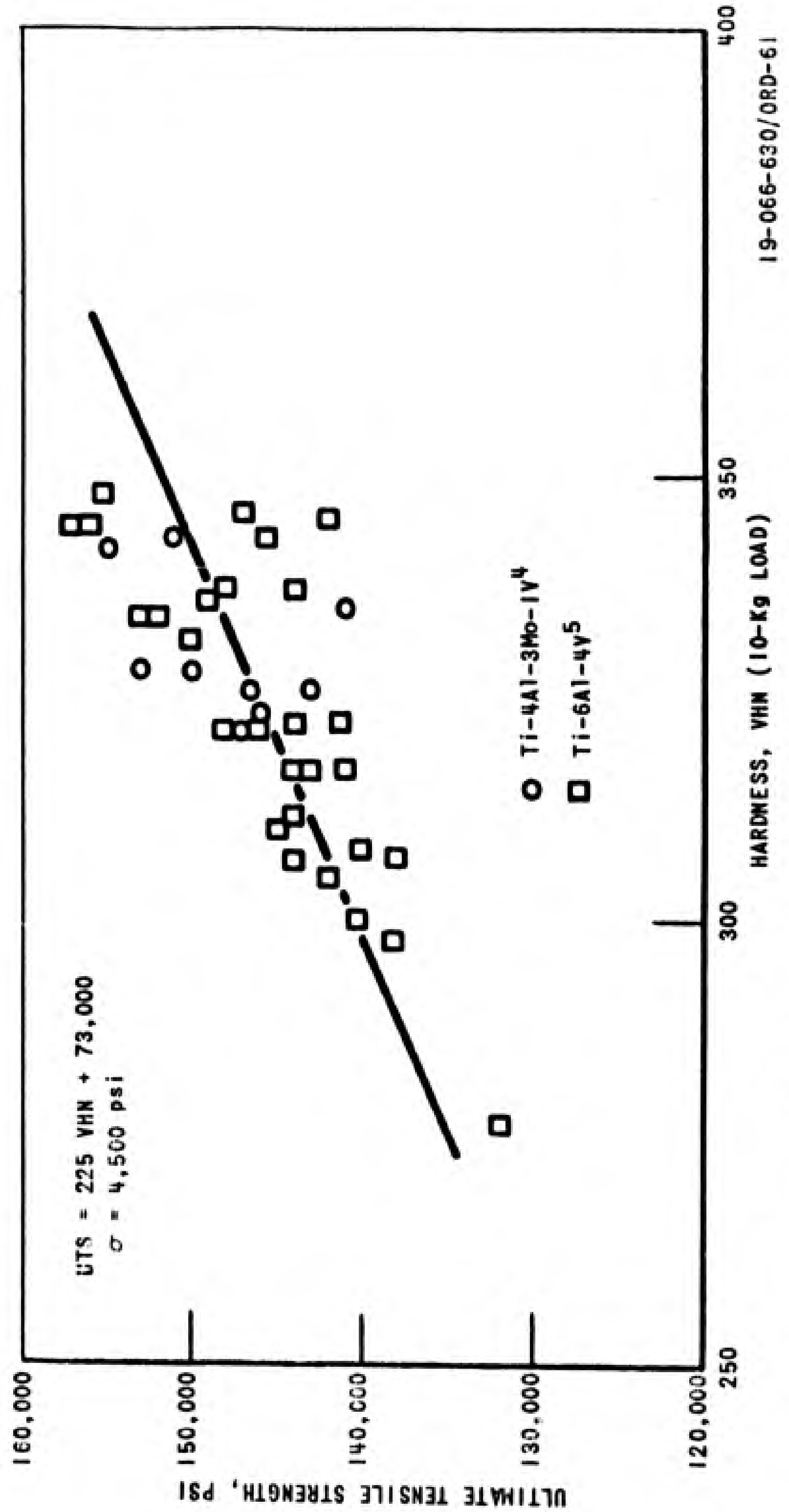
TENSILE STRENGTH-HARDNESS RELATIONSHIP AS A FUNCTION OF TESTING TEMPERATURE (ROOM TEMPERATURE TO -319°F) FOR TITANIUM ALLOYS

