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DEVELOPMENT OF A PRODUCTION PROCESS FOR LARGE CYLINDERS FROM MIXTURES OF SPHERICAL POWDERS OF HIGH STRENGTH TITANIUM ALLOYS AND BERYLLIUM

August 1971

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West Concord, Massachusetts

Approved for public release;
distribution unlimited

FINAL REPORT FOR PROGRAM II **Contract Number DAAG46-71-C-0076 P00005**

Prepared for

ARMY MATERIALS AND MECHANICS RESEARCH CENTER
Watertown, Massachusetts 02172

AMMRC CR 71-18

DEVELOPMENT OF A PRODUCTION PROCESS FOR LARGE CYLINDERS FROM MIXTURES OF SPHERICAL POWDERS OF HIGH STRENGTH TITANIUM ALLOYS AND BERYLLIUM

Technical Report by

PAUL LOEWENSTEIN

Nuclear Metals Division
WHITTAKER CORPORATION
West Concord, Massachusetts

August 1971

Final Report for Program II   Contract Number DAAG46-71-C-0076 P00005

D/A Project 1T062105A331
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Composite Materials Research for Army Materiel
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ABSTRACT

Microquenched spherical powders of Ti-6Al-6V-2Sn and of beryllium were produced by the Rotating Electrode Process.

Two approaches were used in order to develop a fabrication process for 6-inch O.D. x 1/2-inch wall tubular shells, from the titanium alloy as well as from a mixture of 90^{v}/oTi alloy with 10^{v}/oBe.

The first approach, which proved unsuitable, consisted of a consolidation-upset-forging-cupping sequence. The second approach consisted of a direct single step extrusion in copper cans.

It was shown that a minimum reduction in area of 6:1 is required to obtain sound structures and high strength. Two billets for the production of full size tubular shells were prepared.

FOREWORD

This AMMRC contract report CR 71-18 entitled "Development of a Production Process for Large Cylinders of High Strength Titanium Alloys and Beryllium" was prepared under D/A Project 1T062105A331, Composite Materials Research for army Material." Mr. Warren C. Malatesta of the AMMRC Process Development Division served as technical supervisor of the program.

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I. INTRODUCTION AND BACKGROUND

Wrought shapes produced from high quality powder of a number of high strength metals and alloys have been shown to have properties superior to similar wrought shapes produced from castings.(1) Starting with powders, it is possible to produce materials consisting of more than a single alloy. Such composites can be tailored so as to retain the more desirable features of each of its components.

In previous work(2) a program was performed to prepare and evaluate beryllium Ti-6Al-6V-2Sn alloy composites containing 5, 10, 15, 20, 30, 50 and 75^{v}/o beryllium. The beryllium and the titanium alloy for the composites were converted into shot by the Nuclear Metals patented Rotating Electrode Process. The blended composites were hot compacted at 1100°F followed by two extrusions at 1300°F for a total extrusion reduction of 17.3:1. An optimum combination of properties was obtained in the 90^{v}/oTi alloy-10^{v}/oBe composite. This composite exhibited the following mechanical properties:

Modulus of Elasticity	18.3×10^6 psi
Ultimate Tensile Strength	186,600 psi
0.2% Offset Yield Strength (tensile)	186,600 psi
Elongation in 1-inch	4.7%
Reduction in Area	8.3%
Ultimate Compressive Strength	258,800 psi
0.2% Offset Yield Strength (compression)	197,400 psi
Charpy V-Notch Impact Strength (-40°F)	19.5 ft-lbs
Density (calculated)	0.154 lbs/in^3

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(1) Friedman, G. and Kosinski, E., "High Performance Material from a Hot-Worked Superalloy Powder", Metals Engineering Quarterly, Jan. 1971.

(2) Pickett, J. J., "Fabrication and Evaluation of 6Al-6V-2Sn Titanium Alloy-Beryllium Composites", Nuclear Metals Div. of Whittaker Corp., AMMRC Contract Nos: DA-19-066-AMC-340(X) and OI-19-066-D6-01933(X), NM-6800, July 1, 1967.

These properties were obtained in extruded solid bars having undergone a very substantial reduction in area. Similar properties can be obtained in bars, tubes and shapes produced by processes involving equivalent deformation.

One of the characteristics of such wrought shapes of two different materials, is that the spherical powders become elongated during the working operation. If one of the components is present in a considerably smaller amount than the other, it will appear as an elongated fiber in the extruded product. Such "in situ" fibering partially explains the attractive properties as well as the strong anisotropy of properties in bi-alloy wrought shapes.

It was the objective of the work reported here to develop a fabrication technique for relatively large diameter (6-inch O.D.) heavy wall (1/2 inch) tubular shells of a bi-alloy material consisting of $10^{v}/o$ beryllium and $90^{v}/o$ Ti-6Al-6V-2Sn as well as shells of Ti-6Al-6V-2Sn only. Two possible approaches were to be explored: The first approach consisted of a consolidation - upset forging - back extrusion or cupping sequence. This approach would have required relatively small capacity press equipment. If this approach should fail (as it did) a direct extrusion technique requiring a very large press was to be developed.

II. TECHNICAL APPROACH

A. Cupping

The technique explored first on a reduced scale (yielding tubular shells approximately 4-inch O.D. x 1/2-inch wall) is illustrated schematically in Figure 1. It consists of a first step of consolidation of the powder mixtures. The compacted billet is then upset from 3-1/2 inch diameter to 4-1/2 inch diameter in two steps, resulting in a relatively short compact or pancake. This in turn is back extruded into a cup having an O.D. of 4-1/2 inch and an inside diameter of 2-3/4 inch. A number of questions were raised at the beginning of this work. In particular, it was not known if the total amount of work expended in three relatively small steps would be equivalent to the same amount of work carried out in a single step. It was also not known if working the material in two different directions (the working direction in upsetting is perpendicular to that occurring in the back extrusion) would result in acceptable physical properties. Finally, there was considerable doubt that this type of procedure would produce a fully dense structure with the required metallurgical bond between the particles.

As will be discussed in the later parts of this report, the results of the cupping experiments, although not extirely negative, were sufficiently questionable to lead to a shift to direct extrusion.

B. Direct Extrusion

The extrusion of a large tubular shell directly from loose powders is shown schematically in Figure 2. The design of the billet was based in part on extrusion tooling owned by AMMRC for use in the large Air Force press (18,000 tons capacity) operated by Wyman-Gordon. This tooling would result in a reduction of area of R = 6.5:1 (R = cross section of billet/cross section of extruded shell). In previous work, good properties were obtained by the direct extrusion in two steps of previously compacted Ti-Be mixtures, in steel cans. It was now proposed to extrude from loose powders, in a copper can with a single reduction ratio larger than each of the two reductions used previously, but smaller than the total cumulative previous reduction ratio. It appeared prudent to check the effect of these changes on properties before a full size billet should be produced. A modest experimental program, producing solid rods from loose powders in a single step extrusion, was therefore performed before the full size billets were produced.

III. WORK DESCRIPTION

A. Production of Powders

1. Ti-6Al-6V-2Sn

Eighteen pounds of titanium alloy powder was made available from AMMRC at the initiation of this program. This powder had been produced by the REP^{TM} method by the Nuclear Metals Division of Whittaker Corporation on a previous program.(2) Figure 3 shows a schematic of the REP device. An additional 95.75 pounds of -35 mesh powder was produced from electrodes supplied by AMMRC. The yield and typical particle size analysis for this powder is shown in Appendix A. When the production of full size billets was incorporated into the program, another 116 pounds of -45 mesh titanium alloy powder was produced from 20 AMMRC supplied electrodes. The particle size analysis for this powder is shown in Appendix B. All of the powder was spherical with a pour density of approximately 62%.

2. Beryllium Powder

A total of approximately 99 pounds of beryllium powder was used during all parts of this program. The spherical powder was produced by the REP process and was available in Nuclear Metals Division's stock.

