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FABRICATION OF ULTRAFINE BERYLLIUM WIRE

Final Report

August 1, 1963

by

E. A. Murphy
R. G. O'Rourke

Prepared under Navy, Bureau of Weapons
Contract No. NOw 63-0137-c

RESEARCH AND DEVELOPMENT
The Brush Beryllium Co.
CLEVELAND, OHIO

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ABSTRACT

The results of six month's work directed toward development of a process for the production of ultrafine beryllium wire by warm drawing techniques are described. Clad drawing was found to be unacceptable. Using conventional drawing techniques, long lengths, 200 feet and over of 0.0018 inch-diameter, shorter lengths, 50 to 25 feet of 0.0015-inch diameter, and very short lengths, under 2 feet of 0.00115-inch diameter beryllium wire were produced. The mechanical properties of drawn beryllium wire between the sizes of 0.010 and 0.001497-inch diameter are described.

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I. INTRODUCTION

The object of this project was to develop techniques for drawing QMV® beryllium wire to 0.001-inch diameter, or as small as possible, to establish the optimum properties of the wire, and to furnish 100 feet of the best product produced. Previously, The Brush Beryllium Company successfully developed techniques for fabrication of beryllium wire at sizes down to 0.00477 inch under two Navy contracts: Nos. NOas 59-6030-c[1] and NOas 60-6108-c.[2]

The work reported here was essentially a continuation of the previous programs

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II. CLAD DRAWING

A. Experimental Work and Results

1. Procedure

In an attempt to avoid the materials handling problems and wire drawing equipment problems which are associated with extremely fine wire, this program was directed initially toward the use of the jacketing process[3] in conjuction with using existing wire draw dies, equipment, and warm draw technique. [2] The jacketing process consists of inserting beryllium wire (0.00477-inch diameter) in a tubular steel jacket measuring 0.014-inch OD x 0.006-inch ID. The assembly would then be pointed, lubricated, and drawn to 0.00477 inch. It was planned that this process would be repeated until the beryllium wire was reduced to 0.001-inch diameter.

The beryllium selected for use during this program was 475 feet of Lot No. 2-6295 and 400 feet from Lot No. 2-8842. Both materials were 0.00477-inch diameter wire which had been produced previously for inventory by The Brush Beryllium Company. The wire was fabricated from warm extruded 0.500-inch diameter rods and drawn to 0.062-inch diameter with intermediate anneals. The beryllium wire was then drawn to 0.00477-inch diameter without anneals. The chemical analysis of both S-200-B materials is listed in Table I. Lot No. 2-6295 was used exclusively during the clad drawing work while both materials were used extensively during the conventional drawing experiments.

The cladding material was 1010 steel and was supplied by Superior Tube Company in an annealed condition. A random inspection of this tubing was done before canning and revealed good dimensional uniformity, an excellent ID surface, a typical carbon steel OD surface, and none of the major defects which are often associated with tubular products.

The single die draw bench that was used is shown in Figure 1. The draw force is obtained from a Zero-Max variable-speed drive that is connected to a 6 1/4-inch diameter capstan. The capstan and die area are enclosed in ovens that supply the heat requirement to the process. Strategic placement of thermocouples allows close control of the oven temperature.

2. Warm Drawing Results

The first canned assemblies were 12 inches long and used "as-drawn" beryllium wire, with and without a lubricated surface. These

TABLE I

CHEMICAL ANALYSIS

Element	2-8842 % by Weight	2-6295 % by Weight
Be	98.38	98.65
BeO	1.64	1.60
C	0.12	0.11
Al	0.06	0.04
Fe	0.124	0.13
Mg	0.05	0.018
Si	0.025	0.028
Mn	--	0.0095
Cr	--	0.014
Ni	--	0.016