FIGURE 5



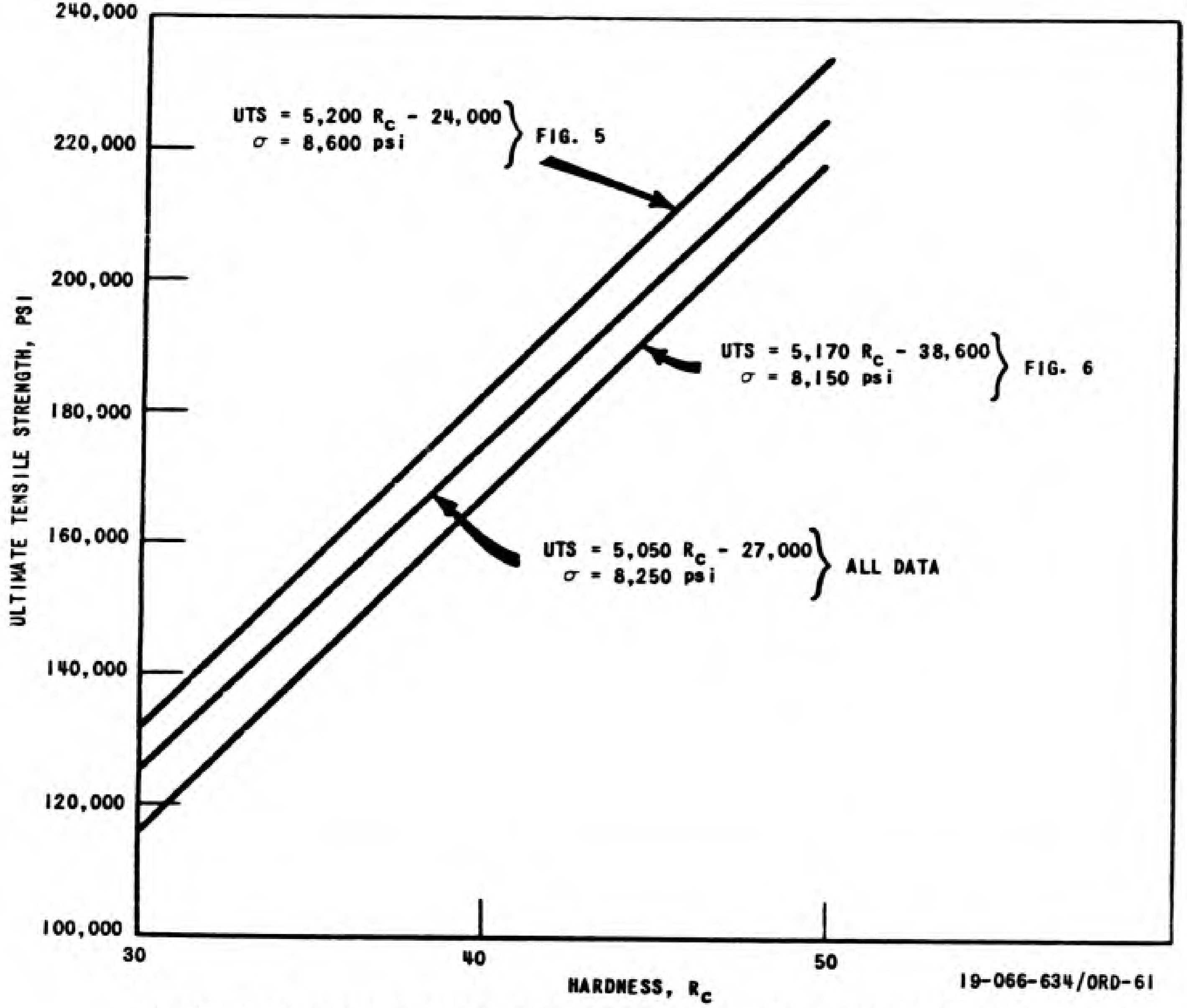
TENSILE STRENGTH-HARDNESS RELATIONSHIP AS A FUNCTION OF HEAT TREATMENT AND SECTION SIZE FOR TITANIUM ALLOYS