B. Blending of Powders

The titanium alloy and beryllium powders for bi-alloy billets were weighed in small batches and blended in a V-cone blender. In order to produce a 10^{V}/oBe - 90^{V}/oTi alloy mixture, a weight relationship of 4.3^{W}/oBe - 95.7^{W}/oTi is used.

Transfer from the blender to the cans is carried out with a minimum of vibration and shock in order to avoid segregation.

C. Consolidation-Upsetting and Cupping

The cupping process has been shown schematically in Figure 1. A flow sheet for the process showing the disposition and numbering for the six (6) billets is shown in Figure 4.

1. Canning

The cans for the six billets consisted of carbon steel tubing 3-1/2 inch O.D. x 3-inch I.D. x 6-3/4 inch long. Carbon steel end plugs 1/4-inch thick were welded at each end. The end plug with the evacuation tube was welded after the cans were filled with the powder mixtures. (Approximately 2100 gms of titanium alloy for billets 1, 2, 3 and 1995 gm of 90^{V}/oTi alloy - 10^{V}/oBeryllium for billets 4, 5 and 6). The billets were placed on a vacuum system heated to 800°F for outgassing. When a vacuum of better than 0.5μ was obtained, the billets were cooled on the system and the evacuation tube was sealed off.

2. Consolidation

The six billets were heated to 1100°F for 2 hours in an electric furnace. Each billet was then placed in a 3.545-inch I.D. extrusion liner and consolidated under a force of 900 tons held for 5 seconds. Hardened steel penetrators 3-inch O.D. x 3-1/2 inch long each provided with two steel slip rings 3-1/2 inch O.D. x 3-inch I.D., were placed at both ends of the billet. Such penetrators avoid folding of the steel can. After consolidation the penetrators were removed and the can material was cut flush with the end plugs. Billets 3 and 6 were retained at this point for evaluation.

3. Upsetting

Billets 1, 2, 4 and 5 were processed through the upsetting steps.* A carbon steel end plate 1/4-inch thick and 4-inch O.D. was tacked to each end of each billet. These plates center the billets in the 4.050-inch I.D. extrusion liner. The billets were heated to 1300°F for 2 hours, placed in the extrusion liner and upset using a force of 1300 tons held for a minimum of 5 seconds.

After the first upsetting operation the centering plates were removed and new plates 4-1/2 inch O.D. were tacked to the ends of each billet. The upsetting operation was then repeated using a 4.555-inch I.D. extrusion liner and a pressing force of 1400 tons.

Billets 2 and 5 were retained at this point for evaluation.

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*The first upset involves 31.2% increase in area, the second upset 26.8% for a total of 65.5%.

4. Cupping

Billets 1 and 4 were processed through the cupping step. The billets were turned to an O.D. of 4.450 inch to permit insertion into the 4.555-inch I.D. extrusion liner. The billets were heated to 1300°F for two hours. A hardened steel penetrator 2-3/4 inch O.D., 4-1/4 inch long with a 1/2-inch radius at one end, provided with two centering rings 4-1/2 inch O.D. x 2-3/4 inch I.D. x 1/2-inch long was pushed into the billets with a terminal force of 1400 tons. This operation produced a cup having an O.D. of 4-1/2 inch, an I.D. of 2-3/4 inch, a total length approximately 4 inches with a thickness of the bottom of approximately 3/4 inch. (These dimensions include the carbon steel can.)

5. Evaluation

The carbon steel canning was removed from the six billets by pickling in nitric acid and each was cut in half longitudinally. Sections were removed for metallographic examination and for density determination.

The compacted $90^{v}/o$Ti-$10^{v}/o$Be billet (Billet #6) was found to be poorly bonded. The compacted powder mixture contained numerous cracks and tended to break apart upon cutting and handling. The remaining two $90^{v}/o$Ti-$10^{v}/o$Be billets (Billets #4 and 5), after upset forging and after back-extrusion, were dense and bonded. All $100^{v}/o$Ti billets were dense and bonded after all stages of processing.

Both back-extruded tubular shells (Billets #1 and 4) showed very rough O.D. surfaces with much folding and many surface cracks. Both shells exhibited considerable dead (unworked powder particles) metal in the bottom corners of the shells and the outer 2/3 of the shell walls. The $100^{v}/o$Ti shell bottom was cracked. These back-extruded shells are shown in Figure 5.

The microstructure of five of the six processed billets are shown in Figures 6 through 12. It was not possible to obtain a microspecimen of the Billet #6, the as-compacted $90^v/o$Ti-$10^v/o$Be billet. Of interest is the microstructure of the two back-extruded billets (Figures 8, 9 and Figures 11 and 12). In both pieces the maximum amounts of metal deformation is found at the bottom center of the shell bottom and at the inside corner. Microporosity and negligible powder particle deformation is evident in the shell wall. This is the reverse of the deformation structure which was expected for the back-extruded shells. The structure of the upset forged and warm compacted billets is generally what was expected.

The density of the several billets, as determined by the loss of weight in water method, after the several process steps, are given in Table I.

Unlike a forward extrusion operation where the billet is fully restrained, in a back-extrusion operation the alloy billets are not fully constrained and the powder particles can move relative to each other without undergoing deformation and fibering. The billets are free to flow non-uniformly, to fold and crack.

The reduction in area in the back-extrusion (or cupping) operation is low, approximately 1.6:1. At the inception of this program it was recognized that this reduction in area was probably too low. A reduction in area in extrusion of 16:1 had been used in the previous work. It was hoped that the double upset proceeding the cupping would have a cumulative effect and partially alleviate the low reduction of cupping. Apparently this did not occur. Based on these evaluations it was recommended that further work on the indirect upset forging and back-extrusion approach be halted in favor of a direct forward extrusion approach. The AMMRC technical monitor approved this change and the contract was modified accordingly (P00005).

D. Rod Extrusions

Before making a final commitment to the full size direct extrusion from loose powders, an experiment was conducted consisting of four solid rods of $90^v/oTi-10^v/oBe$ in copper cans extruded at a reduction ratio of R = 2, 4, 6 and 8:1.

1. Billet Preparation

Four copper cans 2-inch O.D. x 0.065-inch wall, 3-1/2 inches long with 1/4-inch thick end plates were filled with $90^v/oTi-10^v/oBe$ spherical powder. The billets were evacuated to better than 0.5μ at 800°F, cooled and sealed. A 1-inch long copper nose piece was back welded to each billet.

2. Extrusion

The four billets were heated for 1-1/2 hours to 1300°F. The extrusion data is shown in Table II.

3. Evaluation

The four rods were pickled in nitric acid in order to remove the copper. Specimens for metallography, density measurements and compression tests were taken from the middle of each rod. Figures 13, 14, 15 and 16 show longitudinal sections of the four rods at magnifications of 25X and 100X. The rod extruded at a reduction ratio of 2:1.

Figure 13 shows many voids and only slightly deformed beryllium particles. At a reduction ratio of 4:1 (Figure 14) there are few voids. The beryllium is deformed, but the aspect ratio of the fibers which are produced is insufficient for satisfactory properties. The 6:1 and 8:1 extrusions yielded sound structures, with good fibering and good fiber distribution (Figures 15 and 16).

Table III shows the results of density measurements and of compression tests carried out in two specimens each from the 6:1 and 8:1 extrusion. The compression specimens were machined to 1-1/2 inch x 1/2 inch, aged at 1050°F for 6 hours and compression tested at a head speed of 0.02 inches/minute. The results indicate that full strength is obtained at a reduction ratio of 6:1, which corresponds to the reduction ratio for the full scale tooling available to AMMRC on the Wyman-Gordon 18000 ton forging press. Comparing the data obtained by single step extrusion with the earlier data obtained by hot pressing followed by double extrusions with a cumulative reduction of 17.3:1(1) it appears that a 6:1 direct extrusion yields material with an appreciably higher compressive yield stress (233 ksi vs. 187 ksi) and with a slightly lower ultimate stress (249 ksi vs 258 ksi). It should be noted that considerably more testing would be required in order to substantiate the significance of these differences.