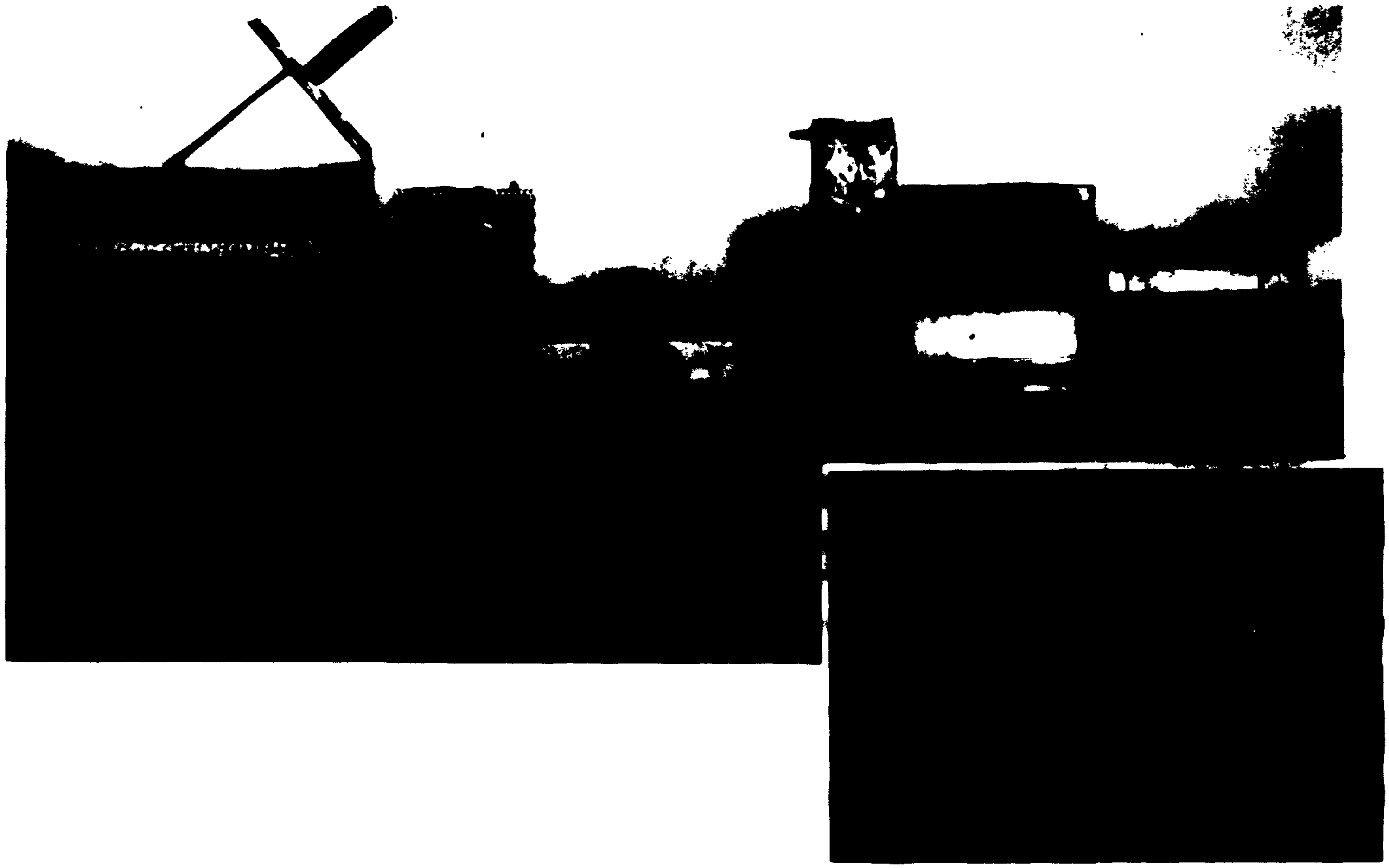


Fig. 1 - Fine Wire Drawing Machine

assemblies were given various reductions of 10% and/or 20% at 800°F and at draw speeds of 10-15 feet/min. After each pass, the rear portion of the drawn assembly was pickled in dilute nitric acid in order to strip the beryllium to facilitate inspection. It was found that the hardened beryllium wire failed in tension several times over a 4-inch length, regardless of the percent reduction or presence or absence of lubricant. It should be noted that the dilute nitric acid stripped the assemblies easily and quickly and did not react with the beryllium wire.

Following the above, annealed* beryllium wire was then inserted in the mild steel tubes and processed through drawing reductions at 800°F at a draw speed of 10 feet/min. The beryllium wire was reduced successfully without failure when the assembly was given 3-20% reductions followed by one 10% pass. It was found that a fourth 20% reduction or one additional 10% pass would lead to tensile failure similar to that experienced with the "hard" beryllium wire. Table II shows the beryllium reductions obtained from this technique.

TABLE II

CLAD DRAWING DATA

Pass No.	Die Size (in.)	Cumulative % Reduction of Assembly (%)	Beryllium Diameter (in.)	Cumulative % Reduction of Beryllium (%)
Start	0.014	--	0.00477	--
1	0.01297	14.4	--	--
2	0.01167	30.5	--	--
3	0.01051	43	0.00425	20.6
4	0.00997	49.3	0.0041	26.1
5[a]	0.00946	54.2	0.0038	36.7
6[a]	0.00897	59	0.0037	38.7

[a]Beryllium failed in tension in approximately 50% of the assemblies.

[b]Beryllium failed in tension in all of the assemblies.

From the data shown in Table II, an erratic behavior in the amount of beryllium reduction between the fourth and fifth pass is noted. Together with this fact and the 50% loss due to tensile failure after the

*Anneal: 1500°F in argon atmosphere, 15 min. hold, air cooled.

fifth pass an intermediate anneal was inserted into the process after the fourth pass. Annealing was done in a vacuum induction furnace having a molybdenum susceptor and operated at a pressure of less than 5 microns. The beryllium-carbon steel assembly was heated to 1650°F, held for 2 minutes, and cooled rapidly in vacuum.

All attempts to draw annealed assemblies ended in failure during the first pass. The beryllium wire appeared to have a definite "necking tendency" that was not evident in earlier failures.

An evaluation of beryllium wire was made by selecting 10 feet of 0.00477-inch diameter from the starting coil and warm drawing it to 0.00407-inch diameter in three equal passes using the established technique.[2] All passes were preformed successfully and the resultant wire was considered to have excellent quality.

No success was achieved in sensitizing type 0302 stainless material for intergranular disintegration by acid baths that are passive to beryllium. Therefore, no attempt was made to use this material as a clad in the drawing work reported herein.

III. CONVENTIONAL WARM DRAWING

A. Warm Drawing Procedure

Because of the disappointing results from the clad drawing technique, the procedure was changed to include drawing the wire to 0.001-inch diameter, or as small as possible, using the general drawing techniques established in other work.[2] This practice consists of reducing bare beryllium wire at 800°F in 10% reduction of area passes at a speed of 5 - 15 feet per minute using the standard moly-disulfide lubrication system.

1. Tools and Equipment

In order to facilitate the handling of the small size wire and to achieve the required reductions, additional tools and equipment were added to the existing wire draw bench. One set of 28 diamond draw dies having a 10% reduction schedule was obtained between 0.00407 and 0.00098-inch diameters. All other dies necessary to process other starting diameters were on hand. Pay-off and powered take-up spool assemblies were added to the wire draw bench. The pay-off spool was positioned up-stream from the pre-heat furnace and provided an adequate means to introduce the wire to the drawing line. Space was provided between the pay-off spool and the pre-heat furnace to accommodate a simple continuous lubricator. The take-up spool is powered by a fractional h. p. motor-Zero-Max variable speed drive combination.

The take-up spool assembly features a 4 oz. minimum-torque slip clutch between the Zero-Max and the reel and is positioned 5 feet downstream from the capstan. At this distance it was found that the wire level winds itself in a suitable manner eliminating any need for a level-wind mechanism. The reels are standard 2-inch OD x 3 inches long, made of plastic, and were obtained from the Boonton Molding Company of New Jersey.