FIGURE 6



TENSILE STRENGTH-HARDNESS RELATIONSHIP FOR TITANIUM ALLOYS

FIGURE 7



SUMMARY OF TENSILE STRENGTH-HARDNESS RELATIONSHIP FOR TITANIUM ALLOYS

FIGURE 8

APPENDIX

EFFECT OF TEMPERATURE ON THE TENSILE STRENGTH-HARDNESS PROPERTIES OF TITANIUM ALLOYS

Ti-Alloys	Test Temp. (°F)	UTS (psi)	HARDNESS		
			R_c	VHN(10-Kg Ld)	VHN(50-Kg Ld)
7Al-4Mo	+212	-	-	326	
	RT	160,000	36.6	350	349
	-105	188,000	-	404	-
	-240	208,000	47.4	467	468
	-319	241,000	48.5	542	554
7Al-3Mo	+212	-	-	315	-
	RT	160,000	35.8	348	-
	-105	186,000	-	388	-
	-240	213,000	43.8	445	-
	-319	240,000	49.8	571	-
6Al-4V	+212	-	-	272	-
	RT	143,000	32.6	308	-
	-105	171,000	-	357	-
	-240	198,000	43.6	412	-
	-319	221,000	46.3	472	-
4Al-3Mo-1V	+212	-	-	247	-
	RT	117,000	25.6	278	-
	-105	141,000	-	323	-
	-240	166,000	39.8	376	-
	-319	200,000	42.8	443	-
16V-2.5Al	+212	-	-	206	
	RT	129,000	32.2	208	256
	-105	182,000	-	237	-
	-240	202,000	37.9	305	353
	-319	*	44.2	385	407
13V-11Cr-3Al	+212	-	-	269	-
	RT	136,000	29.9	301	-
	-105	181,000	-	348	-
	-240	232,000	38.4	444	-
	-319	**	51.3	554	-

*Specimen broke in threads.

**Specimen broke prematurely.

TENSILE STRENGTH-HARDNESS PROPERTIES OF TITANIUM ALLOYS AS A FUNCTION OF HEAT TREATMENT AND SECTION SIZE

Ti-6Al-4V(3)			Ti-6.5Al-3Mo-1V(3)			Ti-6Mo-3Al(3)		
Condition	UTS (psi)	Hardness R_c	Condition	UTS (psi)	Hardness R_c	Condition	UTS (psi)	Hardness R_c
1L2	137,000	35.3	AL2	156,000	36.7	GL2	195,000	42.9
3	133,000	33.8	3	145,000	35.2	3	177,000	41.6
6	125,000	33.6	4	149,000	35.4	4	168,000	40.4
2L2	135,000	34.3	6	143,000	36.6	6	148,000	36.5
3	131,000	33.7	BL2	147,000	35.7	HL2	189,000	41.6
6	126,000	34.0	3	138,000	35.3	3	169,000	39.2
3L2	130,000	33.7	4	144,000	34.4	4	155,000	38.7
3	126,000	31.2	6	139,000	33.7	6	147,000	33.4
6	122,000	31.3	CL2	139,000	33.0	JL2	168,000	37.2
4L2	136,000	38.6	3	134,000	32.1	3	149,000	35.4
3	125,000	34.3	4	137,000	33.7	4	142,000	34.5
6	118,000	33.9	6	133,000	32.7	6	139,000	33.0
5L2	140,000	34.8	DL2	174,000	39.2	KL2	205,000	44.2
3	130,000	33.7	3	161,000	37.3	3	180,000	42.5
6	125,000	32.3	4	157,000	36.1	4	165,000	40.4
6L2	137,000	35.2	6	152,000	35.5	6	150,000	36.8
3	129,000	32.4	EL2	172,000	39.2	LL2	181,000	46.2
6	125,000	32.5	3	156,000	37.2	3	175,000	39.4
			4	153,000	36.3	4	166,000	40.2
			6	146,000	33.9	6	147,000	36.1
			FL2	167,000	38.7	ML2	195,000	44.1
			3	158,000	36.3	3	170,000	39.7
			4	149,000	35.1	4	155,000	39.5
			6	139,000	34.5	6	140,000	35.7

Code for Ti-6Al-4V

1, 2 and 3 = Solution Treatment 1550°F - 1 Hour - WQ; Age time 16 Hours - AC
4, 5 and 6 = Solution Treatment 1650°F - 1 Hour - WQ; Age time 1 Hour/in. diameter - AC
1 and 4 = Aging temperature 950°F
2 and 5 = Aging temperature 1050°F
3 and 6 = Aging temperature 1150°F
L = Longitudinal specimens
2, 3 and 6 = Section diameter; in.