E. Full-Size Billets

The direct extrusion of large size heavy wall shell requires a press capable of very high forces. Such a press of 18,000 tons capacity is available at Wyman-Gordon, Grafton, Massachusetts. A set of tooling belonging to AMMRC having been used on a previous unrelated job is also available. The tools consist of a container with an I.D. of 12.83 inches, a die having an aperture of 6.62 inches and a mandrel 4.5-inch O.D. Since the extrusion would take place in a forging press adapted for extrusion, the billet length is limited to approximately 6 inches due to a limitation of the length of the extruded product to 30 inches. This tooling produces a reduction ratio R = 6:1.

The copper canning designed for this extrusion consists of an outer can 12-1/2 inch O.D. x 1/4-inch wall, and inner can 5-1/4 inch O.D. x 1/4-inch wall, two 1/2-inch thick end plates, one with an evacuation tube and a 1-inch copper rear plate as well as a 1-5/8 inch thick conical copper lead in piece.

The fabrication of this assembly caused considerable difficulty. In a first attempt, 1/4-thick deoxidized copper plate was rolled and TIG welded for the inner and outer copper can and the end plates were forged. All of the components showed some degree of porosity, which increased with each attempt at repairing. Another set of components of OFHC copper was then produced by E.B. welding. The end plates were made of 1/4-inch thick OFHC copper and were TIG welded to the tubular canning components. One billet was filled with 100% titanium alloy (27.6 kg), the other billet was filled with 90%Ti-10^{V}/oBe (24.9 kg). Both billets are being held under vacuum at NMD and will be sealed off shortly before the extrusion on the 18,000 ton Wyman-Gordon press.*

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*This extrusion does not form part of this program and will be carried out by AMMRC.

F. Conclusions and Recommendation

Two different approaches to the production of large size, heavy walled tubular shells from a $90^{v}/o$Ti-6Al-4V-2Sn-$10^{v}/o$Be powder mixture were explored. The first consisted of a consolidation-upsetting-cupping sequence. The second consisted of the direct extrusion of the tubular shell from loose powders. The first approach produced cups which showed a high degree of variation in fibering and structure in various parts of the cup as well as heavy can folding and cracking. This approach was abandoned in favor of the direct extrusion.

It should be noted that in spite of this decision, such a sequence, with proper modifications could be modified in order to produce a satisfactory end product. This may be of some importance if a part requiring a bottom or closed end were required.

The effects of this program were then shifted to the direct extrusion approach. Data was generated through rod extrusion showing that a minimum extrusion ratio of about 6:1 is required in order to obtain satisfactory structures and strength properties.

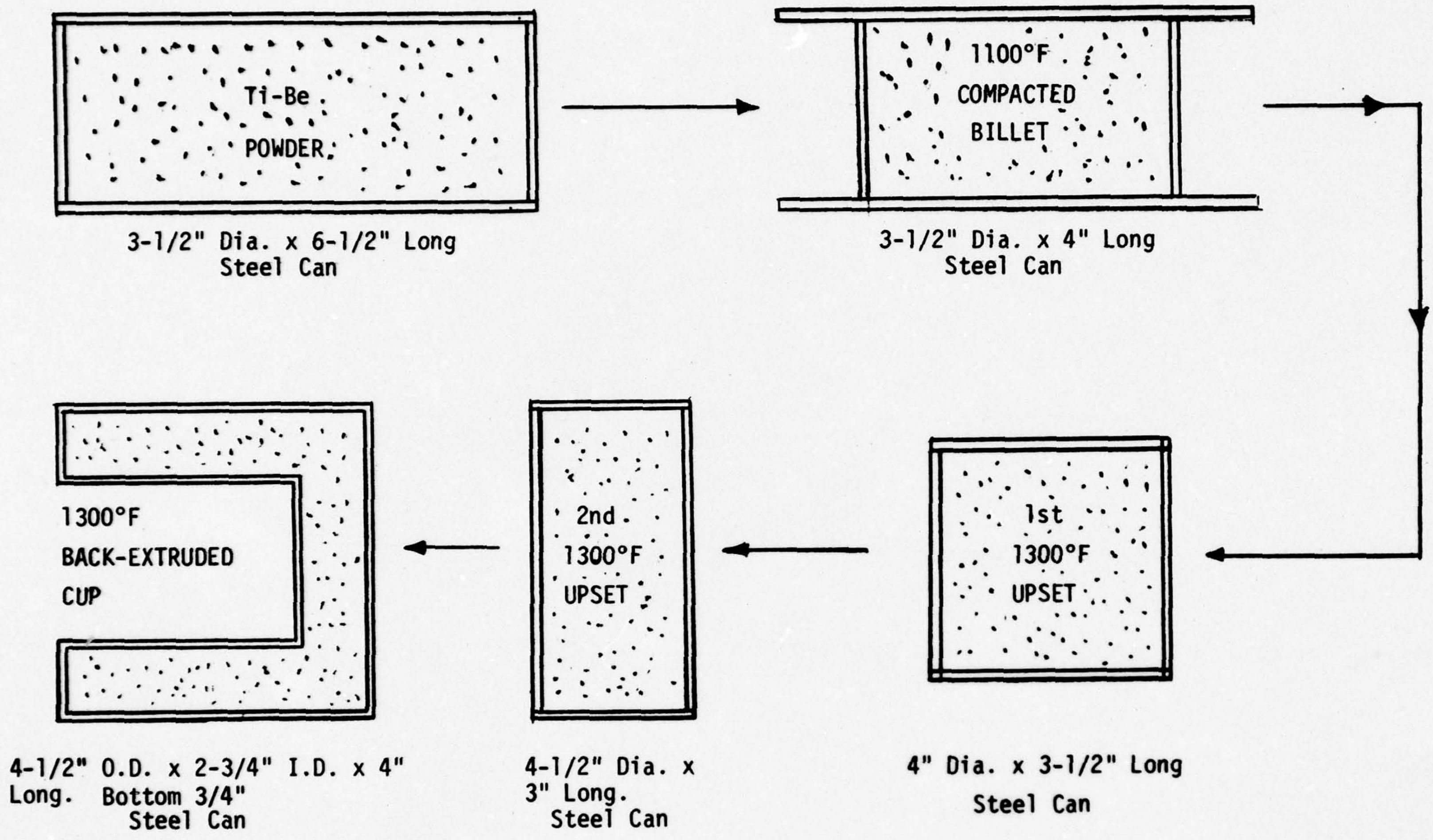
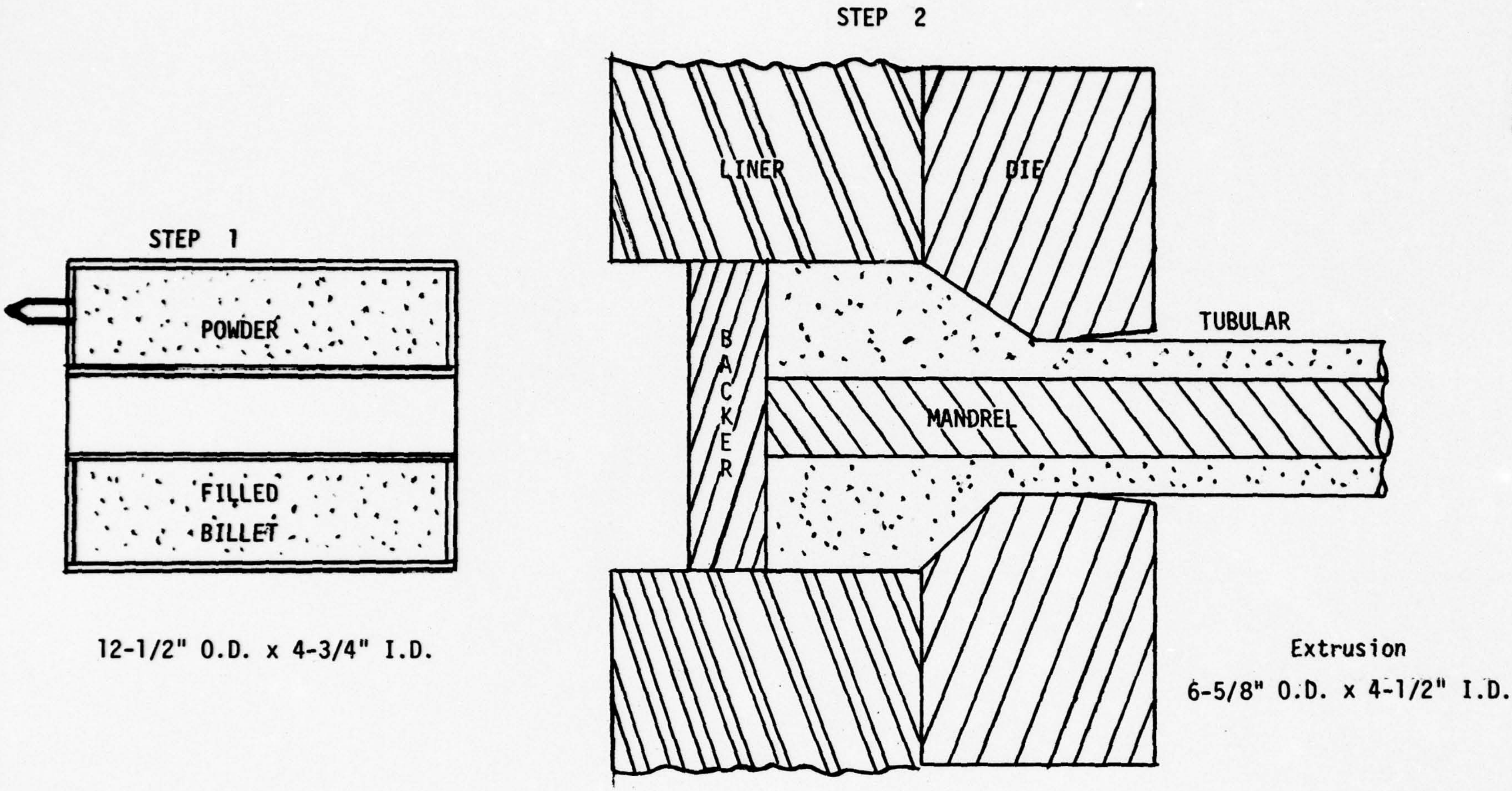