Other auxiliary equipment was found necessary for cleaning and inspection of the product and dies below the nominal size of 0.004 inches. Inspection of dies and product is done under a microscope, 15, 45, or 90X, having the proper mounting and lighting fixtures. In-process product inspection and die threading were made easier by using a standard 5-inch diameter portable magnifier. The die cleaning operation uses a Branson "Sonogen" ultrasonic generator with a solution of water plus a porcelain and metal cleaner as the bath. Together with these tools, the general "hand" technique of processing difficult small diameter die problems was thoroughly demonstrated by the Indiana Wire Die Company and has been used quite extensively during this program.

2. Pre-Drawing Operations

Lubricants were applied to the wire using the continuous lubricator positioned "in-line" between the pre-heat furnace and pay-off reel. However, as work progressed, it was found necessary to relocate the lubricator between the capstan and wind-up reel for wire sizes under 0.002-inch diameter. This change reduced the back drag to a minimum and eliminated the need for an additional lubricating operation at the small sizes.

The standard[1] moly-disulfide lubricant, Dag 206, was used successfully on wire sizes above 0.002-inch diameter. Performance of this lubricant below 0.002-inch diameter was considered poor, primarily because of its inconsistency in providing the wire with a light, even coat.

As an alternate, a modified Dag 206, having a 9 1/2% solid content and a smaller particle size, was used on the smaller wire diameters. This lubricant was used over the standard drawn lubricant, and was applied on the wire at sizes below 0.003-inch diameter.

Pointing the wire, regardless of size, was accomplished by pickling in a dilute nitric-hydrofluoric solution.

The limited amount of annealing that was done during this program used standard vacuum annealing procedures with a helium gas quench. The wire to be annealed was first prepared by removing all lubricants and foreign matter from the wire surface by pickling at room temperature in a dilute nitric acid bath.

B. Warm Drawing Results

The first warm draw run (Table III) brought into focus a minor lubricating problem and the importance of proper die handling facilities and techniques. Although little trouble was experienced until the 0.002053-inch diameter die, it was noted that a lubricant build-up occurred in the tapered section of the die during the draw run. This build-up increased in quantity as the die size decreased. The difficulty of removing the lubricant also increased as the die size decreased. Rethreading dies having this build-up in the taper was impossible. This situation was eliminated with the addition of the ultrasonic cleaner and thinning the standard lubricant with water at a ratio of 15 to 1.

The failures shown in Table III for the first run were thought to be caused by improper lubrication, especially between 0.002053 and 0.001848-inch die sizes. The failures noted below 0.001663-inch die size were caused partly by improper handling. The draw run was stopped at 0.001497-inch die size, because a dirty die prevented all threading attempts.

TABLE III

WARM DRAWING RESULTS FOR ULTRAFINE WIRE

	1st Run	2nd Run
Material Lot No.	2-6295	2-6295
Die Temp. °F	700	700
Nominal Die Size	Start 0.00477 inch x 50 feet, As-drawn from 0.062 inch	Start 0.00477 inch x 50 feet, As-drawn from 0.062 inch
0.00453	OK	OK
0.00429	OK	OK
0.00407	OK	OK
0.00386	OK	OK
0.003663	Broke 16 feet from end	OK
0.003475	OK	OK
0.003297	OK	OK
0.00313	OK	OK
0.002967	OK	Broke at Capstan lost 1/3
0.002815	OK	OK
0.002671	OK	OK
0.002534	OK	OK
0.002404	OK	OK
0.002281	OK	OK
0.002164	OK	Tensile breaks -scrap-
0.002053	Broke in half	
0.001948	Broke in half	
0.001848	Broke at rear	
0.001753	OK	
0.001663	Broke in half	
0.001578	Broke in half	
0.001497	Scrap - unable to point	

TABLE III (Continued)

WARM DRAWING RESULTS FOR ULTRAFINE WIRE

	3rd Run	4th Run
Material Lot No.	2-6295	2-8842
Die Temp. °F	700	700
Nominal Die Size		Start 0.00477 inch x 200 feet As-drawn from 0.062 inch
0.00453		OK
0.00429		OK
0.00407		Tension break lost 65 feet
0.00386		OK
0.003663		Broke at reel and die lost 25 feet
0.003475		OK
0.003297		Broke at die, lost 50 feet
0.00313		Broke at die
0.002967		Broke at die, lost 60 feet
0.002815		Broke at die
0.002671		OK
0.002534		Broke up at die
0.002404		Scrapped out
0.002281		
0.002164	Start 0.002164 inch x 50 feet from 1st Run	
0.002053	OK	
0.001948	OK	
0.001848	Tension break on take-up spool and on Capstan	
0.001753	OK	
0.001663	Furnace breakdown - lost 3 points and broke at rear	
0.001578	Broke in half	
0.001497	Broke in half from handling	
0.001420	OK	
0.001347	Broke up	

TABLE III (Continued)

WARM DRAWING RESULTS FOR ULTRAFINE WIRE

	5th Run	6th Run
Material Lot No.	2-8842	2-6295
Die Temp. °F	700	700
Nominal Die Size	Start 0.00477 inch x 50 feet Anneal at 1450°F - 1 hour	Start 0.00477 inch x 25 feet Annealed at 1450°F
0.00453	OK	OK
0.00429	OK	OK
0.00407	OK	OK
0.00386	OK	Broke in die
0.003663	Point breaks	Broke in die
0.003475	OK	OK[a] - for 7 feet
0.003297	OK	OK
0.00313	OK	OK
0.002967	Tension breaks at die, 18 feet OK	OK - used for tensiles
0.002815	OK	
0.002671	OK	
0.002534	OK	
0.002404	OK	
0.002281	OK	
0.002164	Broke lubricating	
0.002053	OK	
0.001948	OK	
0.001848	Broke up	
0.001753	Ran a 4 foot length OK	
0.001663	OK	
0.001578	OK	
0.001497	Points broke and scrapped out	

[a]Used new Lubricant

TABLE III (Continued)

