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U. S. ARMY REQUIREMENTS FOR TITANIUM ALLOYS WITH RESPECT TO VEHICULAR APPLICATIONS

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Presented by
S. V. Arnold

U. S. Army Representative
to
Materials Advisory Board Panel
for
Titanium Alloy Sheet Rolling Program

7 May 1959

Prepared by
Ordnance Tank Automotive Command
and
Watertown Arsenal Laboratories

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1 May 1959

Watertown Arsenal
Watertown 72, Mass.

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U. S. ARMY REQUIREMENTS FOR TITANIUM ALLOYS WITH RESPECT TO VEHICULAR APPLICATIONS

PART I

Titanium Fabrication Problems and Development Needs

INTRODUCTION

Predicted U. S. Army requirements for titanium in vehicles have not materialized. Although the reasons vary with the particular application, the principal deterrent has, and continues to be, cost--both of the mill product and also of fabrication. The cost of mill product has discouraged evaluation for those applications where material cost is an appreciable factor, as for example armor plate. The cost of fabrication reflects difficulties attributable to inherent deficiencies in the metal and/or inadequate processing procedures. In this brief paper the staffs of the Ordnance Tank Automotive Command and the Watertown Arsenal Laboratories have collaborated in explaining the problems which beset use of titanium in vehicles so that this Panel may better appreciate the type of technical support which would be most helpful. For those of you who are not familiar with the organization of the Ordnance Corps of the U. S. Army, the Ordnance Tank Automotive Command has mission responsibility for development of military vehicles and the Watertown Arsenal Laboratories have materials research responsibility for steel, titanium and other transitional metals as well as armor materials. We have also taken this opportunity to present information regarding our experience with regard to the costs of procuring titanium and fabricating prototypes over the past several years. Comparisons of estimated costs for titanium vs. steel and/or aluminum in a light armor vehicle application are likewise included (see Part II).

1. PRIMARY FABRICATION PROBLEMS

Titanium applications in vehicles may be divided into two categories: armor fashioned directly from plate, and shaped items. Let us first consider problems in primary fabrication.

Forging practice for titanium alloys has not as yet reached a stage of development equivalent to that for competitive materials, steel and aluminum. Because titanium forgings cannot be produced to as close tolerances, machining and scrap costs rise. Because the metal must be worked in temperature ranges where it is comparatively stiff, heavier (and more costly) equipment must be used, or the number of intermediate heatings needs be increased to the tune of higher handling costs, greater surface contamination and, perhaps, impaired properties. Die wear in forging shaped parts of titanium is another factor.

As for casting shapes of titanium alloys, practice has been brought to the stage where melts of about 150 lbs can be poured at intervals of several hours. It is probably unfair to imply that this in any way indicates the limits of capability (and, indeed, melts of 500 lbs at more frequent intervals of pour are certainly feasible). However, mold design to assure large, sound castings is yet undeveloped, largely because there has been no demand sufficient to warrant scale-up of facilities and exploration of the mold problem. Obviously, reliability of cast parts remains for the present a moot question.

Use of titanium plate as armor has been of exceptional interest for more than a decade. Watertown Arsenal has studied this aspect since inception of the Army's titanium development effort in 1947. The Ordnance Tank Automotive Command constructed a prototype personnel carrier in 1955 (see Figure 9). Unfortunately, there was more study of titanium for armor early in this period when funds were readily available, but at that time the quality of the metal was somewhat inferior to that of the present product. In recent years evaluation has continued, but at a reduced rate commensurate with drastically reduced funding. There has been a certain amount of small scale testing of sheet and thin plate, but material costs for heavier gages has precluded examination of these latter.

Evaluation of armor performance is not a simple matter, as might appear. Resistance to a considerable variety of armor piercing ammunition must be ascertained, not only with regard to type, but also size, and for oblique as well as normal impacts (see Figures 1, 2, 3 and 4). Experience of years allows some feel for performance of steel armor so that such extensive testing can in some degrees be curtailed, but we are not sufficiently familiar with titanium armor to attempt this. Whereas there is good reason to expect 10-25% improvement in performance on a weight basis as compared with steel, the Ordnance Corps will not reach a conclusion of this importance on an extrapolation of the data available.

The reasonableness of this stand will, perhaps, become more apparent when we consider the effect of plate thickness. The present size of commercial arc-melted ingots limits the amount of working which may be given a heavy plate; the heavier the plate, the less working and the coarser the resultant grain structure. We expect ballistic performance to fall off with coarsening structure.

There is also the matter of heat treatment. Our experience with modern alloys is limited to Ti-6%Al-4%V and Ti-4%Al-4%V. These alloys have shown no benefit to ballistic performance from solution treating and aging to higher strengths. If such benefit had been shown, we should then predict that lack of hardenability in titanium armor alloys would be a problem in heavy sections. By comparison, steel armor is improved by heat treatment to higher strength levels and can realize these levels in heavy sections by virtue of greater hardenability.

2. SHOP PROBLEMS

From these comments you may infer that, except for the matter of ingot size as affecting macrostructural quality, mill processing of titanium armor plate is presently adequate. This is probably so. Whereas difficulties in developing satisfactory practices for forging and casting titanium

FIGURE 1

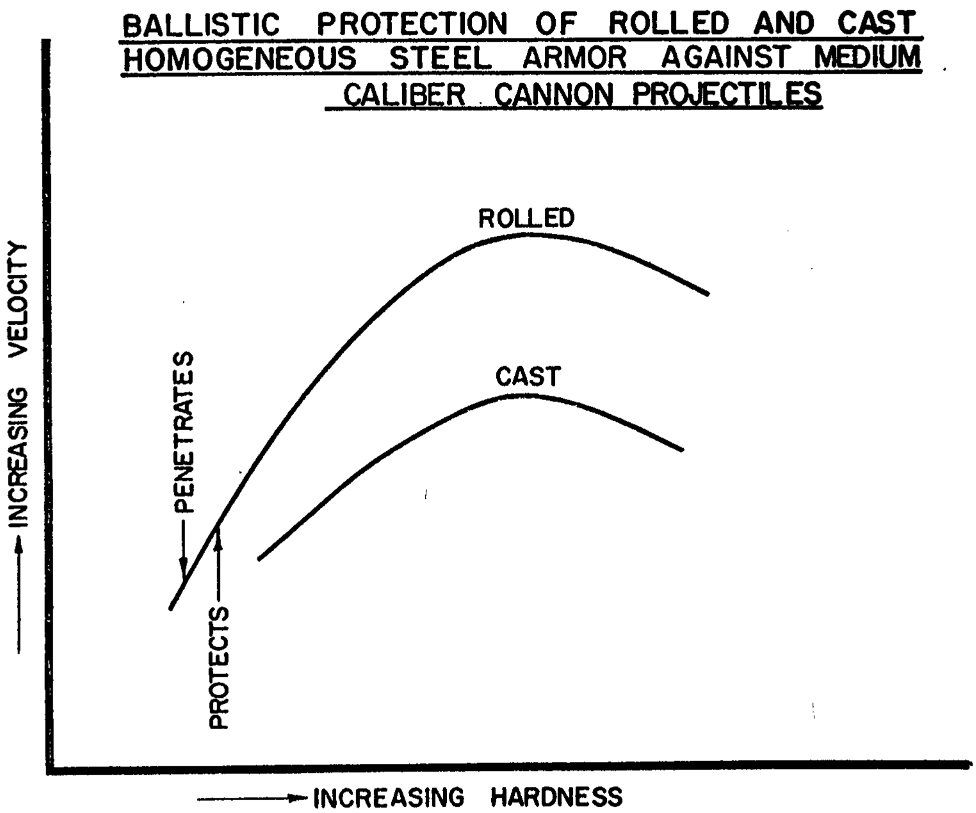


FIGURE 2

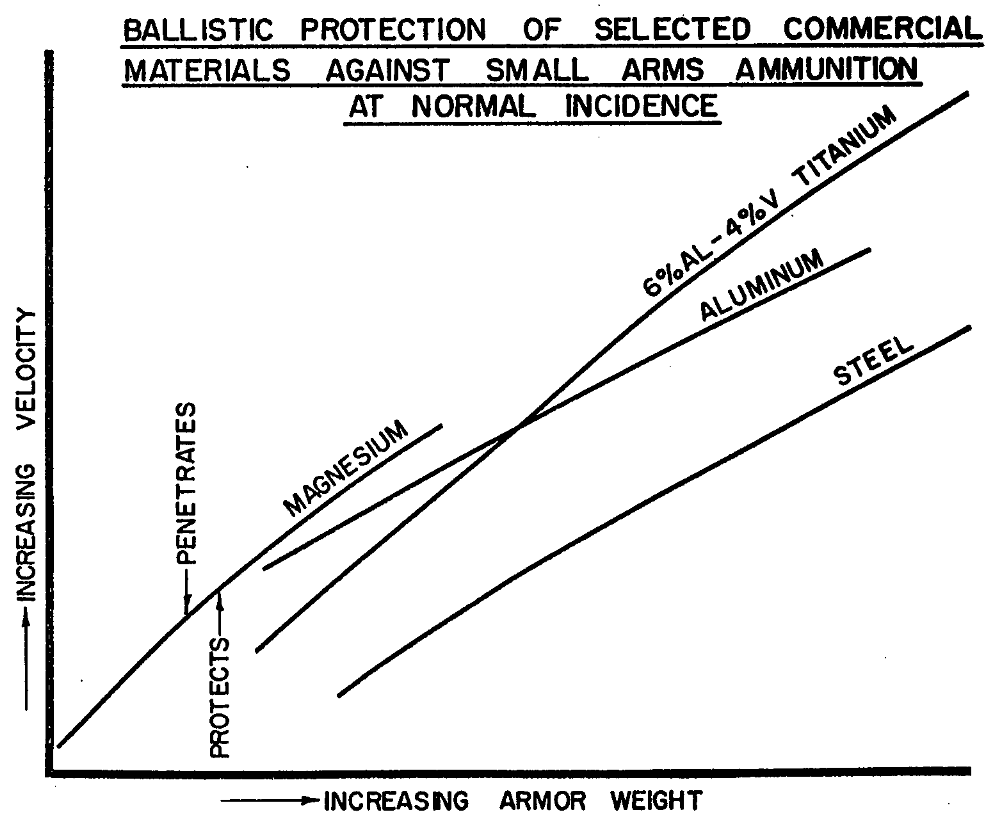


FIGURE 3

WEIGHT SAVINGS FOR SELECTED COMMERCIAL MATERIALS AGAINST 200 GRAINS WEIGHT SHELL FRAGMENTS AT 45°

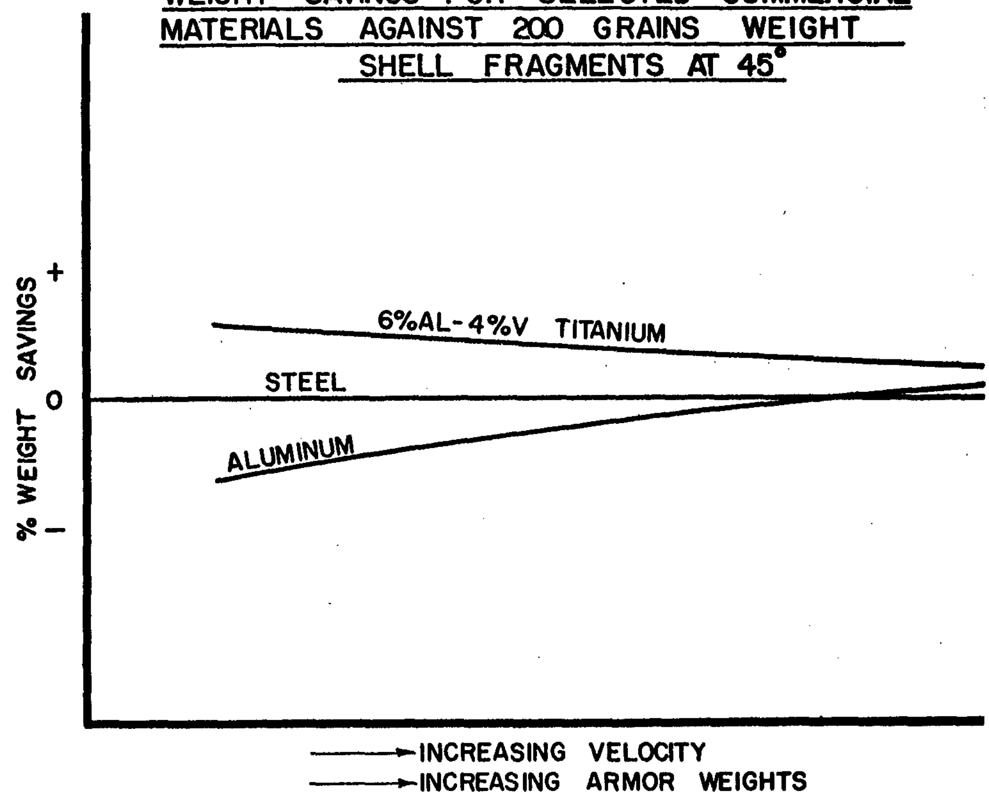
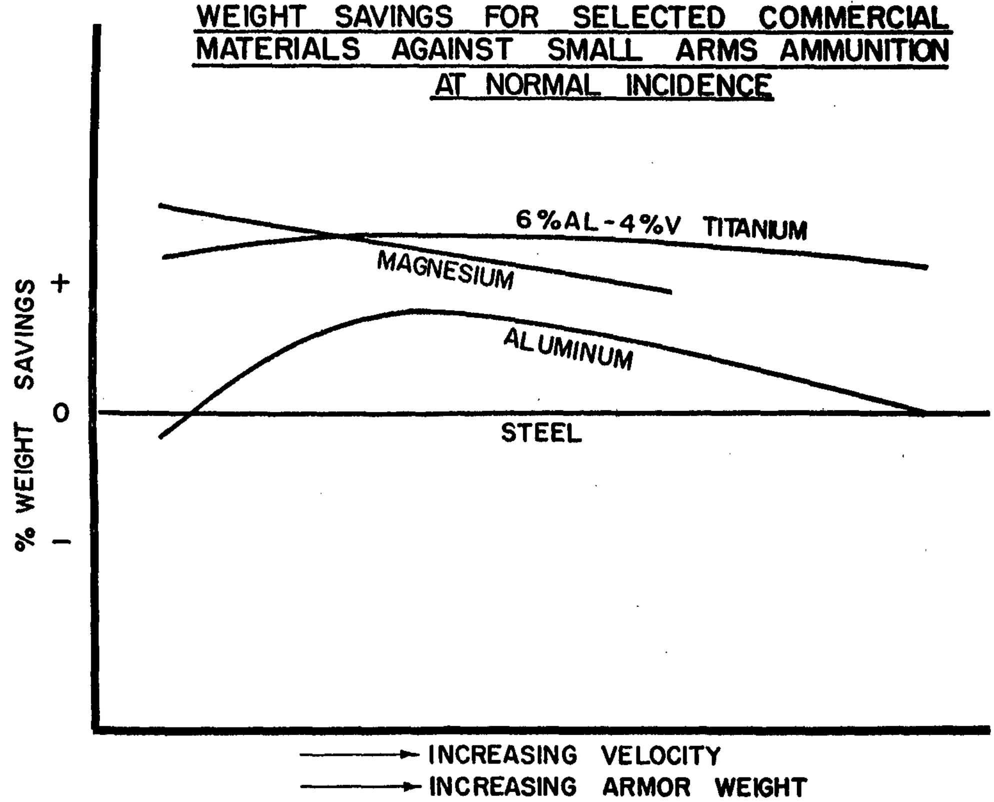