Code for Ti-6.5Al-3Mo-1V

A, B and C = Solution Treatment 1650°F - 1 Hour - WQ; Age time 24 Hours - AC
D, E and F = Solution Treatment 1760°F - 1 Hour - WQ; Age time 1 Hour/in. diameter - AC
A and D = Aging temperature 1000°F
B and E = Aging temperature 1100°F
C and F = Aging temperature 1200°F
L = Longitudinal specimens
2, 3, 4 and 6 = Section diameter; in.

Code for Ti-6Mo-3Al

G, H and J = Solution Treatment 1550°F - 1 Hour - WQ; Age time 24 Hours - AC
K, L and M = Solution Treatment 1625°F - 1 Hour - WQ; Age time 1 Hour/in. diameter - AC
G and K = Aging temperature 800°F
H and L = Aging temperature 900°F
J and M = Aging temperature 1000°F
L = Longitudinal specimens
2, 3, 4 and 6 = Section diameter; in.

APPENDIX (Cont'd)

TENSILE STRENGTH-HARDNESS PROPERTIES OF TITANIUM ALLOYS

Ti-4Al-3Mo-1V[4]		Ti-6Al-4V[5]	
Tensile Strength (psi)	Hardness VHN	Tensile Strength (psi)	Hardness VHN
146,000	323	132,000	277
147,000	321	138,000	296
146,500	326	140,000	300
143,000	326	140,000	308
150,000	328	138,000	307
153,000	328	144,000	317
141,000	335	143,000	317
151,000	343	141,000	317
155,000	342	144,000	322
		141,000	322
		149,000	336
		148,000	337
		144,000	337
		145,500	343
		142,000	345
		147,000	346
		142,000	305
		144,000	307
		145,000	310
		144,000	312
		146,000	321
		148,000	321
		150,000	331
		152,000	334
		153,000	334
		156,000	344
		157,000	344
		155,000	348

REFERENCES

1. SISCO, F. T., The alloys of Iron and Carbon, v. 2, McGraw-Hill Book Co., New York, 1937, p. 615-620.

2. LESSELLS, J. M., Some Notes on the Indentation Hardness Test, Symposium on the Significance of the Hardness Test of Metals in Relation to Design, American Society for Testing Materials, 1943.

3. HICKEY, C. F., Jr., Mechanical Properties of Titanium Alloys as a Function of Heat Treatment and Section Size, Watertown Arsenal Laboratories, WAL TR 405.2/7, July 1960.

4. DELGROSSO, E. and KUZMENKO, P., Heat Treatment Response, Mechanical Properties, and Stability of Titanium Steel Alloys, Chase Brass and Copper Company, WADC TR 58-409, January 1959. DMIC File Card No. 31823.

5. HARDY, R. G., Development of Titanium Alloy Castings, Interim Report No. 4, Boeing Airplane Company, Seattle, Washington Division, Contract AF33(600)-36450, December 1958 to February 1959. DMIC File Card No. 31995.

6. RICE, L. P., CAMPBELL, J. E., and SIMMONS, W. F., The Evaluation of the Effects of Very Low Temperatures on the Properties of Aircraft and Missile Metals, Battelle Memorial Institute, February 1960, WADD TR 60-254.

WATERTOWN ARSENAL
TECHNICAL REPORT DISTRIBUTION

Report No.: WAL TR 405.22/1 Title: Tensile Strength-Hardness Correlation for Titanium Alloys
April 1961

Distribution List approved by Ordnance Materials Research Office, 1 December 1960

No. of Copies	TO
1	Director, Army Research Office, Department of the Army, Washington 25, D. C.
1	Commanding Officer, Army Research Office (Durham), Box CM, Duke Station, Durham, North Carolina
	Chief of Ordnance, Department of the Army, Washington 25, D. C.
1	ATTN: ORDTB - Materials
1	ORDIP - Plans and Programs Branch
	Commanding General, Aberdeen Proving Ground, Maryland
1	ATTN: Ballistic Research Lab.
3	ORDBG-LM, Tech. Library, Bldg. 313
	Commanding General, Army Ballistic Missile Agency, Redstone Arsenal, Alabama
1	ATTN: Dr. G. H. Reisig
	Commanding General, Frankford Arsenal, Philadelphia 37, Pa.
2	ATTN: Pitman-Dunn Labs.
	Commanding General, Ordnance Tank-Automotive Command, Detroit Arsenal, Center Line, Michigan
1	ATTN: ORDMC-RM.1, Mr. Charles Salter
	Commanding General, Ordnance Weapons Command, Rock Island, Ill.
1	ATTN: ORDOW-IX
2	ORDOW-TX
1	Commanding General, U. S. Army Ordnance Special Weapons Ammunition Command, Dover, New Jersey
	Commanding General, U. S. Army Rocket & Guided Missile Agency, Redstone Arsenal, Alabama
1	ATTN: ORDAB-DV
5	ORDXR-RGA, Mr. R. L. Wetherington
1	ORDXR-RMO, Lt. E. J. Wilson
	Commanding Officer, Detroit Arsenal, Center Line, Michigan
1	ATTN: ORDMX-BMW
1	ORDMX-AL