WARM DRAWING RESULTS FOR ULTRAFINE WIRE

	7th Run	8th Run
Material Lot No.	2-8842	2-6295
Die Temp. °F	700	700
Nominal Die Size	Start 0.00477 inch x 50 feet Annealed at 1700°F, 1 hour hold	Start 0.00477 inch x 50 feet, Annealed at 1700°F, 1 hour hold
0.00453	OK	Broke several times[a]
0.00429	Broke at die twice	OK for 10 feet
0.00407	OK	Point breaks - used for tensiles
0.00386	OK	
0.003663	Points broke - used for tensiles	
0.003475		
0.003297		
0.00313		
0.002967		
0.002815		
0.002671		
0.002534		
0.002404		
0.002281		
0.002164		
0.002053		
0.001948		
0.001848		
0.001753		
0.001663		

[a]New lubricant used for the first time

TABLE III (Continued)

WARM DRAWING RESULTS FOR ULTRAFINE WIRE

	9th Run
Material Lot No.	2-6295
Die Temp. °F	700
Nominal Die Size	Start 0.00477 inch x 100 feet As-drawn from 0.062 inch
0.00453	OK 112 feet
0.00429	OK 125 feet
0.00407	OK 138 feet
0.00386	OK 150 feet
0.003663	OK 175 feet[a]
0.003475	OK 185 feet
0.003297	OK 206 feet[b]
0.00313	OK 217 feet
0.002967	OK 255 feet[a]
0.002815	OK 278 feet
0.002671	OK 315 feet
0.002534	OK 358 feet
0.002404	OK 387 feet
0.002281	OK 435 feet
0.002164	OK 490 feet
0.002053	OK 545 feet
0.001948	OK 555 feet[c]
0.001848	Tension breaks drew 120 feet and 80 feet
0.001753	Drawing 80 foot lengths. Had 2 tension breaks 75 feet OK
0.001663	Broke up

[a]Excessive reduction noted, new dies ordered

[b]New lubricant used for the first time

[c]Very little reduction noted, new die ordered

TABLE III (Continued)

WARM DRAWING RESULTS FOR ULTRAFINE WIRE

	10th Run[a]
Material Lot No.	2-8842
Die Temp. °F	700
Nominal Die Size	Start 0.00477 inch x 100 feet As-drawn from 0.062 inch
0.00453	OK
0.00429	OK
0.00407	OK
0.00386	OK
0.00367[a]	Not available
0.003663	Tension breaks
0.003475	OK
0.003297	OK
0.00313	OK
0.00303[a]	Not available
0.002967	Broke in die
0.002815	OK
0.002671	OK
0.002534	OK
0.002404	Broke on Capstan
0.002281	Scrapped out
0.002164	
0.002053	
0.001948[a]	
0.001848	
0.001753	

[a]New lubricant - used old dies

TABLE III (Continued)

WARM DRAWING RESULTS FOR ULTRAFINE WIRE

	11th Run[a]	12th Run
Material Lot No.	2-8842	2-6295
Die Temp. °F	700	800
Nominal Die Size		
0.00453		
0.00429		
0.00407		
0.00386	Start at 0.00386 inch x 60 feet from Run 10	
0.00367	Tension breaks	
0.003663	Broke in die	
0.003475	OK	
0.003297	Broke in die	
0.00313	OK	
0.00303	OK	
0.002967	OK	
0.002815	OK	
0.002671	OK	
0.002534	Broke in die	
0.002404	OK	
0.002281	Broke in die	Starting material 0.002 from old 0.001948 die from Run 9
0.002164	OK	
0.002053	OK	
0.001948	Broke in die	OK
0.001848	OK	Handling break 125 feet OK
0.001753	Scrapped out	Drew 35 feet and had a tension break at payoff reel -Held-

[a] New dies inserted in draw schedule

TABLE III (Continued)

WARM DRAWING RESULTS FOR ULTRAFINE WIRE

	Run 13	Run 13(a)
Material Lot No.	2-6295	2-6295
Die Temp. °F	800	800
Nominal Die Size	Start 0.00477 inch x 95 feet As-drawn from 0.062 inch	
0.00453	OK	
0.00429	OK	
0.00407	OK	
0.00386	Broke lubricating 115 feet OK	
0.00367	OK	
0.003663	OK	
0.003475	OK	
0.003297	Tension breaks 110 feet OK	
0.00313	OK	
0.00303	OK	
0.002967	OK	
0.002815	Tension break 130 feet OK	
0.002671	OK	
0.002534	OK	Start rear half from Run 13
0.002404	Broke in half 180 feet OK	OK for 80 feet
0.002281	Broke in half 40 feet OK Die galled	Tension break 70 feet OK
0.002164	Tension and point breaks, 25 feet OK	Tension break, 55 feet OK
0.002053	OK	Handling break, 50 feet OK
0.001948	Handling break, 25 feet OK	OK
0.001848	OK	OK
0.001753	Handling break, 20 feet OK	Die galled, broke up, scrapped
0.001663	Broke in die, 15 feet OK	
0.001578	OK	
0.001497	Tension breaks, drew 3 feet no back drag	
0.001420	OK	
0.001347	OK	
0.001278	Handling break, 2 pieces 3 feet OK	
0.001150	Point broke, 17 inches OK	

TABLE III (Continued)

WARM DRAWING RESULTS FOR ULTRAFINE WIRE

	Run 13(b)	Run 13(c)
Material Lot No.	2-6295	2-6295
Die Temp. °F	800	800
Nominal Die Size		
0.00453		
0.00429		
0.00407		
0.00386		
0.00367		
0.003663		
0.003475		
0.003297		
0.00313		
0.00303		
0.002967		
0.002815		
0.002671		
0.002534		
0.002404	Start rear half of Run 13	
0.002281	OK for 45 feet	Start rear part of 13a
0.002164	OK	OK
0.002053	Point broke, 25 feet OK	OK for 18 feet
0.001948	OK	
0.001848	OK	
0.001753	Die galled, scrapped out	
0.001663		
0.001578		
0.001497		
0.001420		
0.001347		
0.001278		
0.001150		