FIGURE 4

WEIGHT SAVINGS FOR SELECTED COMMERCIAL MATERIALS AGAINST SMALL ARMS AMMUNITION AT NORMAL INCIDENCE



vehicle components may take some time to solve, production of titanium armor plate appears to be an existing capability. There remains the matter of consumer fabrication, however, and that involves welding. For like reasons as previously cited, our experience in welding heavy titanium plate sections is scant. Shop practices for welding various joint designs in such heavy plate remain to be developed. Only when this has been done can ballistic performance of titanium plate weldments be assessed. Although welding problems are a deterrent, if ballistic performance of titanium plate were sufficiently superior, mechanical modifications of joint design might be adopted in order to realize this improvement.

3. ALLOY DEVELOPMENT REQUIREMENTS

The foregoing should indicate that the direction for alloy development of titanium armor is presently obscure. We can hypothesize that a certain combination of strength and toughness will be shown optimum. Armor alloys must retain toughness to low temperatures. If increased strength and adequate toughness can be realized by solutionizing-and-aging, then recourse to such treatment will follow and "hardenability" will be desirable in heavier thicknesses. One may predict that application of titanium armor will call for various forming operations, if other than flat sections are to be used. Accordingly, hot formability will be needed. It goes without saying that weldability is a most important factor. Strong, tough welds must be possible by both manual and automatic techniques.

In forgings to be used for structural parts, rather than armor, highest strength consistent with toughness approximating 10 ft lbs Charpy "V" notch impact strength at -40°F is sought. These should be combined with greater forgeability. The alloy must not require such high forging temperature as to make difficult attainment of target properties. Again, weldability is desirable, although it is not essential in many components.

The Ordnance Corps is currently utilizing high-strength, tough titanium alloys in a number of experimental prototype evaluation projects, but its "industrial" usage is at present necessarily limited to forged and extruded shapes requiring only "mechanical connections." For example, the Ti-6%Al-4%V alloy was developed specifically for a special weapons project now in limited production and which requires 0.1% yield strength values of 143,000 psi with 11% elongation, 23% reduction in area, and 11 ft-lbs. impact strength at -40°F. Currently a newly developed alloy, Ti-6%Al-6%V-2%Sn, with small amounts of iron and copper is demonstrating remarkable performance at 0.1% yield strengths in the range of 170,000-185,000 psi with 6-12% elongation, 13-35% reduction in area, and 6-12 ft-lbs. impact strength at -40°F at these strength levels. Obviously, in this non-armor "mechanically connected" application, high-strength steel in the order of 300,000 psi yield strength would be necessary to compete with this alloy on a strength/weight basis.

With regard to castings, the need for process development looms so large that niceties of alloy development are not significant at this stage.

It is, perhaps, well to observe that titanium technology is, for Army vehicle application at least, not so deficient in alloy development as it is in processing techniques. Although it is not reasonable to divorce alloy properties from behavior in fabrication, it is pertinent to remark that mill processing costs at least double the base price of the metal, while secondary fabrication costs are commonly twice those for steel, more than twice those for aluminum. We estimate that a certain personnel carrier armored with titanium can be built 10% lighter, but at twice the cost of one armored as effectively with steel. If the same carrier is equipped with various components fashioned from titanium, another 10% can be lopped off the weight--and the price tripled (see Section 5, Part II). That reduced weight may mean a lot in maneuverability, transportability, increased fuel economy and easier servicing.

It is evident, however, that performance superiority must be thoroughly assessed in justifying application of titanium alloys in Army vehicles.

4. RECOMMENDED PROCEDURE

The first and most important step is to evaluate candidate alloys in the armor application. This will not be difficult, nor should it require more than six months after receipt of plate---and assignment of sufficient priority. The evaluation will, however, be costly. On the basis of assumed costs ranging from \$14 to \$8 per pound corresponding to thickness variation from 1/4" to 6" (cost figures which seem realistic in view of our recent experience) complete ballistic evaluation of a single titanium alloy will cost \$500,000--of this amount \$430,000 would be spent on the plate itself. Lest you visualize vast quantities of plate corresponding to this cost, Table I shown will indicate that the number of plates to be tested in each thickness is actually quite modest. To be sure, evaluation can be restricted to thicknesses particular to a selected vehicular application. Likewise, screening tests using plate approximately 1/2" thick and scale-model armor-piercing projectiles can provide "ball-park" ratings. For those interested typical illustrations of ballistic screening tests are given in Inclosure 1. We cannot, however, rely on screening test data in choosing an armor composition for a prototype, much less a production vehicle.

We recommend that thorough ballistic evaluation of several commercial titanium alloys, each representative of an alloy type, be accomplished immediately.

Concurrently, and possibly continuing thereinafter, we propose screening (by small scale tests) of other candidate alloys to determine whether more complete evaluation is warranted.

A person familiar with Army specifications for rolled-homogenous steel armor plate may inquire whether we have established quantitive relations between mecahnical properties of titanium plate and ballistic performance.

Table I

ARMORED VEHICLE DESIGN DATA

Comprehensive Ballistic Test Firing Program For Titanium Alloy Material

Armor Thickness (Inches)	Size of Plate (Inches)	No. of Plates	Total Wt. of Plates (Lb.)	Projectile* Cal. & Type	Angle of Attack (Degrees)
1/4	18 x 18	8	106	.30" FSP (44 gr.)	0,30,45 & 60
				.50" FSP (207 gr.)	0,30,45 & 60
				20MM FSP (830 gr.)	45 & 60
3/8	18 x 18	5	100	.30" AP M2	0,30,45 & 60
				.50" AP M2	30,45 & 60
1/2	18 x 18	5	133	.30" FSP (44 gr.)	0
				.50" FSP (207 gr.)	0,30,45 & 60
				20MM FSP (830 gr.)	0,30,45 & 60
				.50" AP M2	0
				.30" AP M2	0
3/4	18 x 18	12	477	.30" AP M2	0,30,45 & 60
				.50" AP M2	0,30,45 & 60
				.30" FSP (44 gr.)	0,30,45
				.50" FSP (207 gr.)	0,30,45 & 60
				20MM FSP (830 gr.)	0,30,45 & 60
1	18 x 18	8	424	.30" AP M2	0,30,~~45~~
				.50" AP M2	0,30,45 & 60
				20MM FSP (830 gr.)	0,30,45 & 60
				20MM AP M95	0,30,45 & 60
1-1/2	24 x 24	6	828	.50" AP M2	0,30,45
				20MM AP M95	0,30,45 & 60
				37MM AP	0,30,45 & 60
2	36 x 36	6	2538	57MM AP M70	0,30,45 & 60
				20MM AP M95	0
				37MM AP	0,30,45 & 60
4	60 x 60	7	16,800	37MM AP	0,30
				37MM AP M70	0,30,45 & 60
				76MM AP T128	30,45,60
				90MM AP T33	60
6	60 x 60	7	25,200	57MM AP M70	0
				76MM AP T128	0,30,45
				90MM AP T33	30,45,60

*FSP - Fragment simulating projectile
.30AP - Small arms ammunition
.50AP - Machine gun ammunition
20MM AP, etc. - Standard armor piercing projectiles

The answer is "No". We have not tested enough plate in various thicknesses and compositions to accumulate sufficient data from which such relations can be established, if indeed they exist. Aluminum armor, by the way, does not display all the relationships which hold for steel. We should like to think that such useful relationships can be formed as a means of simplifying our task; the answer can be gained only through experience.

In conclusion: titanium armor offers the most promise for Army vehicle application. A thorough evaluation of ballistic performance should prove this potential prior to construction of prototype vehicles. Once armor potential has been demonstrated, process development in welding, forging and casting should be supported.

SVA/acm
1 May 1959

PART II

TITANIUM PROTOTYPE APPLICATIONS

INTRODUCTION

While the cost of material is most often given as the reason for not using titanium in Ordnance components being produced in quantity, other reasons including (1) the complicated and expensive welding techniques required; (2) the very difficult and to-date commercially undeveloped casting process; (3) the necessity for using lower forging temperatures (as compared to steel) and more sophisticated forging techniques to obtain the necessary grain refinement of titanium; and (4) the insufficient accumulation of data in ballistic response, engineering design data, and shop practices have been equally as great deterrents. In many instances substitution of titanium material for steel has been resorted to in prototype applications in order to generate the necessary design information, to develop methods and techniques for metallurgical processing and manufacture and to correlate the mechanical and physical properties with Ordnance materiel performance.

It is hoped that the various prototype applications given in this part of the report will serve to illustrate most of the various metallurgical areas which need further development. While development of a titanium alloy responsive to heat treatment to much the same degree as steel alloys would be very advantageous in that it would simplify the metallurgical processing problems, these problems are being studied and practical and economical methods being evolved.

1. TITANIUM FORGING, MACHINING AND MATERIAL COST EXPERIENCE

During the past few years the experience of the Ordnance Corps in utilizing high-strength, tough titanium alloys in forged and extruded shapes has, for the most part, resulted in development of the necessary techniques, skills, test data, and other information such as to demonstrate that in certain applications the advantages of using titanium more than compensates for higher material and fabrication costs. In general, forging costs are 125 - 150% of those for steel and machining costs 100 - 125%. However, final machining operations for titanium alloys may be only 75% as expensive as those for high-strength steels competitive on a strength/weight basis.

Figure 5 depicts the titanium alloy cost experience of Watertown Arsenal in procuring commercial quantities (> 10,000 lbs.) of high strength (130,000 - 143,000 psi yield strength) tough[1] alloys in round bar shapes for subsequent

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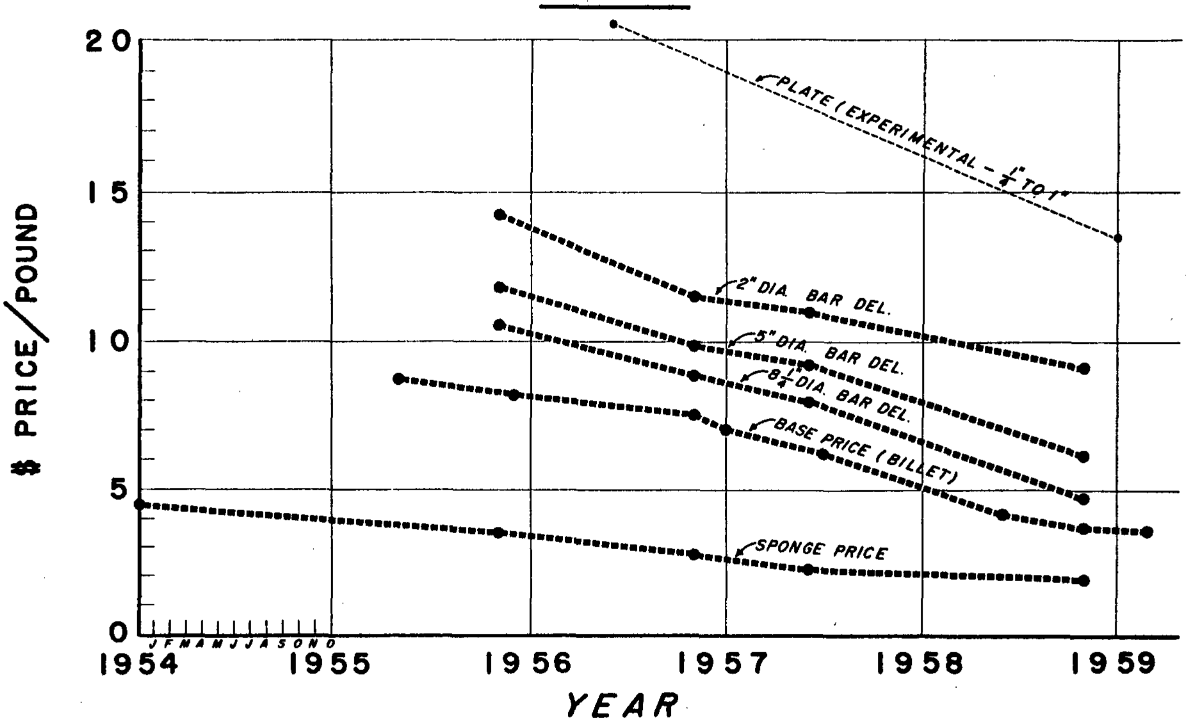
[1] Inclosure 2, Specification WA-PD-76C(1) "Titanium and Titanium Alloy, Wrought (For Critical Components)"