Transmittal Date - 6/26/61

No. of Copies	TO
1	Commanding Officer, Diamond Ordnance Fuze Laboratories, Washington 25, D. C. ATTN: ORDTL .012, Technical Reference Branch
1	Commanding Officer, Ordnance Materials Research Office, Watertown Arsenal, Watertown 72, Massachusetts ATTN: RPD
1	Commanding Officer, Picatinny Arsenal, Dover, New Jersey ATTN: Feltman Research Labs.
1	Commanding Officer, Rock Island Arsenal, Rock Island, Illinois ATTN: Laboratory
1	Commanding Officer, Springfield Armory, Springfield 1, Mass. ATTN: ORDBD-TX
1	Commanding Officer, Watervliet Arsenal, Watervliet, New York ATTN: ORDBF-RT
1	Army Reactor Branch, Division of Research Development, Atomic Energy Commission, Washington 25, D. C.
5	Commander, Wright Air Development Division, Wright-Patterson Air Force Base, Ohio ATTN: WWRCEE
1	Chief, Bureau of Ships, Department of the Navy, Washington 25, D. C. ATTN: Code 341
1	.Chief, Bureau of Naval Weapons, Department of the Navy, Room 2225, Munitions Bldg., Washington 25, D. C. ATTN: RMMP
1	Chief, Office of Naval Research, Department of the Navy, Washington 25, D. C. ATTN: Code 423
1	Chief, Naval Engineering Experimental Station, Department of the Navy, Annapolis, Maryland
1	Commander, Naval Ordnance Test Station, China Lake, California ATTN: Code 5557

No. of Copies	TO
1	Director, Naval Research Laboratory, Anacostia Station, Washington, D. C. ATTN: Technical Information Officer
1	Commander, Naval Weapons Laboratory, Dahlgren, Virginia ATTN: A & P Lab.
10	Commander, Armed Services Technical Information Agency, Arlington Hall Station, Arlington 12, Virginia ATTN: TIPDR
15	U. S. Atomic Energy Commission, Office of Technical Information Extension, P. O. Box 62, Oak Ridge, Tennessee
1	Defense Metals Information Center, Battelle Memorial Institute, Columbus, Ohio
1	National Aeronautics and Space Administration, 1520 H Street, N. W., Washington 25, D. C.
1	The Director, Jet Propulsion Laboratory, California Institute of Technology, Pasadena 3, California ATTN: Dr. L. Jaffe
5	Dr. W. R. Lucas, George C. Marshall Space Flight Center, Huntsville, Alabama ATTN: M-S&M-M
1	Mr. W. A. Wilson, George C. Marshall Space Flight Center, Huntsville, Alabama ATTN: M-F&AE-M, Bldg. 4720
5	Commanding Officer, Watertown Arsenal, Watertown 72, Mass. ATTN: ORDBE-LXM, Technical Information Section
1	Author

cy#2 NASA Scientific [illegible] Facility [illegible]

84 -- TOTAL COPIES DISTRIBUTED

93 Total number of copies printed

2 Copies for OTS

1 copy for Publ. Editor

6 extra copies for author

cy#3 N.Y. Naval Shipyard (911B) [illegible]

Copy# 5 & [illegible] Mr. Driscoll 1/23/63

cy#4 N.Y. Naval Shipyard 2/20/63 (911B)

PB 156126
AD ______ Accession No. ______
Watertown Arsenal Laboratories, Watertown 72, Mass.
TENSILE STRENGTH-HARDNESS CORRELATION FOR TITANIUM ALLOYS - Charles F. Hickey, Jr.