TABLE III (Continued)

WARM DRAWING RESULTS FOR ULTRAFINE WIRE

	Run 14	Run 14(a)	Run 14(b)
Material Lot No.	2-6295	2-6295	2-6295
Die Temp. °F	800	800	800
Nominal Die Size	Start 0.00477 inch x 72 feet. As-drawn		
0.00453	OK		
0.00429	OK		
0.00407	OK		
0.00386	OK		
0.00367	OK		
0.003663	OK		
0.003475	OK		
0.003297	OK		
0.00313	OK		
0.00303	Tension break, 157 feet OK		
0.002967	OK		
0.002815	OK		
0.002671	OK		
0.002534	OK	Start rear of Run 14	
0.002404	Broke in half, 125 feet OK	OK for 110 feet	
0.002281	OK	OK	
0.002164	OK	Broke in die, 80 feet OK	
0.002053	OK	OK	
0.001948	OK	OK	
0.001848	OK for 220 feet	Broke in die, 57 feet OK and 22 feet OK	Start 22 feet length from Run 14a
0.001753	Broke in three pieces 31, 35, and 140 feet	Broke in three pieces	OK
0.001663	31 feet and 35 feet went OK, 140 feet broke up, scrapped	Broke at die scrapped	Point breaks, 24 feet OK
0.001578	34 feet length OK 38 feet length OK		25 feet OK (held)
0.001497	Points broke on 34 foot length, held. Points broke on 38 foot length, drew 25 feet OK and held		

TABLE III (Continued)

WARM DRAWING RESULTS FOR ULTRAFINE WIRE

	Run 15
Material Lot No.	2-6295
Die Temp. °F	800
Nominal Die Size	Start 0.00477 inch x 20 feet As-drawn from 0.062 inch
0.00453	OK
0.00429	OK
0.00407	OK
0.00386	OK
0.00367	OK
0.003663	OK
0.003475	OK
0.003297	OK
0.00313	OK
0.00303	OK
0.002967	OK
0.002815	OK
0.002671	OK
0.002534	OK
0.002404	OK
0.002281	OK
0.002164	Handling break, 90 feet OK
0.002053	Tension break at pay-off reel, 70 feet OK
0.001948	OK
0.001848	OK
0.001753	OK
0.001663	Tension break in die - galled - 52 feet OK
0.001578	Point breaks, lubricant failed at rear, 35 feet OK
0.001497	Point breaks, wire held at 0.001578

The second draw run again processed without difficulty until the 0.002164-inch die was reached. Repeated tensile failures of wire at the pay-off reel were experienced, scrapping out the entire coil. This failure was caused by the beryllium wire seizing to a tacky plastic surface of the reel. It was found that this condition was due to a reaction between the plastic and a solvent accidentally splashed on the surface of the reel.

The starting material for the third run was supplied by the rear half of the first coil that resulted from the break at 0.002053-inch die size of the first run. This run featured a 20:1 dilution of the standard lubricant (Acheson Dag 206) and the cleaning and inspection procedures mentioned earlier. Although a tension break occurred between the capstan and take-up reel on the 0.001848-inch diameter pass, the first four passes are considered successful. The furnace breakdown during the 0.001663-inch diameter pass rather clouds the draw results of the next pass. It is felt that the break occurring at 0.001578-inch die size may have been initiated on the preceding cooler pass. Improper handling again broke the wire at the 0.001497-inch diameter pass. The material failed completely at the 0.001347-inch die size.

Lot No. 2-8842 in the as-drawn condition was used as starting material for the fourth run. Breaks were experienced on almost every pass starting at the 0.00407-inch diameter size.

The fifth and sixth draw runs featured both lots of material annealed at 1450°F, 1-hour hold. The 8842 material drew without difficulty until the 0.002967 die was reached. Several tension breaks at the die were experienced before an 18-foot length was obtained. This wire then drew without trouble until the 0.001848-inch diameter pass.

Only three successful draw passes were obtained on the annealed 6295 wire. The breaks occurring at the 0.00386 and 0.003663-inch die sizes were typical necked-down tension breaks.

A 1700°F, 1-hour hold, helium quench, solutionize annealing treatment was given to 50 feet of each material in the 0.00477-inch diameter size. The draw data of Runs seven and eight indicate poor results. It was noted that the wire surface of all the annealed lengths was etched and appeared much rougher than the as-drawn wire.

The ninth run duplicated the first three runs, except the modified Dag 206 lubricant replaced the standard lubricant at the 0.003297-inch die size. A longer starting length was also used so that each draw run could be timed accurately and the actual reduction per pass could be calculated. The results of this run were considered excellent. Three trouble spots, 0.003663, 0.002967 and 0.001948-inch diameter, in the die schedule were noticed and replacement dies were ordered. The tension breaks occurring at 0.001848-inch die size were most probably due to microcracks produced by the excessive reduction between the 0.001948 and 0.001848-inch dies. A light gray residue was noticed in the dies under 0.002053 inches after drawing. This material was analyzed and was found to contain moly oxide and BeO as its major and minor constituents.

The tenth and eleventh runs again used as-drawn wire from Lot No. 8842. Run eleven differed from ten in that the new dies were used and the reductions per pass were controlled. The draw results show several breaks occurring in both runs, regardless of the die schedule. At this point it was decided to continue the program with wire from Lot No. 6295 in its "as-drawn" condition as starting material.

The twelfth run was a continuation of run number nine using the new 0.001948-inch die. The new die was found to be adequate, but handling breaks decreased the lengths stopping the work at 0.001753 die size. The light gray substance was again noticed in the die after each draw attempt.

Run thirteen featured a higher die temperature than was used previously. Other operating variables were identical to those of run No. nine. This run progressed successfully until the 0.002404 die size was reached. All tension breaks that occurred were again attributed to lubrication failure. However, one short length was drawn to 0.00115 inch diameter: the last three passes were hand drawn.