Figure 1. Flow Step Sheet for Generation of Back-Extruded Shells.
(Note: Dimensions are overall dimensions including canning.)



<u>Figure 2.</u> FLOW STEP SHEET FOR DIRECT EXTRUSION OF TUBING. (Note: Dimensions are overall dimensions including canning.)

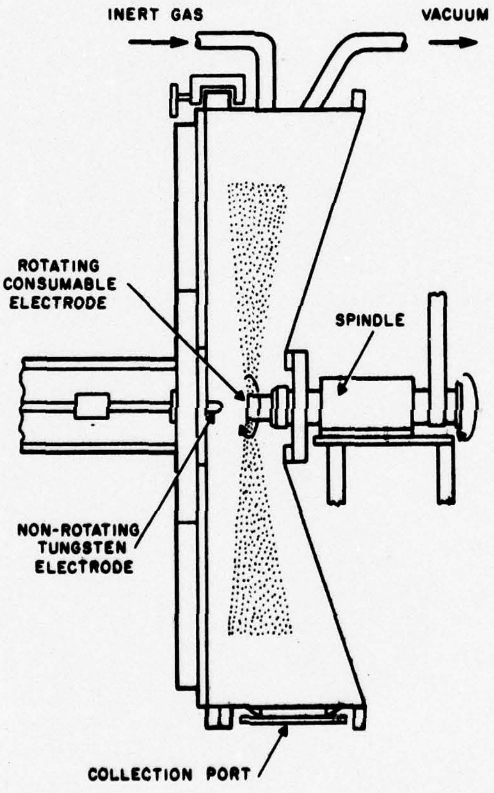


Figure 3. Schematic of The Rotating Electrode Process (REP^{TM}) Patent #3,099,041.

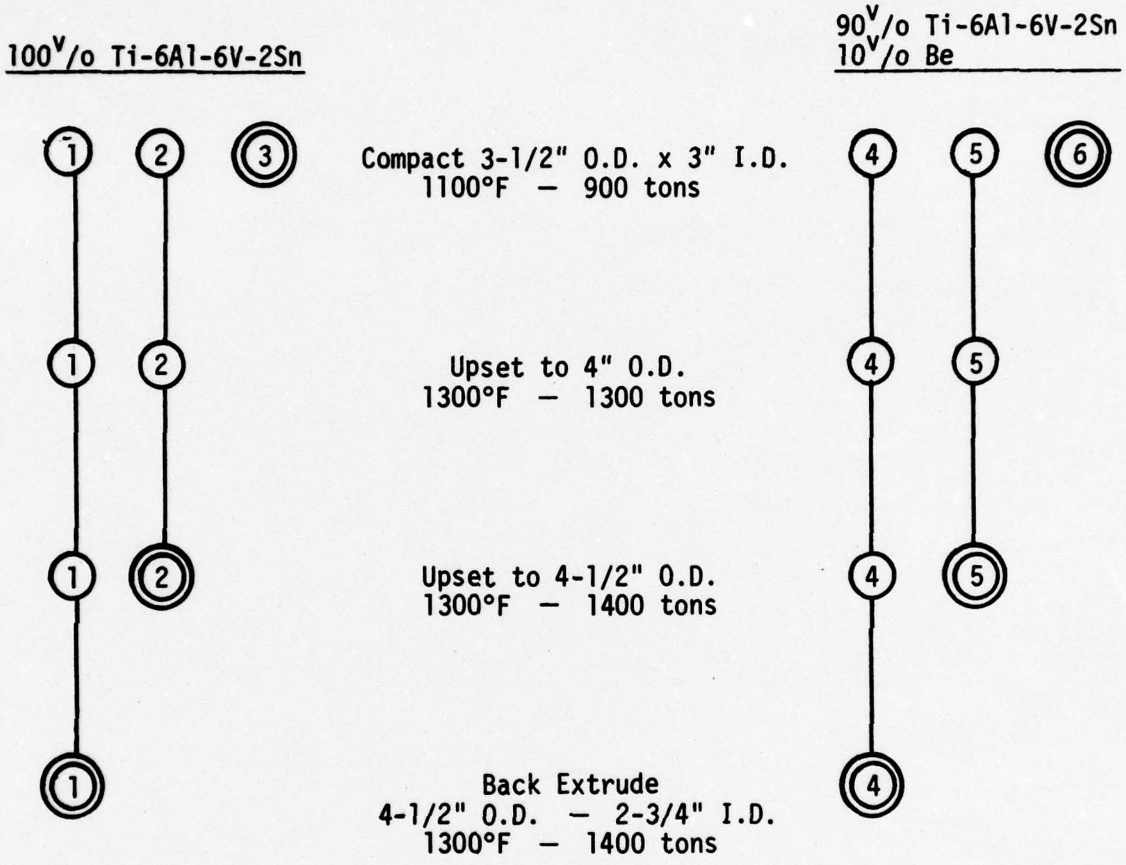


Figure 4. Flow Sheet for Cupping Process.