WATERTOWN ARSENAL

TITANIUM ALLOY COST EXPERIENCE

COMMERCIAL ALLOYS PROCURED IN ACCORDANCE WITH SPECIFICATION WA-PD-76C(I) "TITANIUM & TITANIUM ALLOY, WROUGHT (FOR CRITICAL COMPONENTS)"

COSTS



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QUANTITIES PROCURED

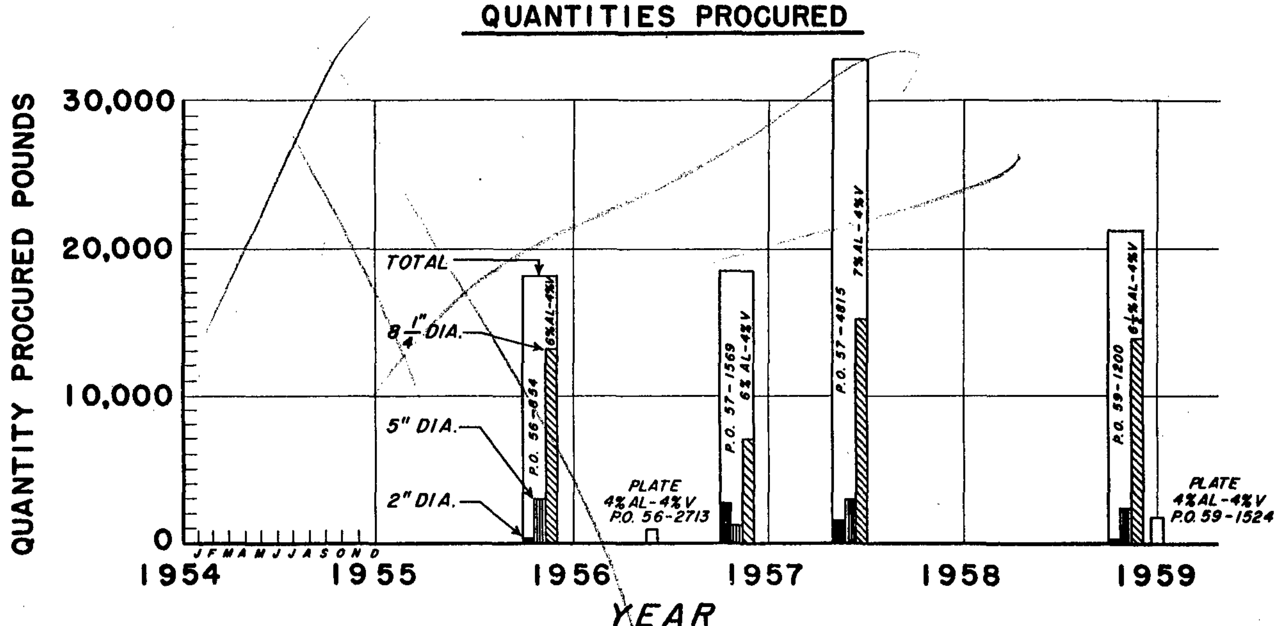

FIGURE 5

23 APRIL 1959

forging and extrusion operations. The actual costs of 2", 5" and 8-1/4" diameter bars are shown in the top graph while the quantities procured are shown in the bottom graph. Very competitive response has been obtained on these moderately large orders from the titanium producers and, as can be seen in the graph, major price reductions have been accomplished by the titanium industry. Also shown on the top of the upper graph are two experimental titanium plate orders, one placed in 1956 and the other in 1958.

Currently the Ordnance Tank Automotive Command is procuring[2] approximately 30,000 pounds of the commercial Ti-6%Al-4%V alloy in plate form from 1 inch to 5 inches in thickness. Ordnance Corps experience with this particular alloy has been that the yield strength level must be kept below 140,000 psi in order to meet the ductility and toughness requirements of Specification WA-PD-76C(1) even in relatively thin section sizes. Ballistic testing of these plates will be invaluable since it will extend the existing terminal ballistic results for this alloy to 5 inches in thickness even though only very limited assessments of metallurgical processing variables can be accomplished with the few plates being ordered.

2. TITANIUM PROTOTYPE COMPONENTS UNDERGOING FIELD TESTING

Figure 6 shows the titanium road wheel that was made from unalloyed material in order to demonstrate the capability of titanium to be shaped to a severe form and to evaluate its wear characteristic in intermittent tank center guide action tests. To date the wheel has been subjected to field testing of 2100 miles on a 50-ton tank; from the standpoint of both the wear characteristics and structural integrity it is satisfactory.

The drive shaft shown in Figure 7 was fabricated in 1955 from a Ti-4%Al-4%Mn alloy and service tested in the as-forged condition. Typical yield strength levels were 130,000 - 135,000 psi. In service tests the drive shaft carries one half of the output of the 810 hp. tank engine and has successfully completed 4000 miles of service testing at Aberdeen Proving Ground, Maryland, and 2000 miles of service testing at the Fort Churchill, Canada, winter test site. Service testing included severe braking tests.

Figure 8 illustrates a front wheel arm assembly typical of those recently made by the Atlas Drop Forge Company. The parts were successfully forged of Ti-7%Al-4%V alloy. Strength properties at the center of the thicker sections (representative of 4-1/2" square sections) were somewhat lower than those obtained in lighter forgings with this alloy. The forging procedure used because of the heavy section size is particularly significant: The alloy was forged high in the beta phase region (from 2000°F to 2200°F) immediately followed by quenching in water. By this method the forging capacity required was reduced to that necessary in forging alloy steel. Field service tests will be conducted on these arm assemblies.

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[2] Inclosure 3, Research and Development Purchase Description No. 59-22

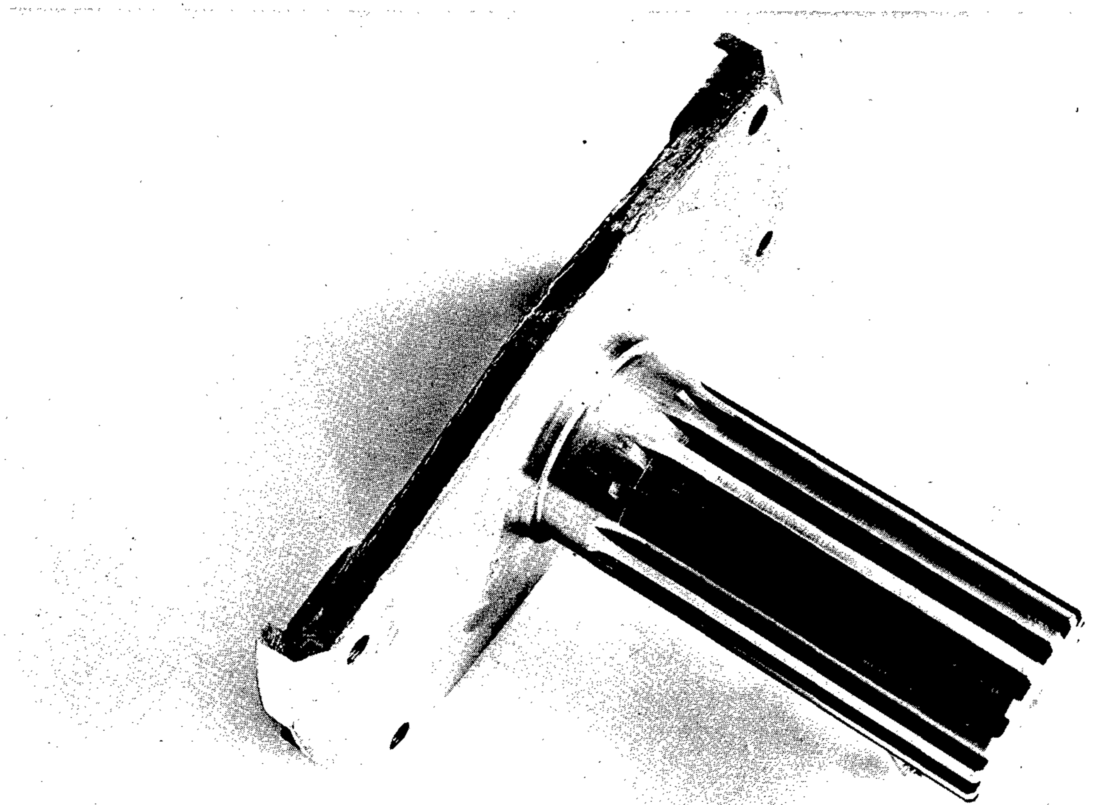
—DETROIT ARSENAL—

NEG. NO. 45181 DATE 24 March 1955

Titanium Metal Roadwheel. View of inside of wheel.

Wtn. 639-16,936

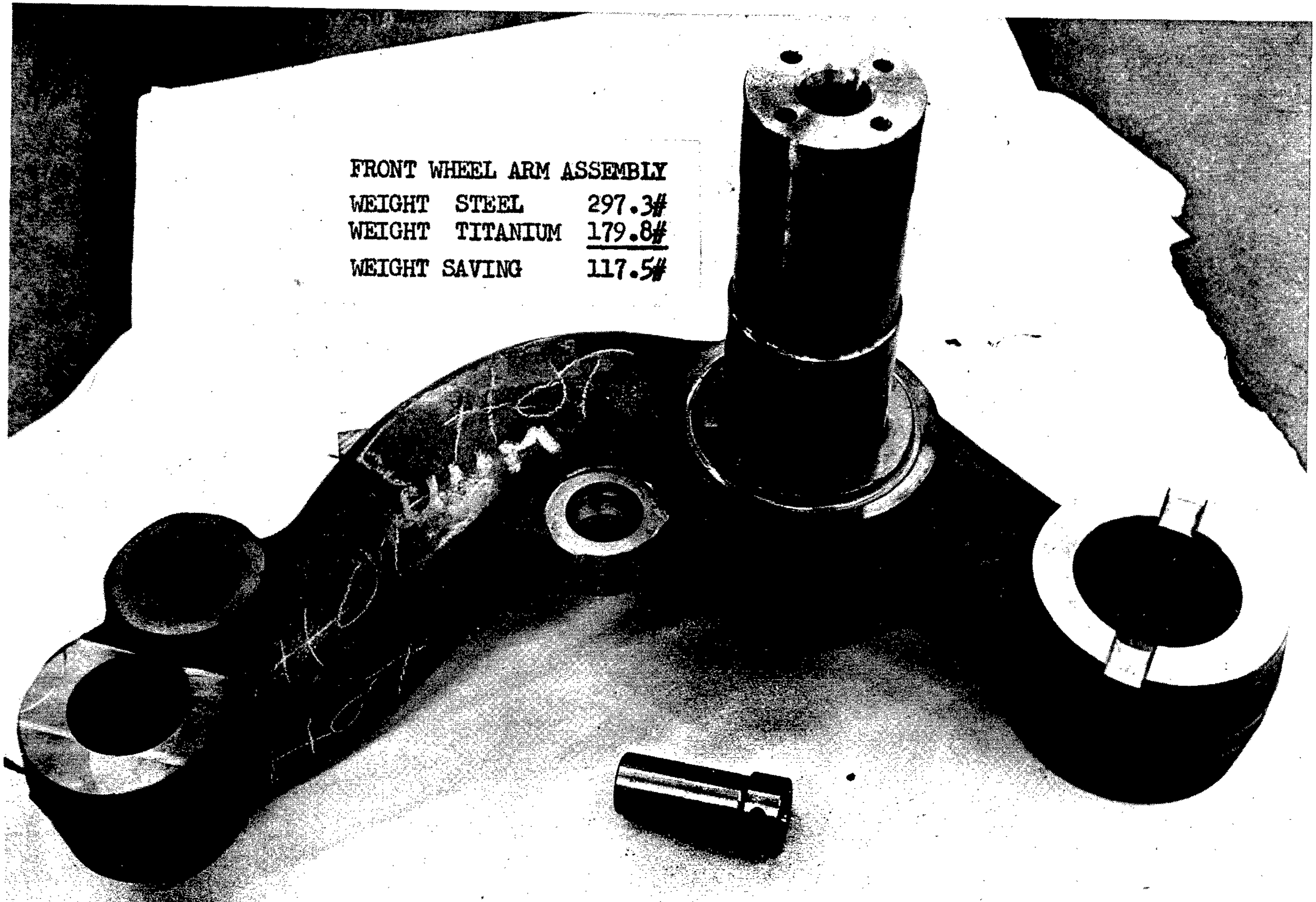
FIGURE 6



—DETROIT ARSENAL—
NEG. NO. 44762 DATE 21 February 1955
M47. Final Drive Shaft, Titanium, (Part #7721059).