Run fourteen duplicated run thirteen except for using a heavier Modified Dag 206 lubricant (cut 2:1 from the as-received product). This lubricant seemed to improve the draw results observed from run thirteen. The 0.001753 die size was reached before several tension breaks were obtained. The light gray deposits were again noticed in dies under 0.002164, but in less quantity. The two breaks listed previously on run fourteen above 0.001753 are unexplained. One coil of 0.001497-inch diameter x 25 feet from run fourteen, together with 2 lengths of 0.001578-inch diameter x 35 feet and 25 feet from run fourteen and fourteen (b) were held for shipping.

Run fifteen duplicated run fourteen in an attempt to complete the 100 foot requirement of the smallest possible diameter of over 25 feet in length. The lubricant again failed at the 0.002053, 0.001663, and smaller die sises. However, one shippable length of 30 feet of 0.001578-inch diameter was fabricated.

C. Product Evaluation

Tensile specimens were supplied in their "as-drawn" condition. The only exceptions to this procedure were those specimens from the annealed lots of 0.00477-inch diameter wire. All specimens were approximately six inches long. They were subjected to uniaxial tension in an Instron Model TM instrument. The cross-head speed was held constant producing a strain rate of 0.1 in./in./min. in the elastic region of the load-deformation curve.

The results of the tensile testing are listed in Tables IV, V, and VI. Table IV shows all data from wire drawn at 700°F for Lot No. 8842. Tensile data for Lot No. 6295 are listed in Table V for wire drawn at 700°F and Table VI for wire drawn at 800°F from run fourteen.

Photomicrographs of wire specimens are shown in Fig. 2 for five different processed conditions.

TABLE IV

SOME MECHANICAL PROPERTIES OF BERYLLIUM ULTRAFINE WIRE (2-8842)

Specimen No.	Drawn Diameter[a] (inch)	Reduction Ratio From Last Anneal	Tensile (Room Temperature) Ultimate[b] ($\times 10^3$ psi)	Yield[c] ($\times 10^3$ psi)	Elong.[d] (%)
RI-2949	0.0105	34.7 to 1	180.3	140.6	1.70
RI-2950			180.5	138.0	1.93
RI-2951		Last Anneal	180.2	138.3	1.86
RI-2952		0.062-inch	182.8	138.9	2.57
RI-2953		diameter	180.4	132.1	1.70
RI-2954			179.5	134.9	1.60
RI-2955			172.8	137.6	1.12
RI-2956			178.0	137.6	1.63
RI-2957			178.3	137.7	1.69
RI-2958			180.3	137.2	1.69
RI-2959			180.6	139.0	1.53
RI-2960			178.9	137.2	1.66
		Avg. Values	179.4	137.4	1.64
RI-2926	0.00502	152 to 1	200.8	171.8	2.29
RI-2927			201.5	164.2	1.69
RI-2928		Last Anneal	206.5	163.7	1.66
RI-2929		0.062-inch	209.7	166.7	2.62
RI-2930		diameter	209.2	162.4	1.84
RI-2931			208.4	162.7	1.84
RI-2932			197.8	154.1	2.02
RI-2934			207.7	164.2	1.93
RI-2935			190.5	152.2	0.96
RI-2936			196.2	157.9	1.58
		Avg. Values	202.8	162.0	1.84
RI-2937	0.003663	295 to 1	176.8	155.7	0.50
RI-2938			185.2	157.9	0.75
RI-2939		Last Anneal	192.6	154.2	1.15
RI-2941		0.062-inch	193.0	153.8	1.17
RI-2942		diameter	190.1	146.4	1.48
RI-2943			183.7	156.2	0.69
RI-2944			184.9	146.6	1.20
RI-2945			186.7	150.6	1.13
RI-2946			191.1	148.8	2.20
RI-2948			178.1	147.4	0.72
		Avg. Values	186.2	151.8	1.09

TABLE IV (Continued)

SOME MECHANICAL PROPERTIES OF BERYLLIUM ULTRAFINE WIRE (2-8842)

Specimen No.	Drawn Diameter[a] (inch)	Reduction Ratio From Last Anneal	Tensile (Room Temperature) Ultimate[b] ($x 10^3$ psi)	Yield[c] ($x 10^3$ psi)	Elong.[d] (%)
RI-2914	0.002815	486 to 1	190.3	155.9	0.95
RI-2915			183.3	155.0	0.65
RI-2916		Last Anneal	189.7	151.8	1.08
RI-2917		0.062-inch	190.2	156.9	1.00
RI-2919		diameter	194.5	153.4	1.25
RI-2920			177.2	151.1	1.30
RI-2923			185.4	149.8	0.86
RI-2924			189.1	155.9	0.86
RI-2925			176.8	154.3	0.49
		Avg. Values	186.3	153.8	0.94
RI-3176	0.002164	820 to 1	166.1	154.4	0.31
RI-3177			190.9	150.9	0.80
RI-3178		Last Anneal	186.8	148.2	0.77
RI-3179		0.062-inch	187.9	152.3	0.74
RI-3180		diameter	182.7	156.6	0.54
RI-3181			179.7	150.4	0.55
RI-3182			177.8	148.7	0.51
RI-3184			189.8	145.5	0.85
RI-3185			199.3	158.2	1.16
RI-3186			185.4	153.3	0.64
RI-3187			185.4	152.3	0.66
		Avg. Values	184.7	151.9	0.70
RI-3188	0.001753	1250 to 1	154.1	121.8	0.54
RI-3189			143.8	133.8	0.30
RI-3190		Last Anneal	154.5	132.6	0.47
RI-3191		0.062-inch	159.1	134.2	0.57
RI-3192		diameter	154.1	134.7	0.40
RI-3194			142.1	134.2	0.27
RI-3196			140.9	136.7	0.24
RI-3197			136.7	136.7	0.20
RI-3198			141.7	136.7	0.25
		Avg. Values	147.4	133.5	0.36

TABLE IV (Continued)

SOME MECHANICAL PROPERTIES OF BERYLLIUM ULTRAFINE WIRE (2-8842)