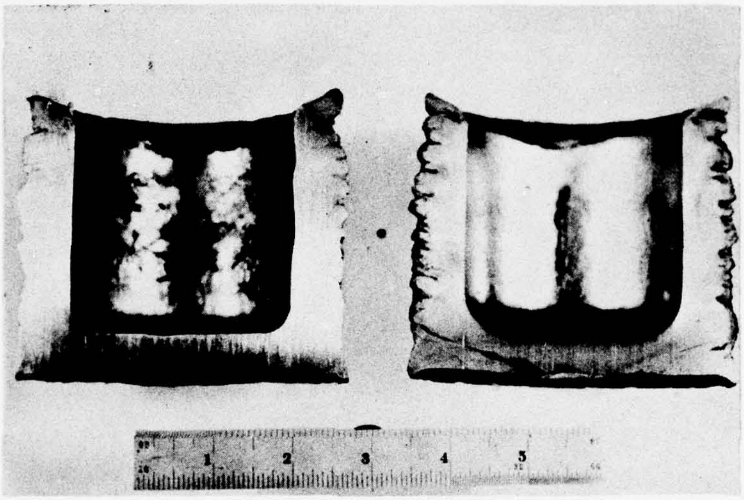


Photo Plate #169D

Figure 5. Cross Section of Back-Extruded Shells.
Steel canning removed.

(Left: Billet #4 90^{v}/oTi-10^{v}/oBe
Right: Billet #1 100^{v}/oTi)

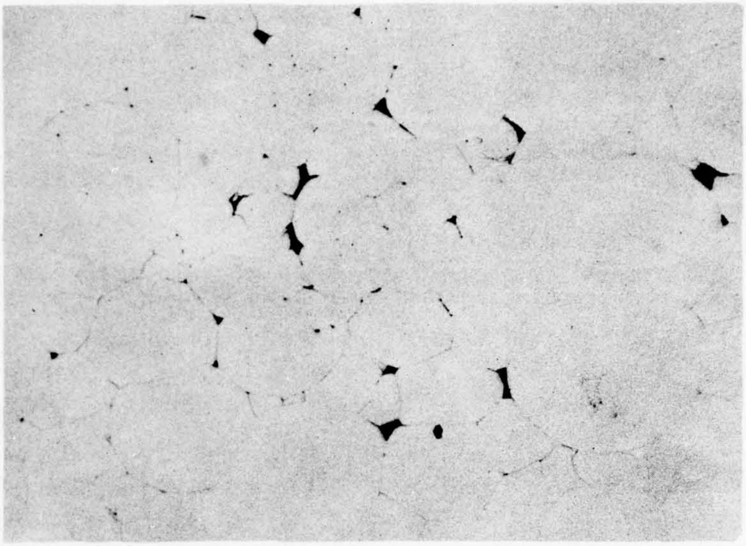


Plate #385C 75X

Figure 6. Photomicrograph of Billet #1 (100^V/oTi) After 1100°F Compaction.

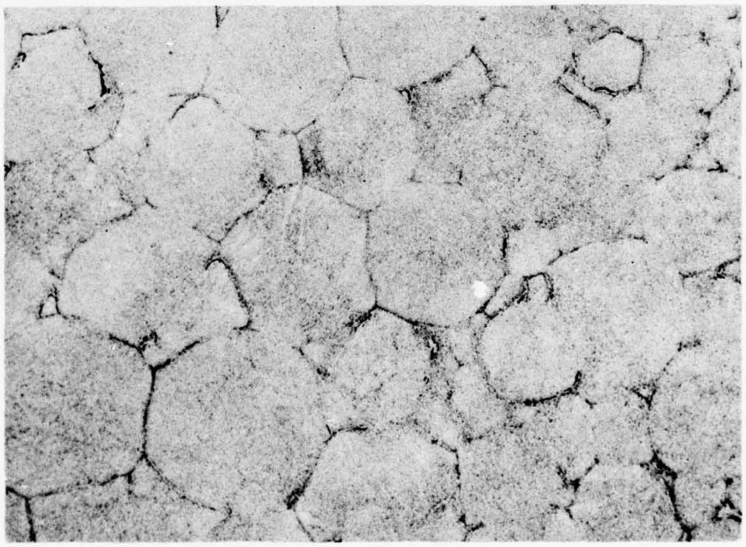


Plate #385B 75X

Figure 7. Photomicrograph of Billet #2 (100^V/oTi) After 1300°F Upsetting.

Plate #385A 75X

Figure 8. Photomicrograph of Billet #3 (100^{V}/oTi) After Back-Extrusion - Bottom of Cups.

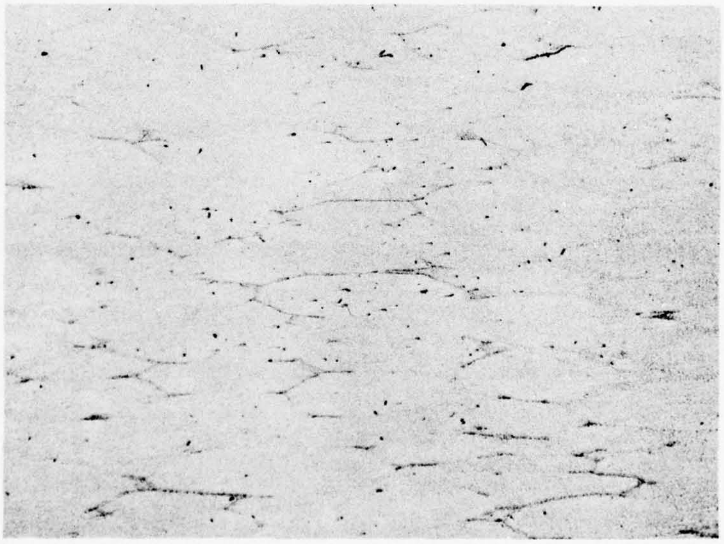


Plate #385 75X

Figure 9. Photomicrograph of Billet #3 (100^{V}/oTi) After Back-Extrusion - Edge of Cup.

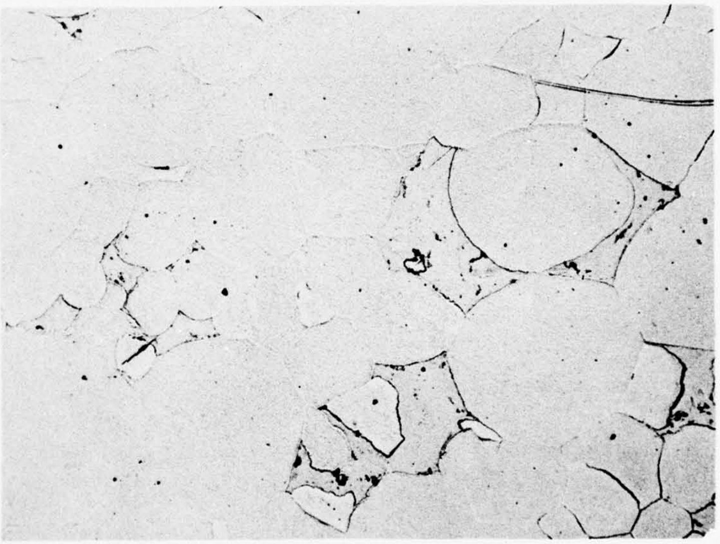


Plate #385F 75X

Figure 10. Photomicrograph of Billet #5 ($90^v/oTi-10^v/oBe$) After Upsetting.