Wtn. 639-16,934

FIGURE 7



—DETROIT ARSENAL—
NEG. NO. 44765 DATE 21 February 1955
M47. Front wheel arm assembly, Titanium components
(Part #7328858).

Wtn. 639-16,935

FIGURE 8

3. TITANIUM PROTOTYPE VEHICLE CUPOLA (ARMOR)

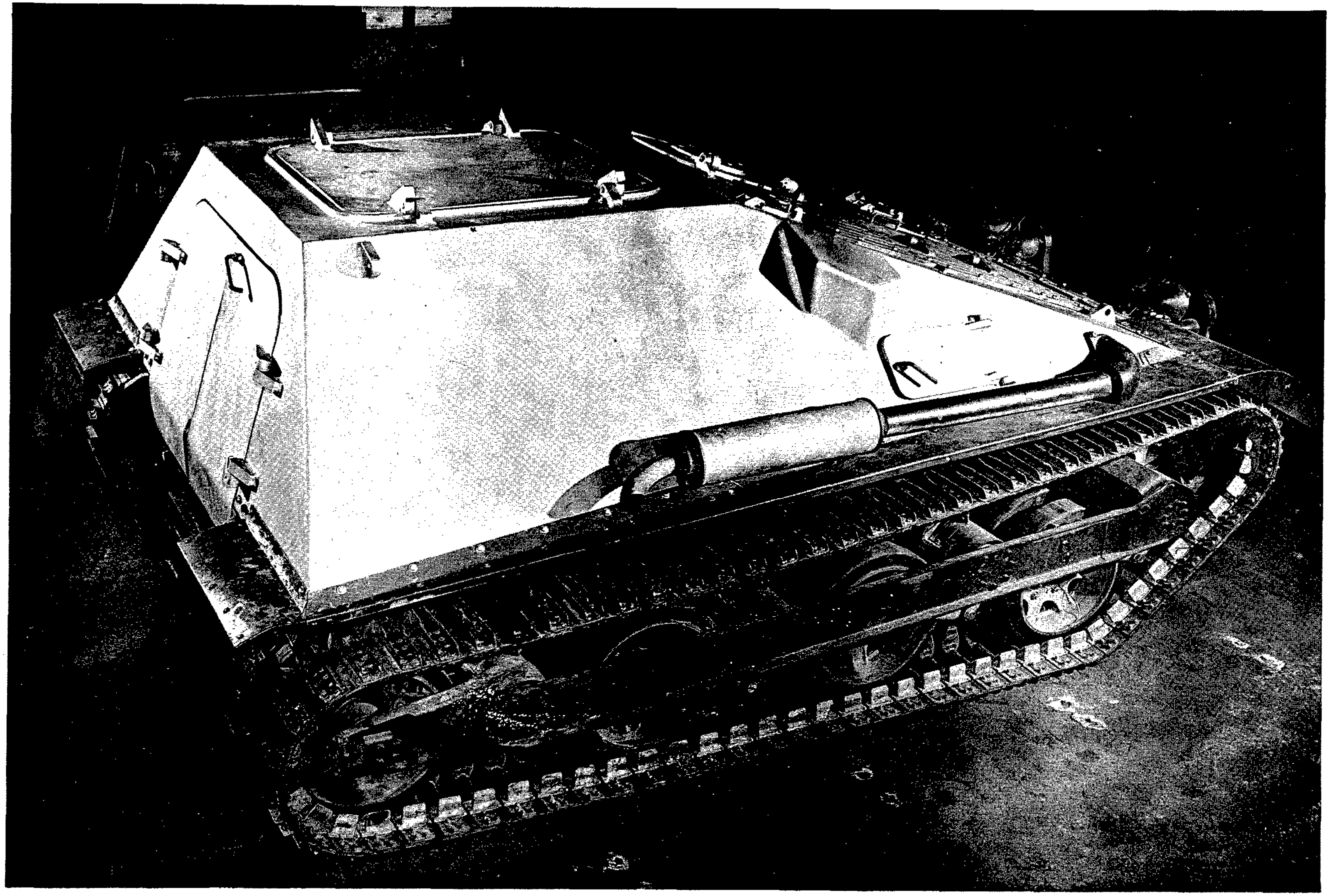
As early as 1955 the upper hull of the T165 (ONTOS) vehicle (See Figure 9) was fabricated from Ti-7%Mn alloy by the A. O. Smith Corporation and Ordnance Tank Automotive Command, Detroit Arsenal. Although alloy development of titanium was not nearly as far advanced then as it is today, a weight saving of over 400 pounds from the original 2200-pound upper structure when made of steel was realized (approximately 20%). It is to be observed in Figure 9 that essentially only welding of flat plates as received from the producer was required. In the present cupola prototype fabrication, forming of surfaces of double curvature in addition to welding of dissimilar titanium alloys are being investigated.

The titanium prototype vehicle cupola consists of a hemispherical segment 5/8" thick, approximately 12 inches in depth and 34 inches in diameter, welded to a flat titanium ring forming the upper half of a 36-inch ball bearing. The cupola has four vision blanks with bullet-proof windows and two gun cradle supports all welded to the hemispherical dome. The material ordered for this prototype project is that reported in Figure 5, experimental plate, Dec. 1958.

Forming of the hemispherical dome is being accomplished both by press forming and hot spinning in order to compare mechanical and ballistic properties of materials fabricated by these two processes. Hot spinning will be done on one of the Lukens Steel Company's huge boiler end-dish spinning machines. The hot blank is placed on a contoured form (male die) and held down by a hydraulic ram. The form, ram head, and blank revolve as a unit while a hydraulically actuated roller spins the blank over the form. Heating of the titanium blank will be done in an atmosphere furnace, and attempts will be made to perform the roll forming operation at temperatures between 1200°F and 1400°F. It is expected that at least one re-heat will be required. A final sizing operation will be performed a little below the recrystallization temperature of the titanium metal. Forming in the hot spinning and sizing operation as well as in the following press forming operation will be to final dimensions on both the internal and external spherical surfaces.

Press forming of the hemispherical dome requires that the titanium blank be canned between thin sheets of (1/32" thick) stainless steel which will be welded together so as to completely enclose the titanium blank. This canning is necessary also to prevent tearing of the material at forming temperatures approaching the beta transus (1400°F to 1600°F). Forming will be accomplished in a 1250-ton press at Watertown Arsenal. Two re-heating operations are planned.

Cost estimates for this cupola are not particularly meaningful because of the experimental processing and fabrication techniques which must be



REAR RIGHT SIDE VIEW
T165 VEHICLE

PHOTOGRAPH BY
A.D. SMITH CORP.

Wtn. 639-16,937

FIGURE 9

employed. However, in order to arrive at a cost comparison between the use of titanium at current prices and of steel in this application, the following cost extrapolations have been made. These estimates do not include die and tooling costs.

		Titanium
Material		
800 lbs. 6%Al-4%V and 4%Al-4%V at $10/lb.		$8,000.00
Fabrication		
Forging, forming, machining, welding, heat treating, and assembly		4,400.00
Accessory Equipment		1,000.00
	Total -	$13,400.00 (Estimated prototype)

The contracted cost for production cupolas of steel is $2,400.00, and the cost ratio is 5.6 to 1.

Weight savings	
Steel mount	620 lbs.
Titanium mount	390 lbs.
Difference -	230 lbs.

Percent weight savings = 37%.

4. TITANIUM PROTOTYPE TANK TRACK (STRUCTURAL)

For vehicle components, such as tank tracks, not requiring ballistic performance per se, weight savings up to 40% over that of steel components are indicated. However, since this prototype tank track has not as yet been subjected to proving-ground performance tests, the weight savings reported here refer only to material properties and successfully processed titanium parts.

While the planned performance tests will quickly provide comparisons with steel tank tracks of the more intangible requirements such as wear and friction, it is to be emphasized that direct substitution of titanium for steel is being done and that no particular attempt has been made to design the track for titanium material.

Table II contains cost comparisons for manufacturing limited quantities (< 200) of steel and titanium tank track components and includes die and tooling costs prorated over the number of components made. The titanium processing and heat-treating costs (line 9), machining costs (line 10), and the die costs (line 11) are actually "experienced" costs. Steel costs were estimated for a comparable "job" sample size.

TABLE II

ESTIMATED COST COMPARISONS FOR LIMITED QUANTITY OF T-109 TITANIUM TANK TRACK ASSEMBLIES (178 UNITS) STEEL AND TITANIUM

21 APRIL 1959

		PIN a		RUBBER ASSEMBLY b		CENTER GUIDE c		CAP, CENTER GUIDE d		BOLT e		GROUSER LEFT f		GROUSER RIGHT g		CONNECTOR h	
		Ti	STEEL	Ti	STEEL	Ti	STEEL	Ti	STEEL	Ti	STEEL	Ti	STEEL	Ti	STEEL	Ti	STEEL
1	DENSITY LB/IN³	.165	.286	.165	.286	.165	.286	.165	.286	.165	.286	.165	.286	.165	.286	.165	.286
2	HARDNESS (Rc)	40	36	—	—	40	36	40	36	40	36	40	32	40	32	40	36
3	APPROX. WGT. OF COMPONENT (#)	(2) 6.52	(2) 11.20	30.3	35	3.34	5.70	1.34	2.62	.70	1.20	3.22	5.58	3.22	5.58	(2) 2.92	(2) 5.00
4	RAW MAT'L COST PER LB. ($) ①	5.50	.17	—	—	5.50	.17	5.50	.17	5.50	.17	5.50	.17	5.50	.17	5.50	.17
5	PROCESSING ②	—	—	D	D	B	A	B	A	A	A	C	A	C	A	B	A
6	HOMOGENEITY ③	A	B	—	—	A	B	A	B	A	B	A	B	A	B	A	B
7	EST. MACHINABILITY RATING ④	45	50	—	—	45	50	45	50	45	50	45	60	45	60	45	50
8	MAT'L COST/UNIT ($) ⑤	(2) 56.10 A	(2) 2.81 B	— A	— B	30.30 A	1.49 B	8.24 A	.42 B	4.72 A	.24 B	26.40 A	1.41 B	26.40 A	1.41 B	(2) 41.80 A	(2) 2.20 B
9	PROCESSING COST THRU HEAT TREAT ($)	(2) 3.00	(2) 4.80	30.95	30.95	18.50	7.90	10.50	4.64	2.50	2.80	32.00	9.90	32.00	9.90	(2) 21.00	(2) 11.70
10	EST. FINAL MACHINING COSTS WITH TOOLING ($)	(2) 133.00	(2) 23.00	—	—	20.00	7.00	20.00	6.00	37.00	12.00	6.00	2.00	6.00	2.00	(2) 32.00	(2) 7.00
11	DIE COST/UNIT ($) ⑥	—	—	—	—	26.30	26.30	8.15	8.15	2.00	2.00	36.25	36.25	36.25	36.25	9.28	9.28
12	EST. TOTAL COST/UNIT $	192.10	30.61	30.95	30.95	95.10	42.69	46.89	19.21	46.22	17.04	100.65	49.56	100.65	49.56	104.08	30.18

NOTES

① COMMERCIAL QUANTITIES > 5000 LBS. (CURRENT PRICES, APRIL 1959)
② (A) ROUTINE COMMERCIAL PROCESSING (STEEL FORGE)
(B) SPECIAL COMMERCIAL PROCESSING (Ti FORGE)
(C) EXPERIMENTAL PROCESSING (SPECIALIZED Ti FORGE)
(D) SPECIAL RUBBER BONDING PROCESSING (RUBBER BOND)
③ (A) DOUBLE VACUUM MELTED TITANIUM
(B) COMMERCIAL ALLOY STEELS
④ MACHINABILITY RATING FS1117 = 100
⑤ (A) ACTUAL
(B) ESTIMATED
⑥ PRORATED OVER 178 PIECES

EST. TOTAL COST OF ONE TRACK SHOE UNIT
(LIMITED QUANTITY < 200)

STEEL . . . . $ 269.80
TITANIUM . . . . . . $ 716.64

$$\text{COST RATIO} = \frac{716.64}{269.80} = 2.66$$

WEIGHTS OF ONE TRACK SHOE ASSEMBLY

	STEEL	TITANIUM
PINS (2)	11.20 LBS.	6.52 LBS.
CENTER GUIDE (1)	5.70	3.34
CAP (1)	2.62	1.34
BOLT (1)	1.20	.70
LEFT GROUSER (1)	5.58	3.22
RIGHT GROUSER (1)	5.58	3.22
CONNECTOR (2)	5.00	2.92
SUB TOTAL	36.88 LBS.	21.26 LBS.
RUBBER ASSEMBLY	23.80	23.80
TOTAL	60.68 LBS.	45.06 LBS.

REDUCTION IN METALS PARTS WEIGHT — 15.62 LBS.

$$\text{\% REDUCTION IN METALS PARTS WEIGHT} - \frac{15.62}{36.88} - 43\%$$

$$\text{\% REDUCTION IN TRACK SHOE ASSEMBLY} - \frac{15.62}{60.68} - 26\%$$

Wtn. 639-16,921

In this table the cost per pound ratio of titanium to steel is 32 to 1, but, since only 35 pounds of titanium raw material were required as compared to 59 pounds of steel, the actual cost ratio for raw material is 19.4 to 1. Typical mechanical properties realized on these forged and/or heat treated Ti-7%Al-4%V alloy components are shown in Table III, and forged components are shown in Figure 10.