Specimen No.	Drawn Diameter[a] (inch)	Reduction Ratio From Last Anneal	Tensile (Room Temperature) Ultimate[b] ($\times 10^3$ psi)	Yield[c] ($\times 10^3$ psi)	Elong.[d] (%)
RI-2984	0.00477	No Ratio	100.5	71.6	3.45
RI-2985			111.5	71.6	7.08
RI-2986		1450°F -	111.9	66.4	8.60
RI-2987		1 Hour hold	100.2	68.5	4.48
RI-2988		Anneal	102.7	70.4	5.08
RI-2989			91.9	67.5	3.16
RI-2990			93.8	65.8	3.20
RI-2991			95.5	68.9	3.60
RI-2992			88.9	66.9	2.63
RI-2993			107.7	69.2	7.12
		Avg. Values	100.5	68.7	4.84
RI-2973	0.002967	2.59 to 1	167.7	141.7	1.13
RI-2974			148.4	145.3	0.23
RI-2975		Last Anneal	155.4	143.4	0.42
RI-2976		0.00477-inch	148.1	141.4	0.28
RI-2977		diameter	149.4	141.7	0.35
RI-2978			168.3	136.8	1.10
RI-2980			164.3	147.5	0.63
RI-2981			157.3	141.3	0.66
RI-2983			160.7	130.1	0.60
		Avg. Values	157.7	141.0	0.60
RI-3027	0.002164	4.96 to 1	154.4	142.7	0.60
RI-3028			159.1	137.0	0.57
RI-3029		Last Anneal	158.5	130.5	0.53
RI-3030		0.00477-inch	155.7	138.7	0.40
RI-3031		diameter	154.4	140.6	0.90
RI-3032			155.0	138.7	0.42
RI-3033			141.9	141.9	0.20
RI-3034			161.0	131.3	0.80
RI-3035			150.4	130.5	0.47
RI-3036			163.1	130.9	0.85
		Avg. Values	155.4	136.3	0.57

TABLE IV (Continued)

SOME MECHANICAL PROPERTIES OF BERYLLIUM ULTRAFINE WIRE (2-8842)

Specimen No.	Drawn Diameter[a] (inch)	Reduction Ratio From Last Anneal	Tensile (Room Temperature) Ultimate[b] ($x 10^3$ psi)	Yield[c] ($x 10^3$ psi)	Elong.[d] (%)
RI-3016	0.00477	No Ratio	103.7	65.5	8.56
RI-3017			108.6	67.7	10.11
RI-3018		1700°F, 1	100.9	69.4	5.59
RI-3019		Hour Hold	101.8	69.7	6.06
RI-3020		Anneal	101.0	69.7	8.19
RI-3021			110.5	68.3	11.54
RI-3023			99.6	68.9	5.20
RI-3024			92.9	68.5	3.87
RI-3025			92.1	69.4	3.47
RI-3026			100.9	66.0	6.12
		Avg. Values	101.2	68.3	6.87
RI-3337	0.003663	1.70 to 1	126.4	126.4	0.20
RI-3338			144.9	127.6	0.80
RI-3339		Last Anneal in	148.2	125.7	1.17
RI-3340		the 0.00477	136.9	122.2	0.55
RI-3343		size	135.7	125.7	0.43
RI-3344			144.1	129.5	0.77
RI-3345			142.6	125.7	0.65
		Avg. Values	139.8	126.1	0.65

[a]The drawn diameter value was considered equal to the specified die diameter and was used in the calculations of the tensile, ultimate, and yield strength values.

[b]Ultimate strength is computed by dividing the maximum load by the area corresponding to the "specified die diameter".

[c]Yield strength is computed by dividing the yield load (at 0.2% offset) by the area corresponding to the "specified die diameter".

[d]Elongation was graphically measured on the load-deformation curve.

TABLE V

SOME MECHANICAL PROPERTIES OF BERYLLIUM ULTRAFINE WIRE (2-6295) Run at 700°F With Standard Lubricant (See Runs 1 and 3 - Table III)

Specimen No.	Drawn Diameter[a] (inch)	Reduction Ratio From Last Anneal	Tensile (Room Temperature) Ultimate[b] ($x\ 10^3$ psi)	Yield[c] ($x\ 10^3$ psi)	Elong.[d] (%)
RI-2756	0.003663	295 to 1	168.5	141.5	0.70
RI-2757			182.7	131.6	2.79
RI-2770		Last anneal	181.7	142.4	1.77
RI-2771		0.062-inch	183.2	139.3	4.09
RI-2772		diameter	182.7	145.4	2.05
RI-2773			182.5	143.4	2.35
RI-2774			182.7	142.0	2.78
RI-2775			165.0	144.7	0.55
RI-2776			181.7	140.7	4.08
		Avg. Values	179.0	141.2	2.35
RI-2758	0.00281	486 to 1	186.5	134.6	2.10
RI-2759			184.7	135.1	1.56
RI-2777		Last anneal	187.4	141.9	1.98
RI-2778		0.062-inch	186.6	141.7	1.48
RI-2779		diameter	183.3	134.6	1.56
RI-2780			185.7	144.4	2.30
RI-2781			185.6	139.0	1.97
RI-2782			180.3	140.0	1.25
RI-2783			184.7	141.2	1.69
		Avg. Values	185.0	139.2	1.77
RI-3079	0.002164	820 to 1	178.4	138.7	0.88
RI-3080			157.7	140.0	0.37
RI-3081		Last anneal	173.2	144.6	0.72
RI-3082		0.062-inch	184.1	140.3	1.17
RI-3083		diameter	177.3	142.7	0.82
RI-3084			182.2	143.3	1.06
RI-3085			189.0	137.6	1.62
RI-3086			174.0	135.9	0.89
RI-3087			172.2	121.3	1.00
RI-3088			167.9	142.7	0.54
RI-3089			186.2	144.1	1.52
RI-3090			179.4	134.6	1.06
		Avg. Values	176.8	138.8	0.97

TABLE V (Continued)