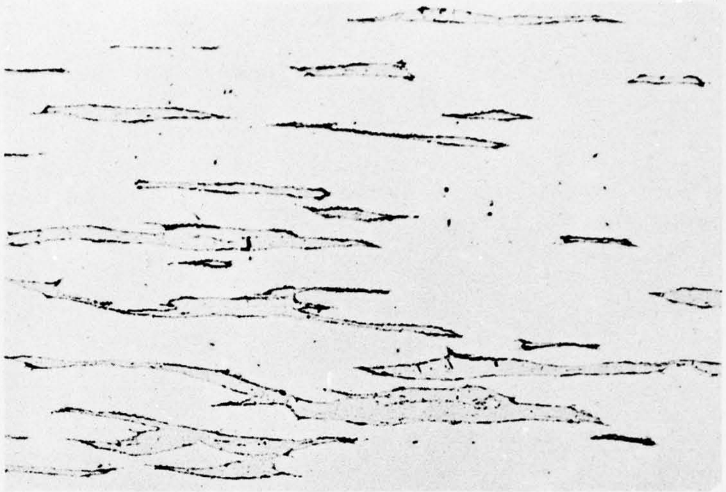


Plate #385D 75X

Figure 11. Photomicrograph of Billet #4 ($90^{v}/oTi-10^{v}/oBe$) After Back-Extrusion - Bottom of Cup.

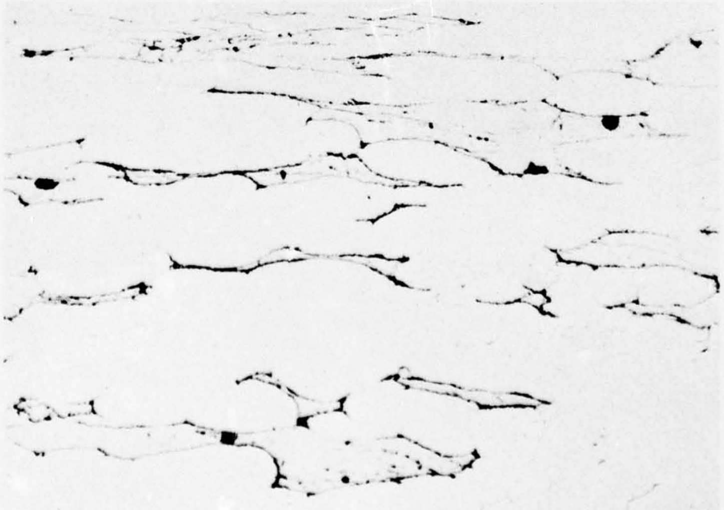


Plate #385E 75X

Figure 12. Photomicrograph of Billet #4 ($90^{v}/oTi-10^{v}/oBe$) After Back-Extrusion - Cup Edge.

Plate #405 25X

Plate #405A 100X

Figure 13. 90^{V}/oTi-10^{V}/OBe Rod Extrusion
Reduction in Area R = 2:1
Longitudinal

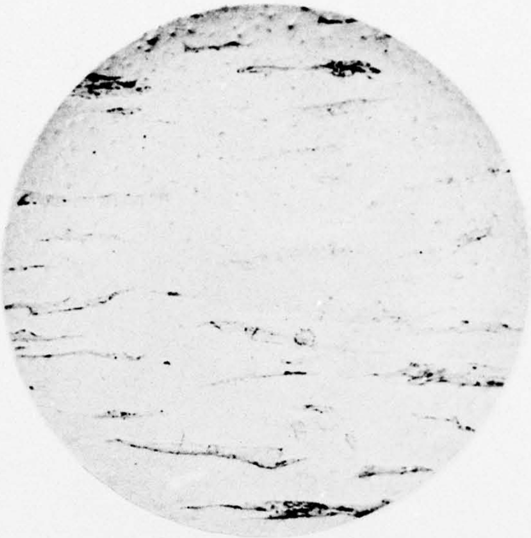


Plate #405B 25X

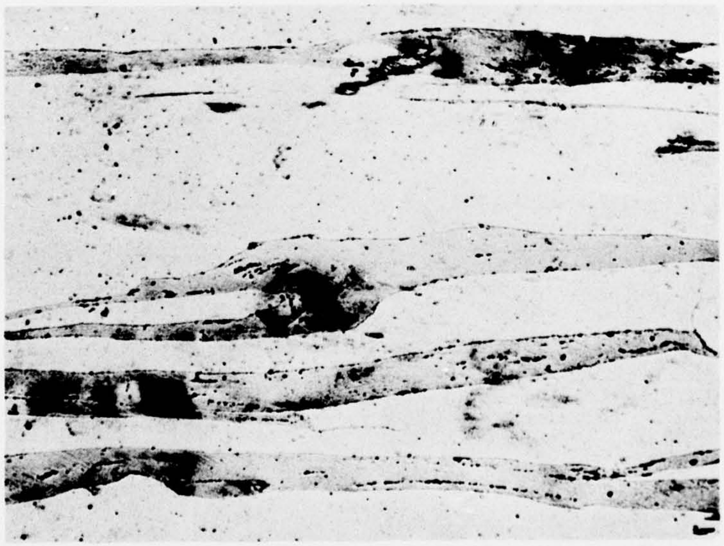


Plate #405C 100X

Figure 14. 90 v/o Ti-10 v/o Be Rod Extrusion.
Reduction in Area R = 4:1
Longitudinal

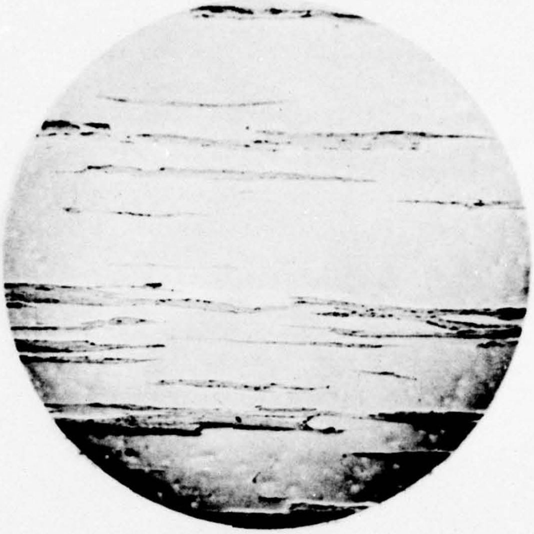


Plate #405F 25X

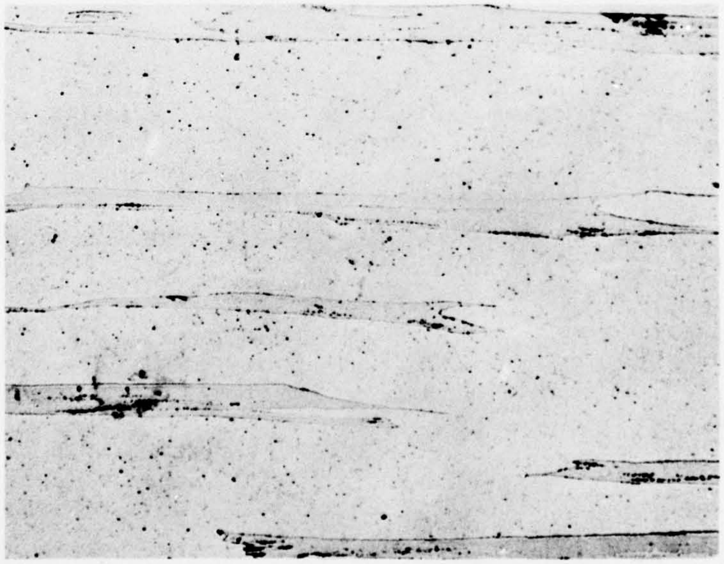


Plate #405G 100X

Figure 15. $90^{v}/oTi-10^{v}/oBe$ Rod Extrusion.
Reduction in Area R = 8:1
Longitudinal