The cost for titanium track shoes, 2.66 times that of steel shoes, is, unfortunately, valid only for this particular limited quantity application. In mass production die and tooling costs became insignificant and major reductions are possible in machining costs and processing costs. For example, steel connectors were procured in 1954 at a cost of $2.21 each, or $4.42 per unit, as compared with $104.08 estimated for titanium connectors (See Table II). Based upon this price and the experience of this limited titanium processing, approximate mass production costs for steel and titanium connectors may be compared as follows:

	Titanium	Steel
Material Cost/unit (Titanium at $5.50/lb.)	$41.80	$2.20
Processing Cost through Heat Treatment	1.15	.75
Final Machining	2.20	1.47
	$45.15	$4.42

Thus, the cost ratio in production quantities would be approximately 10 to 1. It is to be noted that the processing costs through heat treatment and the final machining costs for titanium have been assumed to hold in mass production in the same ratio as those "experienced" in Table II. That is, the forging and heat treating as well as the final machining costs are 1.5 times these costs in steel. The reasons for these higher titanium processing costs are explained in the following paragraphs.

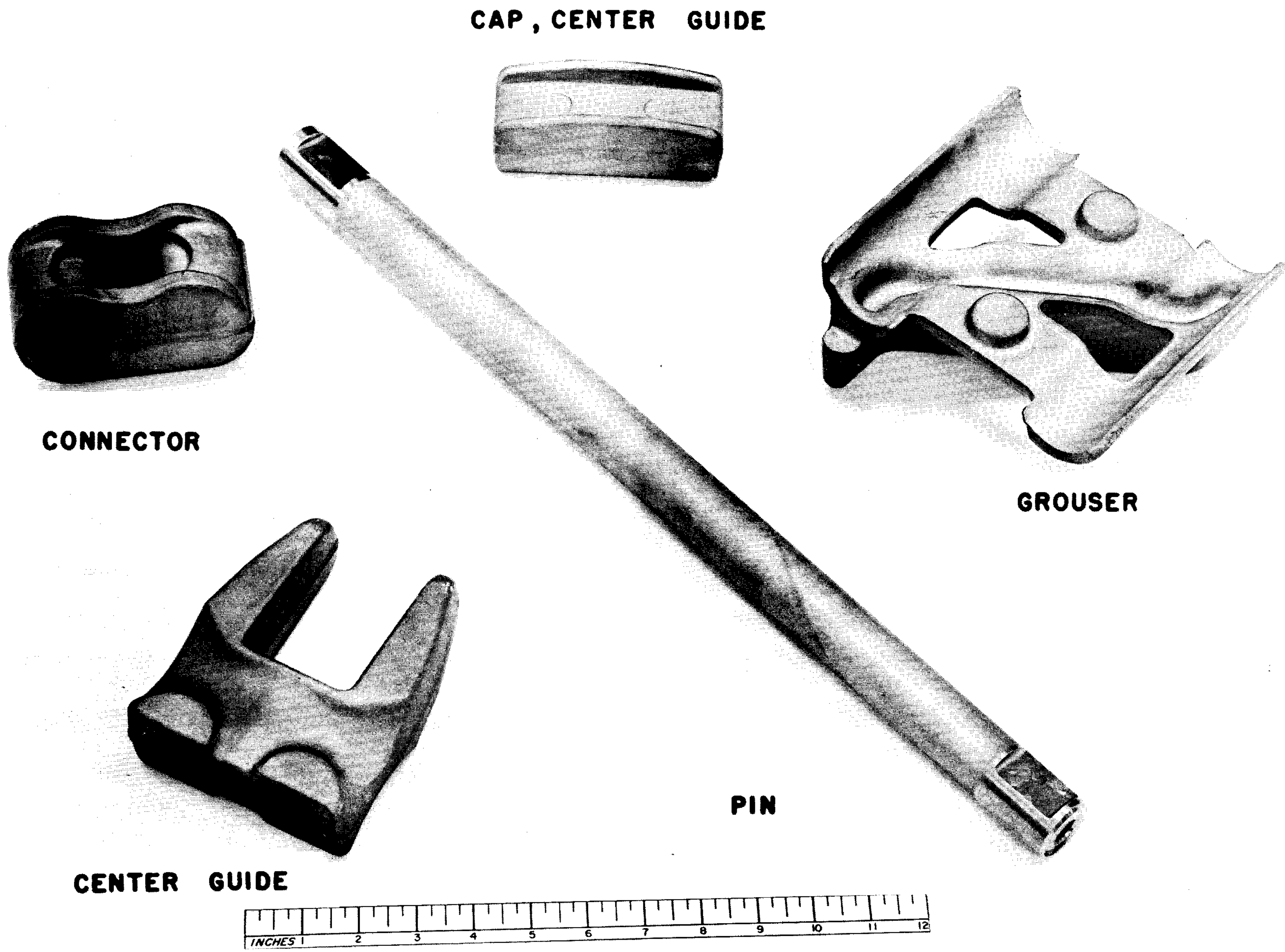
The bolt, center guide, connector, center guide cap, and grousers are forged in closed dies. The pins are machined out of barstock. Since most of the parts are forged, it is apparent that the cost of forging dies prorated one the basis of 178 units (line 11, Table II) constitute a substantial portion of the total cost. Die costs will be about the same for forging either steel or titanium alloys, although the dies may differ in draft angles, radii of die fillets and trimming patterns. Manufacture of dies for forging titanium is based on good die sinking practice, which, however, has been found to depend upon experience obtained in actual titanium forging.

On the other hand, processing costs (line 10, Table II) are considerably higher for titanium due to the lower forging temperature (approximately 400°F less for titanium) and correspondingly higher forging time and more heating cycles are required to forge titanium.

Table III

TYPICAL PHYSICAL PROPERTIES OBTAINED FOR FORGED AND/OR HEAT TREATED 7AL-4V COMPONENTS

ITEM	Y.S. (.1%)	% ELONG.	% R.A.	CHARPY IMPACT (Ft.Lbs.)	FORGE AND HEAT TREATMENT
Bolt	163,000	14.3	39.8	12.4	Forged at 1725°F - W.Q. Sol. Temperature at 1750°F 1-1/2 hrs. W.Q. Aged 1050°F - 4 hrs. A.C.
Pin	155,100 159,200 150,500 155,600	14.0 12.0 15.0 12.0	44.9 40.8 46.2 44.9	13.1 12.9 11.3 10.3	Not Forged Sol. Temperature at 1750°F 1-1/2 hrs. W.Q. Aged 1050°F - 4 hrs. A.C.
Cap, Center Guide	161,500 160,000	13.0 14.0	33.4 37.8	12.0 12.3	Forged at 1775°F - W.Q. Sol. Temperature at 1700°F 1-1/2 hrs. W.Q. Aged 1100°F - 4 hrs. A.C.
Connector	147,500 149,000	14.3 16.4	45.3 44.1	11.6 11.2	Forged at 1775°F - W.Q. Sol. Temperature at 1700°F 1-1/2 hrs. W.Q. Aged 1100°F - 4 hrs. A.C.



FORGED TITANIUM TANK TRACK COMPONENTS

FIGURE 10 WATERTOWN ARSENAL LABORATORIES W.T.N. 681-1216

Tooling costs are approximately the same for either titanium or steel because jig and fixture costs and set-up time are identical for either metal. However, machining costs are somewhat higher for titanium as compared to steel (line 10, Table II). The extreme hardness of forged titanium surfaces (55 - 60 RC) and the requirement for using slower feeds and speeds with carbide-tipped tools increases the machining time and hence raises the machining costs of titanium.

The costs of rubber bonding the rubber pads to the tank track pins is identical for either steel or titanium pins. This is due to the fact that rubber can be bonded equally effectively to either steel or titanium using identical bonding and assembling processes.

5. TITANIUM PERSONNEL CARRIER CONCEPT APPRAISAL

In all new requirements (concepts) for armored vehicles, appraisals are made for all candidate materials. Three materials, aluminum, steel, and titanium have been considered for the T-113 personnel carrier. Estimates of costs for an initial production quantity of carriers of titanium are summarized here, and comparisons made with estimates for personnel carriers of steel and of aluminum.

The T-113 personnel carrier is a new design of armored vehicle which is placed within a category known as air-transportable and air-droppable. Briefly, the total weight of the vehicle must not exceed 20,000 pounds and the ballistic requirement is that it protect against shell fragments from medium caliber cannon. Concept study investigations show that for the T-113 vehicle various thicknesses of armor ranging from 1/2" to 1-3/4" in aluminum, from 3/16" to 5/8" thick in steel, or from 1/4" to 1" thick in titanium would be required.

The estimated weights of T-113 personnel carriers made of aluminum, steel, and titanium are:

	WEIGHT-POUNDS		
	Aluminum	Steel	Titanium
Armored Shell and Framing	9,420	10,070	8,000
Non-armor Components (forgings, etc.)	3,830	4,280	2,600
Total -	13,250 lbs.	14,350 lbs.	10,600 lbs.
Other materials, engine, controls, etc.	5,000	5,000	5,000
Gross Total -	18,250 lbs.	19,350 lbs.	15,600 lbs.

In this estimate titanium weight savings of 20% are assumed for armor components, and titanium weight savings of 40% are assumed for non-armor components in comparison with steel.

The total quantities of material required for T-113 personnel carrier made of these materials exclusive of the power plant and controls are:

	RAW MATERIALS - POUNDS		
	Aluminum	Steel	Titanium
Armor Shell and Framing at 115%	10,830	11,580	9,200
Non-armor Components at 150%	5,750	6,420	3,900
Welding Rod at 5%	470	500	400
Total -	17,050 lbs.	18,500 lbs.	13,500 lbs.

where a 15% scrap factor has been used for the armor construction (simple flat plate construction) a 50% scrap factor has been used for the forging material losses and machining scrap, and a welding rod requirement for 5% of the welded material assumed.

The estimated total costs of material required for the T-113 personnel carrier exclusive of the power plant and controls are:

	COST OF MATERIAL		
	Aluminum	Steel	Titanium
Armor Shell and Framing	$5,960.00	$3,240.00	$ 92,000.00
Non-armor Components	3,160.00	1,800.00	19,500.00
Welding Rod	750.00	140.00	8,000.00
Total -	$9,870.00	$5,180.00	$119,500.00

Aluminum and steel material costs of $.55/lb. and $.28/lb. respectively have been used. Titanium bar material currently is being procured in commercial quantities at $5.00/lb., and it is estimated that the current experimental plate titanium cost would be reduced from approximately $13.50/lb. to $10.00/lb. for limited quantities. The cost of titanium welding rod has been included because of its significant cost of $20.00/lb. in comparison to $1.60/lb. and $.25/lb. for aluminum and steel respectively.

The estimated total costs for manufacturing the initial limited production of T-113 personnel carrier providing for maximum use of aluminum, steel and titanium are tabulated below. A fourth modification combining titanium armor with steel non-armor components is also shown.

	ESTIMATED COSTS			
	Aluminum	Steel	Titanium	Titanium (Armor Only)
Armor Material Cost	$ 6,710.00*	$ 3,380.00*	$100,000.00*	$100,000.00*
Fabrication	2,590.00	3,400.00	6,800.00	6,800.00
Non-armor Mat'l Cost	3,160.00	1,800.00	19,500.00	1,800.00
Fabrication	12,540.00	17,220.00	26,800.00	17,220.00
Power, Control, Misc.	6,000.00	6,000.00	6,000.00	6,000.00
Total -	$31,000.00	$31,700.00	$159,100.00	$131,820.00

Factors of 2 and 1.5 times the steel fabricating costs were used in calculating titanium fabricating costs for armor material and non-armor material respectively.

*Including welding rod.

The following table compares relative estimated costs for fabricating the T-113 personnel carrier from aluminum and titanium with that for steel:

	Aluminum	Steel	Titanium	Titanium (Armor Only)
Material Cost	1.9	1	23.1	19.6
Total Cost	0.98	1	5.0	4.1

If titanium armor plate can be procured for $5.00 per pound, the relation of costs would be as follows:

	Aluminum	Steel	Titanium	Titanium (Armor Only)
Material Cost	1.9	1	14.2	10
Total Cost	0.98	1	3.6	2.7

The relative over-all weights calculated for these various modifications of carrier design are compared below:

Aluminum	Steel	Titanium	Titanium (Armor Only)
94.5%	100%	80.5%	89.5%

In this exercise designs calculated for equivalent ballistic protection have indicated certain savings in weight. It is, of course, possible to design for equal total weight with some improvement in ballistic performance through use of aluminum or titanium.