Report No. WAL TR 405.22/1, Apr 1961, 21 pp - illus - appendix, OMS Code 4230.1.0000.20, Unclassified Report

This investigation was concerned with the establishment of a correlation between tensile strength and hardness for titanium alloys. Materials of current interest were considered and tested over a fairly wide property range. Tensile and hardness properties were obtained as a function of testing temperature, heat treatment, and section size of material. Data were also obtained from a literature survey.

As a result of the findings, a correlation was established between tensile strength and hardness for stable alpha-beta alloys. It does not apply for metastable alpha-beta alloys nor does it adequately define data in all-beta alloys. In addition, a hardness correlation was established between Vickers and Rockwell C for the stable alpha-beta alloys.

NO DISTRIBUTION LIMITATIONS

UNCLASSIFIED

1. Titanium alloys
2. Titanium, tensile strength-hardness

I. Hickey, Charles F., Jr.
II. OMS Code 4230.1.0000.20

PB 156126
AD ______ Accession No. ______
Watertown Arsenal Laboratories, Watertown 72, Mass.
TENSILE STRENGTH-HARDNESS CORRELATION FOR TITANIUM ALLOYS - Charles F. Hickey, Jr.

Report No. WAL TR 405.22/1, Apr 1961, 21 pp - illus - appendix, OMS Code 4230.1.0000.20, Unclassified Report

This investigation was concerned with the establishment of a correlation between tensile strength and hardness for titanium alloys. Materials of current interest were considered and tested over a fairly wide property range. Tensile and hardness properties were obtained as a function of testing temperature, heat treatment, and section size of material. Data were also obtained from a literature survey.

As a result of the findings, a correlation was established between tensile strength and hardness for stable alpha-beta alloys. It does not apply for metastable alpha-beta alloys nor does it adequately define data in all-beta alloys. In addition, a hardness correlation was established between Vickers and Rockwell C for the stable alpha-beta alloys.

NO DISTRIBUTION LIMITATIONS

UNCLASSIFIED

1. Titanium alloys
2. Titanium, tensile strength-hardness

I. Hickey, Charles F., Jr.
II. OMS Code 4230.1.0000.20

PB 156126
AD ______ Accession No. ______
Watertown Arsenal Laboratories, Watertown 72, Mass.
TENSILE STRENGTH-HARDNESS CORRELATION FOR TITANIUM ALLOYS - Charles F. Hickey, Jr.

Report No. WAL TR 405.22/1, Apr 1961, 21 pp - illus - appendix, OMS Code 4230.1.0000.20, Unclassified Report

This investigation was concerned with the establishment of a correlation between tensile strength and hardness for titanium alloys. Materials of current interest were considered and tested over a fairly wide property range. Tensile and hardness properties were obtained as a function of testing temperature, heat treatment, and section size of material. Data were also obtained from a literature survey.

As a result of the findings, a correlation was established between tensile strength and hardness for stable alpha-beta alloys. It does not apply for metastable alpha-beta alloys nor does it adequately define data in all-beta alloys. In addition, a hardness correlation was established between Vickers and Rockwell C for the stable alpha-beta alloys.

NO DISTRIBUTION LIMITATIONS

UNCLASSIFIED

1. Titanium alloys
2. Titanium, tensile strength-hardness

I. Hickey, Charles F., Jr.
II. OMS Code 4230.1.0000.20

PB 156126
AD ______ Accession No. ______
Watertown Arsenal Laboratories, Watertown 72, Mass.
TENSILE STRENGTH-HARDNESS CORRELATION FOR TITANIUM ALLOYS - Charles F. Hickey, Jr.

Report No. WAL TR 405.22/1, Apr 1961, 21 pp - illus - appendix, OMS Code 4230.1.0000.20, Unclassified Report

This investigation was concerned with the establishment of a correlation between tensile strength and hardness for titanium alloys. Materials of current interest were considered and tested over a fairly wide property range. Tensile and hardness properties were obtained as a function of testing temperature, heat treatment, and section size of material. Data were also obtained from a literature survey.

As a result of the findings, a correlation was established between tensile strength and hardness for stable alpha-beta alloys. It does not apply for metastable alpha-beta alloys nor does it adequately define data in all-beta alloys. In addition, a hardness correlation was established between Vickers and Rockwell C for the stable alpha-beta alloys.

NO DISTRIBUTION LIMITATIONS

UNCLASSIFIED

1. Titanium alloys
2. Titanium, tensile strength-hardness

I. Hickey, Charles F., Jr.
II. OMS Code 4230.1.0000.20