Plate #405D 25X

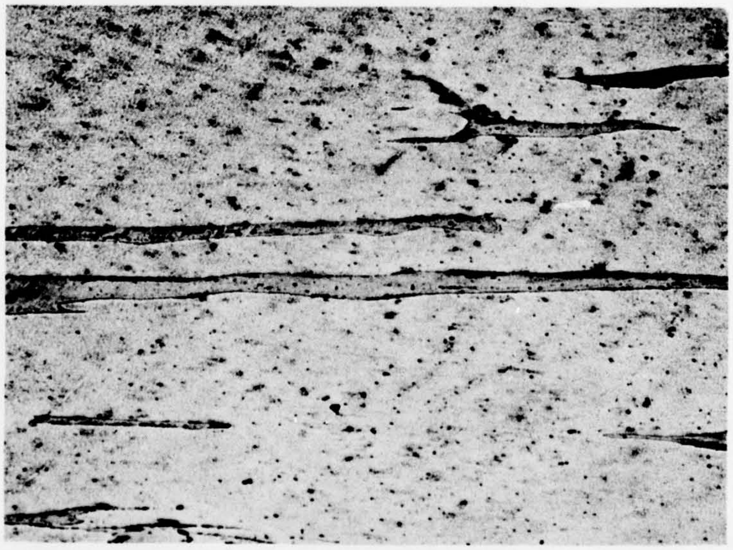


Plate #405E 100X

Figure 16. 90^{V}/oTi-10^{V}/oBe Rod Extrusion.
Reduction in Area R = 6:1
Longitudinal

TABLE I

DENSITY OF PROCESSED 100^{V}/oTi AND 90^{V}/oTi-10^{V}/oBe BILLETS

Billet No.	Composition	Process Condition	Density* (g/cm^{3})	
			End or Wall	Center or Bottom
1	100^{V}/oTi	1100°F compact + 1300°F double upset + 1300°F back extruded	4.532	4.529
2	100^{V}/oTi	1100°F compact + 1300°F double upset	4.533	4.535
3	100^{V}/oTi	1100°F compact	4.529	4.452
4	90^{V}/oTi-10^{V}/oBe	1100°F compact + 1300°F double upset + 1300°F back extruded	4.277	4.268
5	90^{V}/oTi-10^{V}/oBe	1100°F compact + 1300°F double upset	4.246	4.311
6	90^{V}/oTi-10^{V}/oBe	1100°F compact	not determined	not determined

* Theoretical full density

100^{V}/o Ti-6Al-6V-2Sn - 4.539 g/cm^{3}

90^{V}/o Ti-6Al-6V-2Sn — 10^{V}/oBe - 4.270 g/cm^{3} (calc.)

TABLE II

Cu CLAD Ti-10^{v}/oBe TRIAL RODS

Extrusion No.	5037-1	5037-2	5037-3	5037-4
Material	90^{v}/oTi-10^{v}/oBe as loose powder (Ti-6Al-4V-2Sn)			
Material Source	Ti alloy - AMMRC supplied Be alloy - NMD powder stores			
Press (tons)	300	300	300	300
Liner (inches)	2.040	2.040	2.040	2.040
Die (inches)	1.414	1.000	0.815	0.707
Speed (ipm)	30	30	30	30
Billet Temperature (°F)	1300	1300	1300	1300
Heating Medium	Air	Air	Air	Air
Tool Temperature (°F)	900	900	900	900
Lubrication	L-A-T	L-A-T	L-A-T	L-A-T
Reduction RAtio	1.98	4.00	5.95	7.96
Force: Upset	No record	No record	260	280
Run	150 (visual)	200 (visual)	230	248
Extrusion Constant: Upset	——	——	43.7	41.3
Run	67.2	46.3	39.5	35.4
Billet Dimension	Blended mixture of loose powders. Packing density ~65% theoretical.			
Canning Material Dimension	Copper 2" O.D. x 16 gage x 3-1/2" long			
Remarks	No good severe rupture	No good severe rupture	O.K.	O.K.

TABLE III

COMPRESSION AND DENSITY DATA Cu CLAD
90^{V}/oTi - 10^{V}/oBe EXTRUSIONS

Sample No.	Ultimate Strength (ksi)	Yield Strength (ksi)	Density* (g/cm^3)	Notes
6X-1	248.0	231.8	4.345	Positive yield.
6X-2	251.0	234.2		Positive yield.
8X-1	247.9	227.7	4.214	Positive yield.
8X-2	241.6	227.3		0.2% offset yield.

*Calculated density 90^{V}/oTi-6Al-6V-2Sn - 10^{V}/oBe 4.270 g/cm^3.

SCREEN SIZE ANALYSIS APPENDIX "A"

DATE 3·3·71

TECH: S. LARSON

SAMPLE IDENT: 3450-000002

COMPOSITION: Ti-6Al-6V-2Sn

WT. SUBMITTED:

TIMES SPLIT: 4

WT. TESTED: 145.27

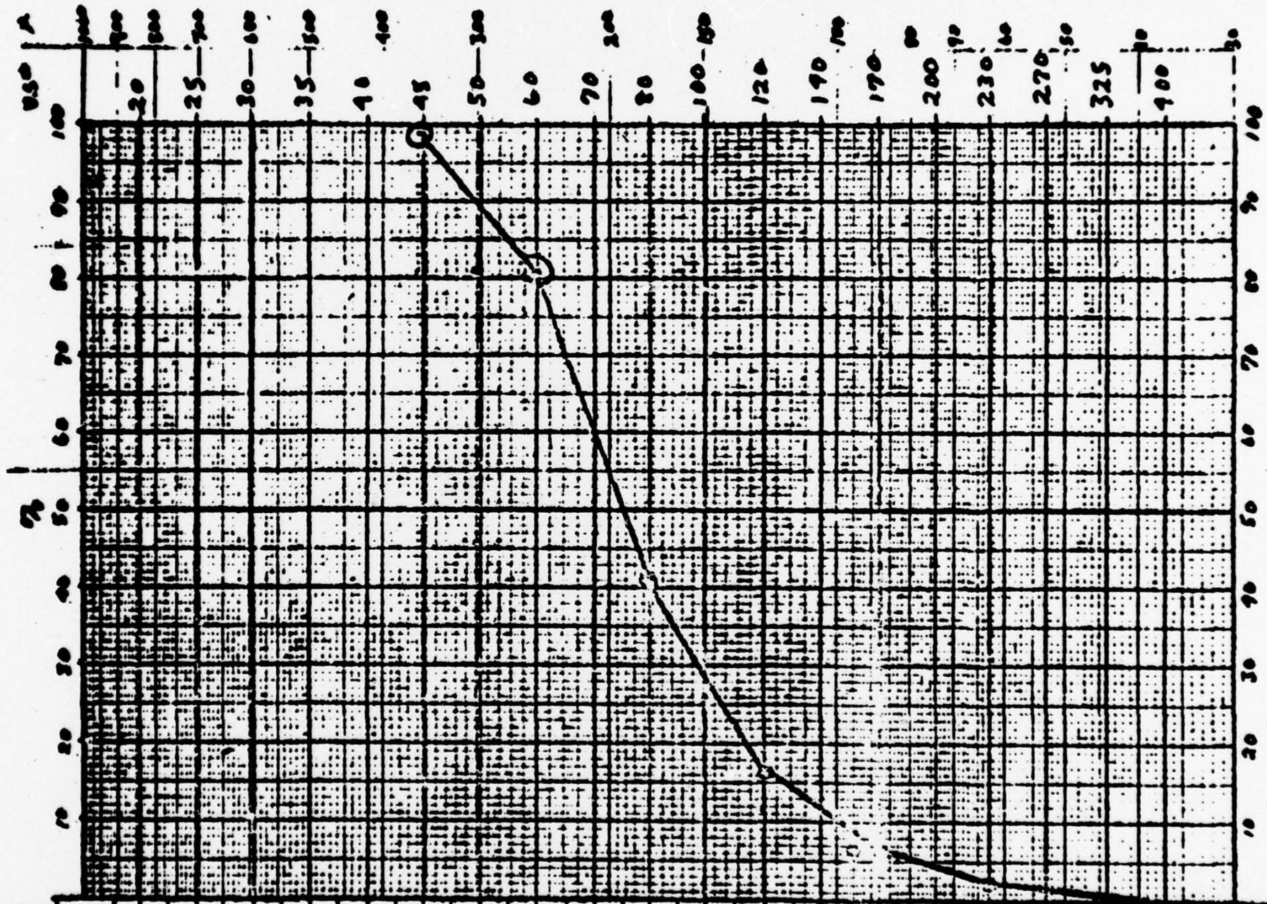
NOTES: FLOW RATE = 26.5

App C = 2.7300

-35 = 95.75 lbs.