ENH/hb
1 May 1959

Inclosure 1

BALLISTIC PERFORMANCE SCREENING TESTS

Ballistic screening tests are conducted on any promising material for use as armor with either small arms ammunition, scale-model or fragment-simulating projectiles. A test smaple of 12" x 12" or larger size is preferred; however, ballistic screening tests have been conducted on samples as small as 6" square. Approximately sixty alloys of titanium have been screened to date including the following types:

a. Unalloyed Titanium

b. Binary Alloys of Titanium

Aluminum
Chromium
Molybdenum
Manganese

c. Ternary Alloys of Titanium

Aluminum-chromium
Aluminum-tantalum
Aluminum-manganese
Aluminum-vanadium
Iron-molybdenum
Iron-manganese
Iron-vanadium
Iron-chromium
Chromium-molybdenum

d. Quaternary Alloys of Titanium

Aluminum-columbium-tantalum
Iron-chromium-molybdenum

Three (3) typical types of ballistic screening tests follow:

1. An example of a fairly comprehensive scale-model ballistic study conducted by Watertown Arsenal is the 6%Al-4%V titanium composition ballistically tested for one thickness (0.625", 14.6 lbs/sq.ft.) with small arms ammunition, fragment-simulating and scale-model projectiles at various obliquities. Ballistic penetration limits were determined for various angles of attack as shown in the following chart:

Type Projectile	0	Obliquity - Degrees 30	45	60
Cal .50 (207-grain) fragment simulator	x	x	x	x
20MM (830-grain) fragment simulator	x	x	x	x
Cal .30 AP M2 Small Arms	x	x		
Cal .50 AP M2 Machine Gun	x	x	x	
Cal .40 AP T33 (Scale Model of 90MM AP)	x		x	
20MM Proof Projectile	x			

Each ballistic limit was determined by averaging the three highest velocity partial penetrations and the three lowest velocity complete penetrations, all velocities averaged being within the 125 ft/sec. maximum difference allowed. For some test conditions, ballistic tests were not conducted because of the gun's muzzle velocity limitations. These tests indicated that the 0.625" thick 6%Al-4%V titanium alloy affords very good protection against the above projectiles since it could match the ballistic performance of rolled homogeneous steel armor and provide a weight saving of approximately 20%.

2. Recently, a lightweight, honeycomb, stainless-steel corrugated configuration was subjected to ballistic screening tests particularly since the material has potential as a structural material because of its high strength and high stiffness characteristics. However, ballistic tests with 5.85 and 17-grain fragment-simulating projectiles indicated that for these limited tests the corrugated stainless-steel panel offered lower ballistic resistance than Hadfield-manganese steel, 4130 steel, and 2024-T4 aluminum alloy having the same areal density. It is anticipated that future production will be capable of fabricating corrugated panels from heavier sheet. When this occurs, and the panels weigh several pounds per square foot of area, samples will be evaluated ballistically to assess the potential of this material as a lightweight armor.

3. Ballistic screening tests on a newly developed high-strength polycarbonate plastic resin material weighing 3.4 lbs/ft^2 was recently tested with 44- and 207-grain fragment-simulating projectiles, and these limited tests indicated that high-strength plastic resin material offered lower ballistic protection when compared to standard Doron II and bonded nylon plastic armor having the same weight. Based on these limited tests, the producer of high-strength plastic resin material was advised that the ballistic resistance of this material can be improved by employing a unidirectional fiberglass fabric, type 143, with high-strength plastic resin 15 to 20% by weight. The unidirectional layers of fiberglass cloth should be alternately stacked so that the warp of every layer of cloth is at right angles to the warp of the adjacent layer. Plastic panels having this make up will be tested when they become available.

FSM/acm
1 May 1959

Inclosure 2

WATERTOWN ARSENAL
WATERTOWN 72, MASSACHUSETTS

WA-PD-76C(1)
12 March 1956
SUPERSEDING
WA-PD-76C
20 January 1956
WA-PD-76
19 March 1954
WA-PD-76A
26 August 1955
WA-PD-128
2 March 1955
WA-PD-128A
14 April 1955

MILITARY SPECIFICATION

Titanium and Titanium Alloys, Wrought
(For Critical Components)

1. SCOPE

1.1 Scope.- This specification covers annealed or heat treated wrought (rolled, extruded, drawn or forged) titanium and titanium alloys in the form of plates, sheet, strip, wire, tubing, bars, billets and shapes for ordnance applications other than armor.

2. APPLICABLE SPECIFICATIONS, STANDARDS, DRAWINGS, AND PUBLICATIONS

2.1 The following specification, of the issue in effect on the date of invitation for bids, forms a part of this specification:

SPECIFICATION

FEDERAL

QQ-M-151 - Metals; General Specification for Inspection of

(Copies of specifications, standards, and drawings required by contractors in connection with specific procurement functions should be obtained from the procuring agency or as directed by the contracting officer.)

3. REQUIREMENTS

3.1 Material.- The material produced under this specification shall be uniform in quality and condition and free from defects setrimental to fabricability or serviceability such as hard spots, laminations, inclusions, pits, folds, seams and cracks.

3.2 Condition.- Unless otherwise specified on the drawings, in the contract or in the order, the material shall be in the annealed or heat treated condition as prescribed by the contractor.

3.3 Physical properties.-

3.3.1 Yield Strength.- The yield strength range shall be as specified in the contract, on the order, or on applicable drawings.

3.3.1.1 Maximum yield strength.- The specified yield strength range may be exceeded providing the per cent elongation, per cent reduction of area, and V-notch Charpy impact resistance do not fall below values specified in Table I or Table II as applicable for the upper limit of the required yield strength range.

3.3.2 Impact resistance.- The transverse V-notch Charpy impact resistance at -40°F shall equal or exceed that shown in Table I or Table II as applicable for the yield strength of the lot being inspected.

3.3.2.1 The longitudinal V-notch Charpy impact resistance at -40°F shall equal or exceed twenty per cent more than that required by Table I or II, as applicable, for the yield strength of the lot being inspected.

3.3.2.2 Material less than 7/16" in thickness or width or 7/10" in diameter.- Charpy impact resistance tests shall not be required on material less than 7/16" in thickness or width or 7/10" in diameter. However, at the option of the contracting officer, the contractor may be required to demonstrate, by special tests prescribed by the contracting officer and agreed to by the contractor, that the material be proposes to furnish is satisfactory insofar as impact resistance is concerned.

3.3.3 Tensile ductility.- The reduction of area and elongation shall equal or exceed the values shown in Table I or Table II, as applicable, for the yield strength of the lot being inspected.

TABLE I

Mechanical Property Requirements for Wrought Products Other than Extrusions

Transverse Direction

Yield Strength Increments PSI .1% Offset	Elongation Minimum %	Reduction of Area[1] Min., %	V-Notch Charpy Impact Resistance, Min. Ft. Lbs. at -40°F
40,000 - 49,999	28	48	48
50,000 - 59,999	27	46	43
60,000 - 69,999	26	44	38
70,000 - 79,999	25	42	33
80,000 - 89,999	24	40	29
90,000 - 99,999	22	38	25
100,000 -109,999	19	35	21
110,000 -119,999	16	32	18
120,000 -129,999	14	29	15
130,000 -139,999	12	26	12
140,000 -149,999	11	23	11
150,000 -159,999	10	21	10
160,000 and over	8	18	9

1. Reduction of area shall not be required when a Type 5 or 5A specimen is used, or when wire is being tested.

TAPLE II

Mechanical Property Requirements for Extruded Products

Transverse Direction

Yield Strength Increments PSI .1% Offset	Elongation Minimum %	Reduction of Area[1] Min., %	V-Notch Charpy Impact Resistance, Min. Ft. Lbs. at -40°F
40,000 - 49,999	28	48	48
50,000 - 59,999	27	46	43
60,000 - 69,999	26	44	38
70,000 - 79,999	25	42	33
80,000 - 89,999	24	40	29
90,000 - 99,999	20	38	25
100,000 -109,999	16	32	20
110,000 -119,999	12	26	16
120,000 -129,999	10	20	13
130,000 -139,999	9	16	10
140,000 -149,999	8	15	9
150,000 -159,999	7	14	8
160,000 and over	7	14	8

1. Reduction of area shall not be required when a Type 5 or 5A specimen is used, or when wire is being tested.

3.3.4 Density.- The maximum density of the wrought titanium or titanium alloys shall be 5.00 grams per cubic centimeter.

3.4 Heat treatment.- When material is heat treated to meet the applicable physical property requirements of this specification, the details of the heat treating procedure shall be provided by the contractor and shall be forwarded with each lot at the time of shipment.

3.5 Dimensions and dimensional tolerances.- Dimensions and dimensional tolerances shall be as specified in the contract, order, or applicable drawings.

3.5.1 Unless otherwise specified, when material is ordered by piece, all tolerances must be minus on the inside diameter, plus on the outside diameter, and plus on the length, width or thickness.

3.5.2 Unless otherwise specified, when material is ordered by weight, toleranches shall not exceed $\pm$ .5% on diameters, $\pm$2.0% on thicknesses, and shall not exceed +1/4" -.000" on length and width.

3.6 Chemical analysis.-

3.6.1 A statement of chemical analysis of each heat shall be provided and shall include all elements intentionally added as well as the maximum amount of the impurities carbon, oxygen, hydrogen, and nitrogen.

3.6.2 Carbon content.- Unless otherwise specified, the carbon content of the material furnished shall not exceed 0.10%.

3.6.3 Hydrogen content.- Unless otherwise specified, the hydrogen content of the material furnished shall not exceed 0.0125%.

4. QUALITY ASSURANCE PROVISIONS

4.1 Definition of terms used in connection with testing under this specification.

4.1.1 Lot.-

4.1.1.1. General.- Except as provided below, a lot shall consist of not more than 25 pieces submitted for inspection at the same time, of the same heat, the same condition, the same processing cycle, the same diameter or thickness, and the same heat treating cycle. A lot shall be heat treated in the same furnace, but may not necessarily be of the same charge.

4.1.1.2 Definitions of lot quanitities for specific items.-

4.1.1.2.1 Shapes.- A lot shall consist of not more than 25 items of the same shape and size.

4.1.1.2.2 Plate, sheet and strip.- A lot shall consist of not more than 500 pounds.

4.1.1.2.3 Barstock.- For barstock less than 5" in diameter, a lot shall consist of not more than 500 pounds. For barstock greater than 5" in diameter a lot shall consist of not more than 1000 pounds.

4.1.1.2.4. Tubing and extruded shapes.- A lot shall consist of one heat treated length unless otherwise specified in the contract or applicable drawing.

4.1.2. Yield Strength.- Yield strength shall be the arithmetical average of all yield strength determinations obtained from tests made in connection with one submission of a lot. Results of tests made on resubmission of a lot after further heat treatment shall be considered separately. In the case of tubing and extruded shapes, each end shall be tested and averaged separately.

4.1.3 Ductility.- Reduction of area and elongation shall be the arithmetical average of all reduction of area and elongation determinations obtained from tests made in connection with one submission of a lot. Results of tests made on resubmission of a lot of parts after further heat-treatment shall be considered separately. In the case of tubing and extruded shapes, each end shall be tested and averaged separately.

4.1.4 Impact Resistance.- Charpy V-notch impact resistance shall be the arithmetical average of all Charpy V-notch impact resistance determinations obtained from tests made in connection with one submission of a lot. Results of tests made on resubmission of a lot after further heat treatment shall be considered separately. In the case of tubing and extruded shapes, each end shall be tested and averaged separately.

4.2 Chemical analysis.- The contracting officer reserves the right to make chemical analysis of any lot to determine compliance with 3.6.

4.3 Tension test.-

4.3.1 Type of specimens.- All tensile test specimens shall be machined to the form and dimensions specified in QQ-M-151. Except as specified in 4.3.1.1 and 4.3.1.2, a type 4 specimen shall be used.

4.3.1.1 When it is impracticable to obtain a .357 type 4 specimen, the largest obtainable type 4, 5, or 5A specimen shall be used as applicable.

4.3.1.2 For plate greater than 1" in thickness, a type 1 specimen shall be used.

4.3.2 Yield strength.- Yield strength shall be determined by the offset method as prescribed in Specification QQ-M-151. The limiting set shall be 0.10% (0.001 inch per inch of gage length). The strain rate shall not exceed 0.005 in/in/min up to the yield strength at 0.2% offset.

4.3.3 Number of tests.- Unless otherwise specified at least two tension test specimens shall be machined from at least one item of each lot. There is no maximum limit to the number of specimens the contractor may elect to take. However, the results of all such specimens shall be included for consideration of acceptance of the lot.

4.4 Charpy impact tests.-

4.4.1 Type of specimen.- Charpy impact test specimens shall be machined to form and dimensions shown in Figure 1.

4.4.2 Number of tests.- Unless otherwise specified at least two specimens shall be taken from at least one item in each lot. There is no maximum limit to the number of specimens the contractor may elect to take. However, the results of all such specimens shall be included for consideration of acceptance of the lot.

4.4.3 Testing temperature.- Impact tests shall be made with the specimens at a temperature of -40°F + 2°F. In order to insure that the specimens and tongs are at the required temperature, they shall be held in a liquid medium which is at the testing temperature for not less than 10 minutes before being broken. The testing machine shall be of a standard Charpy type in good condition and proper adjustment.

4.5 Direction of tests.- Except as specified in 4.5.1, tensile and impact tests shall be taken transverse to the direction of major working, and in plate material, the notch on impact specimens shall be cut perpendicular to the plate surface.

4.5.1 When it is impossible to obtain transverse test specimens, as in the case of small diameter bars or tubing, longitudinal tests shall be taken.

4.6 Test procedure for tubing and extruded shapes.-

4.6.1 Location of test specimens.-

4.6.1.1 Lot comprised of a single length.- At a distance, one and one half times the wall thickness from each end of each tube or extruded shape, a minimum of two tensile and two impact specimens shall be machined from the wall thickness, and as close as possible to midsection of the wall as indicated in Figure 2.

4.6.1.2 Lot comprised of multiple lengths.- When a single tube or shape is cut into multiple lengths and submitted as a lot, each length shall be consecutively marked to identify its position in the original tube or shape. At a distance one and one half wall thicknesses from the ends of the lengths corresponding to the ends of the original tube, a minimum of two tensile and two impact specimens shall be machined from the wall thickness, and as close as possible to the midsection of the wall as indicated in Figure 2.