+35 = 4.0 lbs.

STUBS = 24.75 lbs.



μ	U.S. No.	WT. On	% On	% Finer
1000	18			
841	20			
707	25			
595	30			
500	35	—	[illegible]	[illegible]
420	40			
354	45	2.29	1.58	98.42
297	50			
250	60	25.65	17.68	80.74
210	70			
177	80	57.72	39.79	40.95
149	100			
125	120	36.42	25.11	15.84
105	140			
88	170	14.05	9.69	6.15
74	200			
63	230	6.11	4.21	1.94
53	270			
44	325	2.25	1.55	.39
37	400			
	PAN	.57	.39	00
	TOTAL	145.04	100.00	000.00

SCREEN SIZE ANALYSIS APPENDIX "B"

DATE: 6-15-71

TECH: J. LARSON

SAMPLE IDENT: 3452

COMPOSITION: Ti-6-2

WT. SUBMITTED:

TIMES SPLIT: 5

WT. TESTED: 121.20

NOTES: FLOW RATE : 27.5

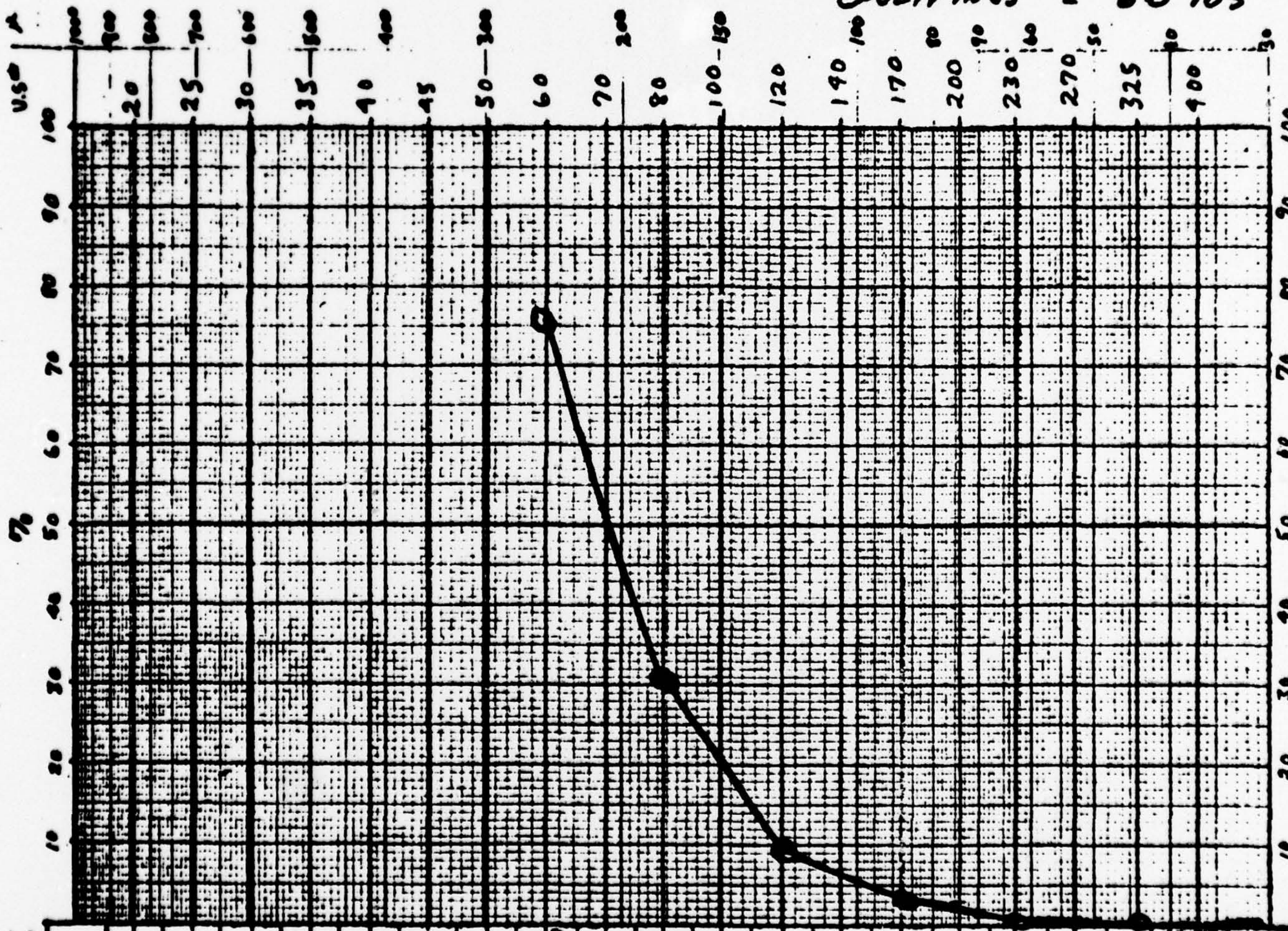
APP C = 2.7148

-45 = 116.0 lbs.

+45 = 10.5 lbs.

STUBS = 25.5 lbs.

SNUBPINGS = 60 lbs



U.S. No.	Wt. On	% On	% Finer
18			
20			
25			
30			
35			
40			
45 ✓	-	-	-
50			
60 ✓	29.66	24.54	75.46
70			
80 ✓	54.23	44.87	30.59
100			
120 ✓	25.49	21.10	9.49
140			
170 ✓	7.69	6.36	3.13
200			
230 ✓	2.90	2.40	.73
270			
325 ✓	.76	.63	.10
400			
PAN ✓	.12	.10	000
TOTAL	120.85	100.00	000

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Army Materials and Mechanics Research Center,
Watertown, Massachusetts 02172
DEVELOPMENT OF A PRODUCTION PROCESS FOR
LARGE CYLINDERS FROM MIXTURES OF SPHERICAL
POWDERS OF HIGH STRENGTH TITANIUM ALLOYS
AND BERYLLIUM - Paul Loewenstein, Nuclear Metals
Division, Whittaker Corporation, West Concord, Massachusetts

UNCLASSIFIED

Key Words

Powder metallurgy
Composite materials
Titanium alloys

Technical Report AMMRC CR 71-18, August 1971, 32 pp -
illus - tables, Contract DAAG46-71-C-0076 P00005,
D/A Project 1T062105A331, AMCMS Code 502E.11.297,
Final Report for Program II, Unclassified Report

Microquenched spherical powders of Ti-6Al-6V-2Sn and of beryllium were produced by the Rotating Electrode Process. Two approaches were used in order to develop a fabrication process for 6-inch O. D. x 1/2-inch wall tubular shells, from the titanium alloy as well as from a mixture of 90v/oTi alloy with 10v/oBe. The first approach, which proved unsuitable, consisted of a consolidation-upset-forging-cupping sequence. The second approach consisted of a direct single step extrusion in copper cans. It was shown that a minimum reduction in area of 6:1 is required to obtain sound structures and high strength. Two billets for the production of full size tubular shells were prepared.

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Watertown, Massachusetts 02172

13. ABSTRACT

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Two approaches were used in order to develop a fabrication process for 6-inch O.D. x 1/2-inch wall tubular shells, from the titanium alloy as well as from a mixture of 90V/oTi alloy with 10V/oBe.

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