4.6.2 Direction of test.-

4.6.2.1 When the outside diameter of tubing equals or exceeds 4" and the wall thickness is 8/10" or greater, Charpy impact and type 4 tensile specimens will be taken transverse to the longitudinal axis of the tube.

4.6.2.2 When the wall thickness if equal to or greater than 5/8" but less than 8/10", Charpy impact and type 4 tensile specimens will be taken in the longitudinal direction.

4.6.2.3 When the wall thickness is less than 5/8", impact tests will not be required.

4.6.2.4 When the wall thickness is less than 0.375", a type 5A tensile specimen shall be taken in the longitudinal direction.

4.7 Test procedure for billets and barstock.- Unless otherwise specified, billets and barstock having a diameter greater than 1-3/4" but less than 2-1/2" will be tested in accordance with Figure 3 and notes thereto. Billets and barstock having a diameter greater than 2-1/2" will be tested in accordance with Figure 4 and notes thereto.

4.7.1 All barstock shall pass the additional requirement that in the "as-received" (mill annealed) condition, the elongation as measured on a transverse tensile specimen located at least one inch from the surface shall be a minimum of 8%.

4.8 Test procedure for plate and flat bars.-

4.8.1 From plate 1/4" or greater in thickness, two tensile and two Charpy specimens will be machined (when possible - see 3.3.2.2) from the center of the cross section, at a distance of 2T or 4" (whichever is less) from any heat-treated edge and transverse to the major rolling direction. (See 4.5)

4.9 Test procedure for sheet and strip.-

4.9.1 Transverse bend properties.- Sheet and strip 1/8 inch and less in thickness shall withstand being bent cold through an angle of 105 degrees without cracking on the outside of the bent portion. The bend shall be made on a radius equal to that shown in Table III.

TABLE III

Yield Strength and Bend Radius Requirements

Yield Strength Increments PSI .1% Offset	Bend Radius[1]
40,000 - 55,000	1T
50,000 - 80,000	2T
70,000 - 100,000	3T
100,000 - 130,000	3T
120,000 - 150,000	5T
150,000 minimum	7T

1. T - Thickness of the Material

4.10 Test procedure for shapes.- When specified and when section size permits two tensile and two Charpy specimens will be machined from the thickest section, and as close to the midsection as possible. (See Figure 5)

4.11 Retests.-

4.11.1 Lot not reheat treated.- The same number and types of test will be required as were originally taken. The average of all tests, both original and retest shall meet the specified requirements for the lot being tested. In the case of tubing, the same number and types of test that failed will be required, and on the rejected end only.

4.11.2 Lot reheat treated.- The same number and type of test will be required as were originally taken and averaged. Test values taken before the reheat treatment will be discarded.

4.12 All sampling, identification marking, and tests which are to be performed at the processing facility or their subcontractor, including the machining of specimens and forging and qualification tests, shall be witnessed by a government inspector unless otherwise specified.

4.12.1 The certified copy of mechanical property and heat-treatment data forwarded with each shipment (see 5.2.1) shall bear the following statement "all testing witnessed by........" and be signed by the government inspector, or if this is impractical shipment shall be accompanied by the inspector's own report which shall contain the foregoing statement regarding witnessing of tests.

5. PREPARATION FOR DELIVERY

5.1 Packing.-

5.1.1 Segregation.- All material shall be properly separated by lots when packed for shipment.

5.1.2 For shipment.- All material shall be packed in such a manner as to insure acceptance by common or other carrier for safe transportation at the lowest rate, to the point of delivery.

5.2 Marking.-

5.2.1 Shipments shall be legibly and indelibly marked with the specification number and yield strength range, the size, and quantity contained therein, the name, brand, or trademark of the contractor, the number of the contract or order, part number, a certified copy of mechanical property and heat-treatment data, and chemical analysis.

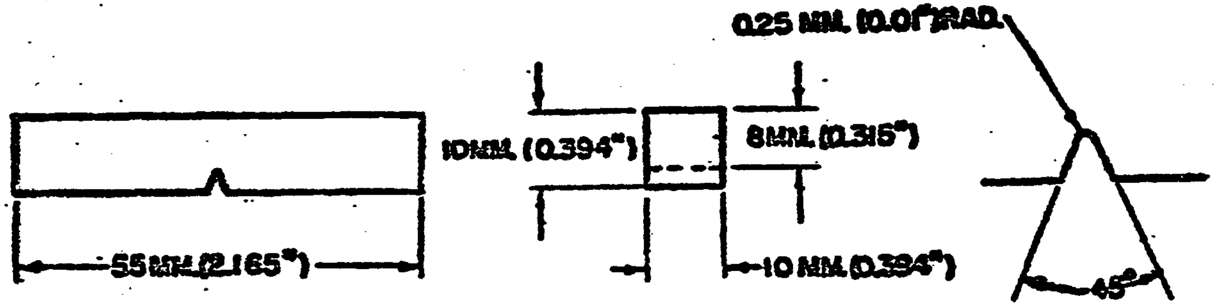
6. NOTES

6.1 Intended use.- The annealed or heat-treated wrought titanium alloys covered by this specification are intended for use in the fabrication of Ordnance material. Fabrication may involve forming and welding operations.

6.2 Ordering data.- Purchasers should specify the number, title and date of this specification, the yield strength range required, the type of product, dimensions and tolerances, and identification marking.

6.3 Each part will be legibly marked or stamped with Heat No. of material, Lot No., piece mark, and part number. In the case of plate and sheet material, the longitudinal direction shall be visibly marked.

Custodian:
Army - Ordnance Corps



PERMISSIBLE VARIATIONS:

CROSS SECTION DIMENSIONS ±0.025 MM. (0.001")

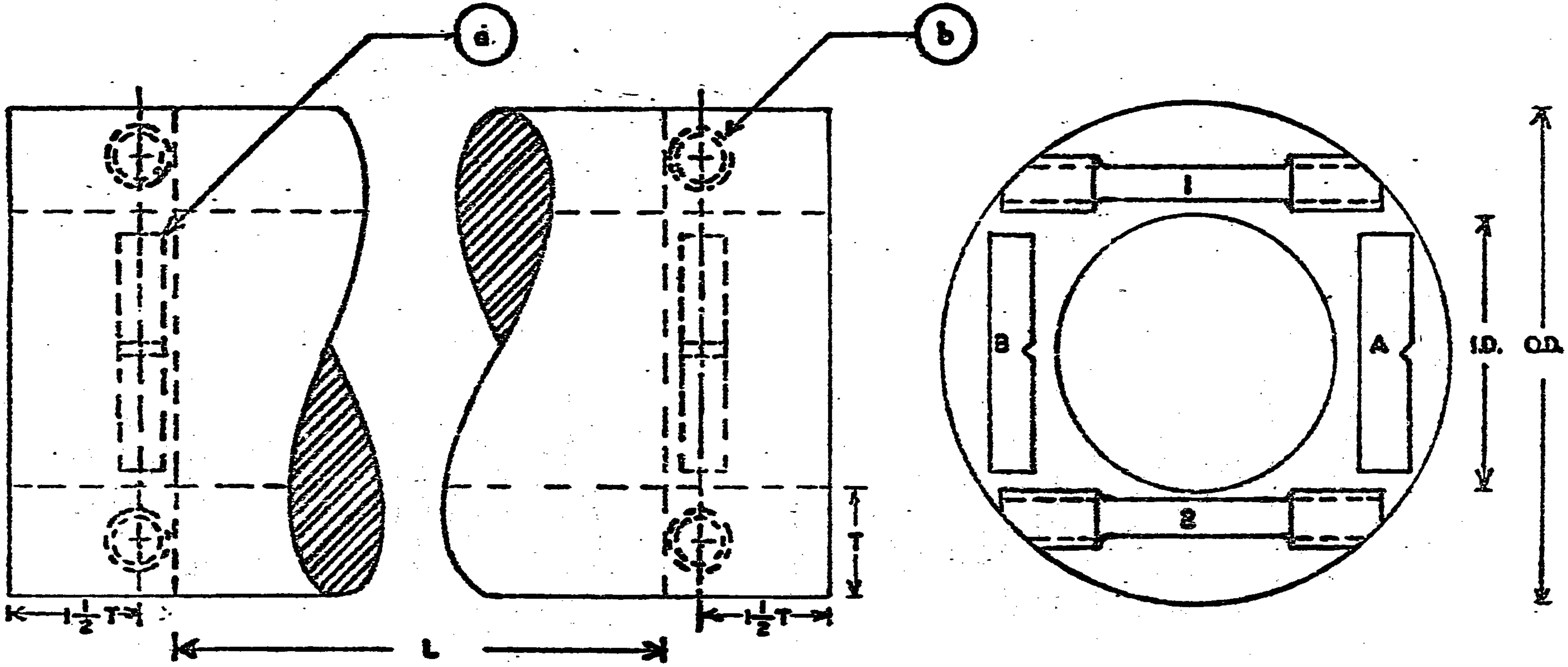
LENGTH OF SPECIMEN------ ±0.25 MM. (0.010")

ANGLE OF NOTCH--------- ±1°

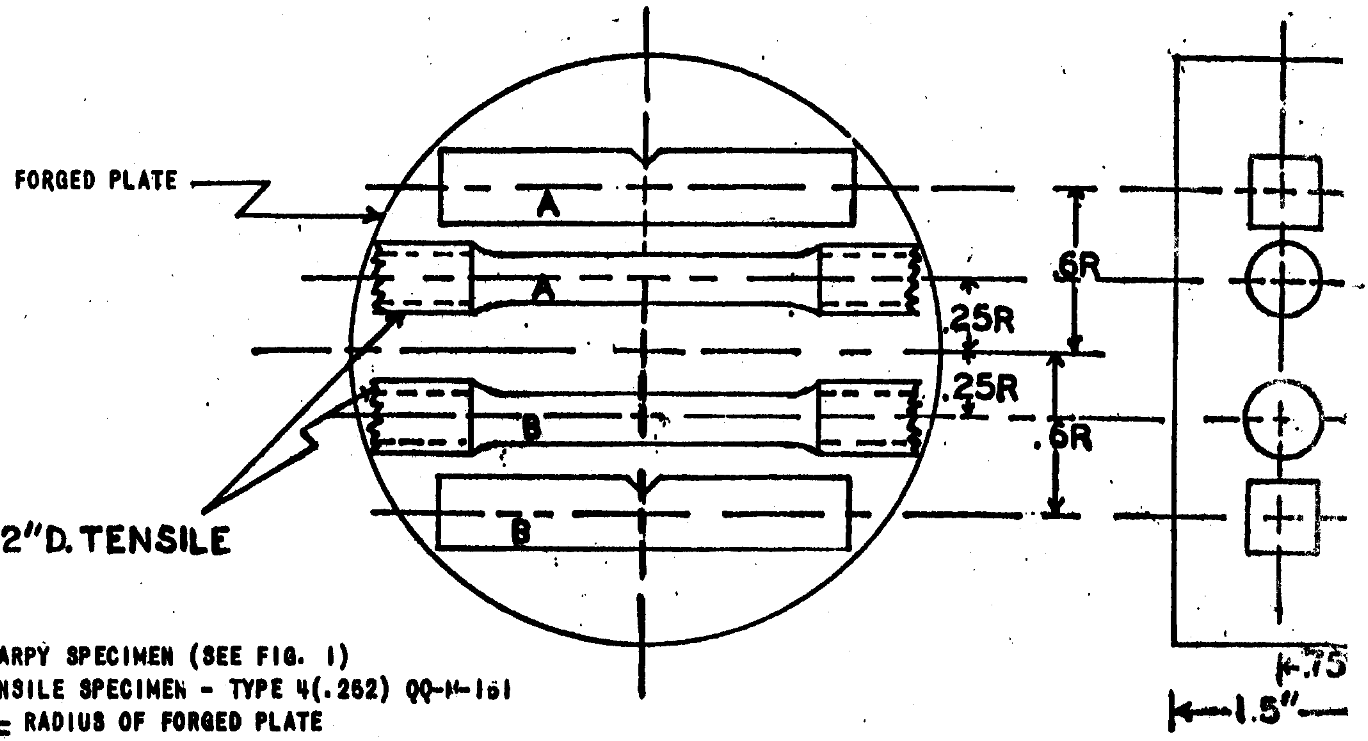
RADIUS------------------ ±0.001"

FIG. 1. V–NOTCH SQUARE CHARPY SPECIMEN

FIGURE 2
TEST SPECIMEN LOCATION
FOR TUBES



NOTE
(a)-CHARPY SEE FIG. I
(b)-TYPE 4 TENSILE QQ-M-151a



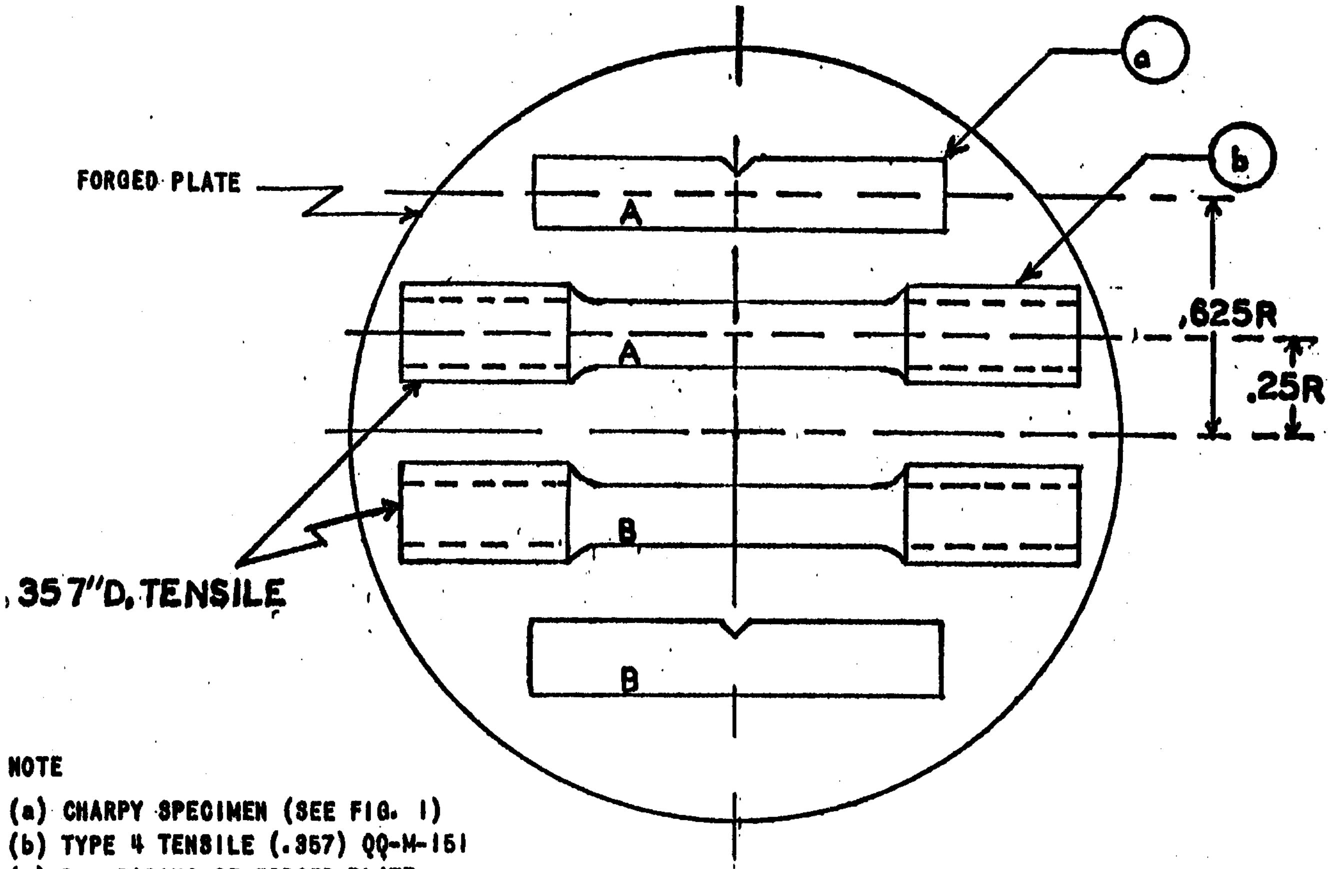
NOTE
(a) CHARPY SPECIMEN (SEE FIG. 1)
(b) TENSILE SPECIMEN - TYPE 4(.252) QQ-M-151
(c) R = RADIUS OF FORGED PLATE

NOTES TO FIGURE 3

1. From each lot of billets or barstock having diameter equal to or greater than 1¾ inches but less than 2½ inches, three ¼ inch lengths will be upset forged in the longitudinal direction and at an appropriate temperature to 1½ inch thick circular plates. Two forged plates will then be heat treated to meet the required mechanical properties. Following heat treatment, the contractor will machine from one heat treated plate, test specimens of the type and size, from locations and in the directions shown in Figure 3 for test purposes. The second heat treated plate and the third unheat treated plate will be forwarded to the Contracting Officer for test. Forging temperature and heat treatment procedures will be forwarded to the Contracting Officer with shipment of the material.

FIGURE 3

LOCATION, TYPE, SIZE AND NUMBER OF TEST SPECIMENS
FOR TESTING BILLETS AND BARSTOCK HAVING A
DIAMETER GREATER THAN 1 3/4"
BUT LESS THAN 2 1/2"



NOTE

(a) CHARPY SPECIMEN (SEE FIG. 1)
(b) TYPE 4 TENSILE (.357) QQ-M-151
(c) R = RADIUS OF FORGED PLATE

NOTES TO FIGURE 4

A. From each lot of billets or barstock having a diameter equal to or greater than 2½ inches but less than 5 inches, three 4 inch lengths will be upset forged in the longitudinal direction and at an appropriate temperature to 1½ inch thick circular plates. Two forged plates will then be heat treated to meet the required mechanical properties. Following heat treatment, the contractor will machine from one heat treated test plate, test specimens of the type and size, from locations, and in the direction shown in Figure 4 for test purposes. The second heat treated plate and the third unheat treated plate will be forwarded to the Contracting Officer for test. Forging temperatures and heat treatment procedures will be forwarded to the Contracting Officer with shipment of the material.

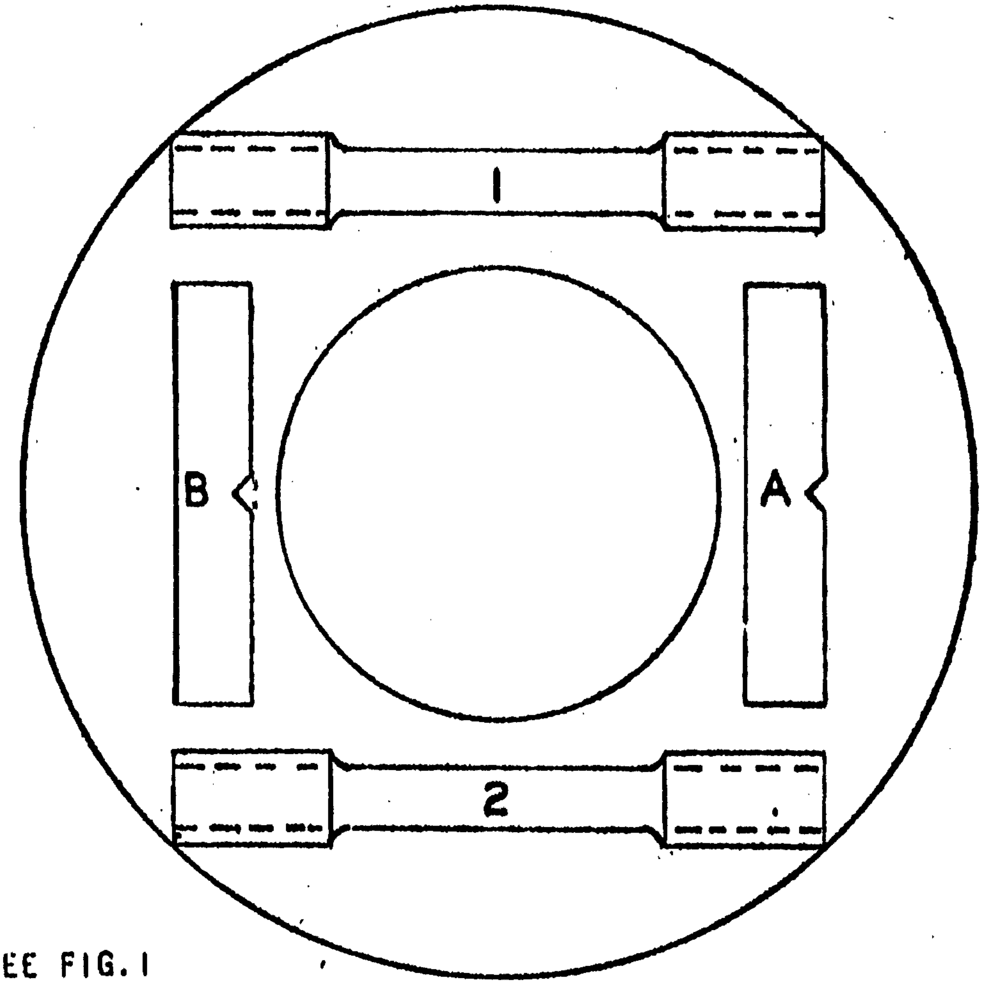
B. From each lot of billets or barstock having a diameter equal to or greater than 5 inches, a single 4 inch length will be cut and quartered longitudinally. Two of the quartered lengths will be upset forged and heat treated as specified in A above. Following heat treatment, the contractor will machine from one plate, test specimens of the type, size, direction and location shown in Figure 4 for test purposes. The second heat treated plate and the two unforged quarters will be forwarded to the Contracting Officer for test. Forging temperatures and heat treatment procedures will be forwarded to the Contracting Officer with shipment of the material.

FIGURE 4

LOCATION, TYPE, SIZE AND NUMBER OF TEST SPECIMENS
FOR TESTING BILLETS, AND BARSTOCK HAVING
A DIAMETER GREATER
THAN 2 1/2 IN.

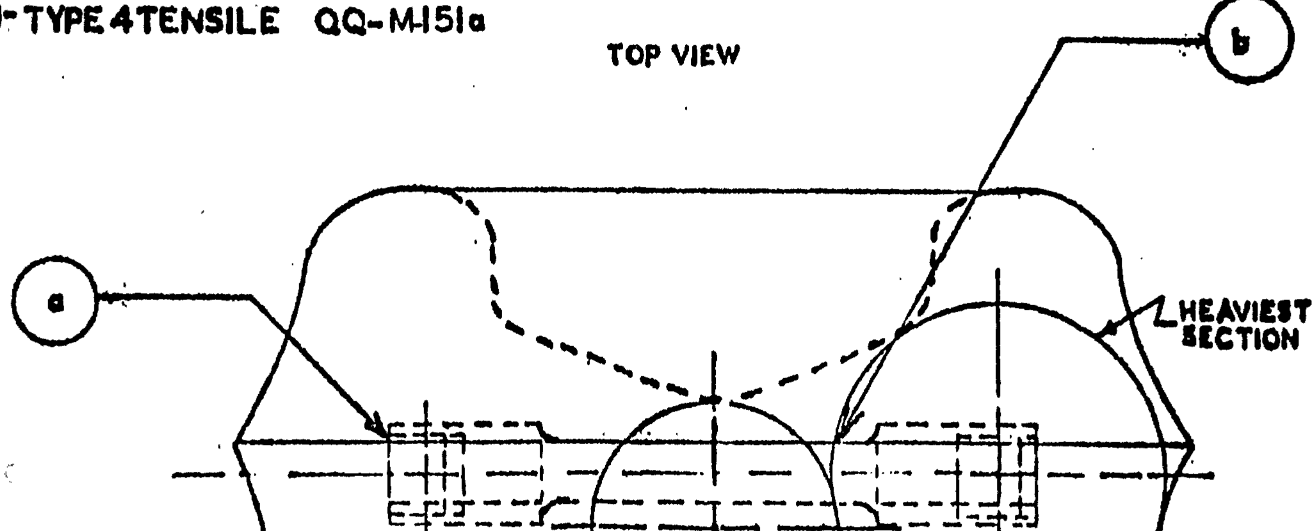
FIGURE 5

SAMPLE FORGING
TEST SPECIMEN LOCATION



NOTE
(a)-CHARPY SEE FIG. I
(b)-TYPE 4 TENSILE QQ-M-151a

TOP VIEW



FRONT VIEW

ARMY-WATERTOWN ARSENAL, MASS.

Inclosure 3

RDPD # 59-22

PART I - OBJECTIVE:

To procure twenty-one (21) titanium armor plates (6% al - 4% V) for ballistic evaluation

PART II - REQUIREMENTS:

The contractor shall furnish the labor, service, equipment, materials, and facilities to provide twenty-one (21) titanium armor plates, one of each under Phase I and two (2) of each under Phase II:

The following requirements shall be included in the preparation of the proposal:

a. Proposed chemical analysis
b. Heat treatment
c. Rolling process (cross or straight)
d. Mechanical properties
e. Each plate to be furnished with two (2) 3" diameter handling holes through plate

The number and sizes of plates are as follows:

1. 36" x 18" x 1"
2. 36" x 18" x 1 1/2"
3. 60" x 60" x 2"
4. 60" x 60" x 2 1/2"
5. 60" x 60" x 3"
6. 60" x 60" x 4"
7. 60" x 60" x 5"

PHASE I: Materials to be in accordance with Military Specification WA-PD-76C(1).

PHASE II: Depending on ballistic test results of Phase I, additional requirements to improve ballistics may be incorporated.

Tests required of Contractor: The Contractor shall perform the following tests:

a. Chemcial analysis of each heat.

b. Tensile strength, yield strength, elongation and reduction of area for each brinell hardness range.

c. Brinell hardness, and -40°F V-notch charpy for each thickness of plate material.

In addition, a fracture test, in accordance to steel armor specification MIL-A-12560, shall be conducted.

Adherence to Ordnance Standard: The plates shall meet the chemcial and physical requirements of Military Specification WA-PD-76C(1). "Titanium and Titanium Alloys, Wrought (for Critical Components)". However, "lot weight relationship, under Paragraph 4.1.1.2.2 in the Specification, shall be changed to read: "a lot shall comprise of each thickness." The material shall be sound and meet the fracture standards stipulated in Military Specification MIL-A-12560.

PART III - SHIPPING INSTRUCTIONS:

All plates shall be shipped from the contractor's plant to Commanding General, Aberdeen Proving Ground, Maryland, ATTN: Mr. W. C. Pless, ORDEG-DP-TU. Shipping cost to be paid by the contractor. It is requested that one SIP 12 Form accompany the plates and one be forwarded to Commanding Officer, Detroit Arsenal, Center Line, Michigan, ATTN: ORDMC-REM.1.