SOME MECHANICAL PROPERTIES OF BERYLLIUM ULTRAFINE WIRE (2-6295) Run at 700°F With Standard Lubricant (See Runs 1 and 3 - Table III)

Specimen No.	Drawn Diameter[a] (inch)	Reduction Ratio From Last Anneal	Tensile (Room Temperature) Ultimate[b] (x 10^3 psi)	Yield[c] (x 10^3 psi)	Elong.[d] (%)
RI-2858	0.001578	1540 to 1	200.4	167.2	0.57
RI-2859			189.2	166.7	0.42
RI-2860		Last anneal	171.8	169.2	0.21
RI-2861		0.062-inch	169.8	166.2	0.23
RI-2864		diameter	190.2	164.6	0.46
RI-2865			202.0	186.1	0.50
RI-2867			166.7	144.2	0.38
RI-2868			138.1	122.7	0.48
RI-2869			199.4	160.6	0.70
RI-2870			165.2	161.1	0.22
		Avg. Values	179.3	160.9	0.42
RI-2994	0.00477	No Ratio	99.8	62.3	12.07
RI-2995			85.1	63.5	4.80
RI-2996		1450°F Anneal	96.8	66.4	8.88
RI-2997		1 Hour Hold	75.5	61.6	2.97
RI-2998			99.4	64.8	12.34
RI-2999			84.2	62.5	4.70
RI-3000			85.4	61.8	6.00
RI-3001			98.6	64.6	10.35
RI-3002			89.0	63.4	6.06
RI-3003			81.7	60.9	4.45
RI-3004			91.8	64.4	6.30
		Avg. Values	89.8	63.3	7.46
RI-3265	0.002967	2.59 to 1	145.1	124.4	0.60
RI-3266			173.3	133.1	1.87
RI-3267		Last anneal	170.2	120.9	2.46
RI-3268		0.00477-inch	171.4	137.0	1.43
RI-3269		diameter	162.0	126.4	0.87
RI-3270			165.2	139.7	0.96
RI-3271			163.7	141.7	1.42
RI-3272			163.9	126.8	2.88
		Avg. Values	164.4	131.3	1.54

TABLE V (Continued)

SOME MECHANICAL PROPERTIES OF BERYLLIUM ULTRAFINE WIRE (2-6295) Run at 700°F With Standard Lubricant (See Runs 1 and 3 - Table III)

Specimen No.	Drawn Diameter[a] (inch)	Reduction Ratio From Last Anneal	Tensile (Room Temperature)		
			Ultimate[b] (x 10³ psi)	Yield[c] (x 10³ psi)	Elong.[d] (%)
RI-3005	0.00477	No Ratio	89.5	64.4	5.08
RI-3006			100.6	64.2	8.85
RI-3007		1700°F Anneal	97.7	66.8	6.85
RI-3008		1 Hour Hold	85.7	66.3	3.54
RI-3009			97.8	65.2	8.34
RI-3010			93.1	64.5	5.78
RI-3011			91.6	63.0	5.83
RI-3012			91.0	65.8	4.98
RI-3014			97.4	63.8	9.13
RI-3015			88.6	63.3	4.68
		Avg. Values	93.3	64.7	6.30
RI-3352	0.00429	1.22 to 1	121.8	107.2	0.90
RI-3353			121.4	101.7	1.23
RI-3354		Last anneal	117.3	99.6	1.24
RI-3355		0.00477-inch	108.4	99.1	0.55
RI-3356		diameter	116.2	105.2	0.55
RI-3357			106.5	98.1	0.55
RI-3358			120.4	98.9	2.11
RI-3359			127.4	103.8	2.10
RI-3360			106.2	92.4	1.06
RI-3361			106.7	96.9	0.70
RI-3362			112.5	98.6	0.80
		Avg. Values	114.7	100.1	1.07

[a]The drawn diameter value was considered equal to the specified die diameter and was used in the calculations of the tensile, ultimate, and yield strength values.

[b]Ultimate strength is computed by dividing the maximum load by the area corresponding to the "specified die diameter".

[c]Yield strength is computed by dividing the yield load (at 0.2% offset) by the area corresponding to the "specified die diameter".

[d]Elongation was graphically measured on the load-deformation curve.

TABLE VI

SOME MECHANICAL PROPERTIES OF BERYLLIUM ULTRAFINE WIRE (2-6295) Run at 800°F With Modified Dag 206 (See Run 14 - Table III)

Specimen No.	Drawn Diameter[a] (inch)	Reduction Ratio From Last Anneal	Tensile (Room Temperature) Ultimate[b] (x 10^3 psi)	Yield[c] (x 10^3 psi)	Elong.[d] (%)
RI-3273	0.00588	111 to 1	168.8	130.4	1.12
RI-3274			178.6	140.7	2.10
RI-3275		Last Anneal	155.0	132.6	0.66
RI-3276		0.062-inch	171.7	137.2	1.08
RI-3277		diameter	179.5	131.8	2.73
RI-3278			175.1	138.6	1.35
RI-3279			179.3	137.4	2.40
RI-3280			180.0	135.8	2.97
RI-3281			174.9	131.8	1.50
RI-3282			168.7	136.3	0.90
		Avg. Values	173.2	135.3	1.68
RI-3224	0.00303	418 to 1	161.7	135.9	0.90
RI-3225			148.4	126.2	0.78
RI-3226		Last Anneal	157.5	137.6	0.67
RI-3227		0.062-inch	184.4	139.5	3.78
RI-3228		diameter	164.5	140.6	1.02
RI-3229			182.0	140.6	1.44
RI-3230			183.1	139.1	2.38
RI-3231			184.2	145.9	1.98
RI-3232			167.3	138.1	1.40
RI-3233			182.3	138.1	2.50
RI-3234			182.6	137.0	1.98
		Avg. Values	172.5	138.1	1.71
RI-3235	0.002164	820 to 1	177.5	138.7	1.33
RI-3236			178.8	139.8	1.76
RI-3237		Last Anneal	174.0	137.6	1.20
RI-3238		0.062-inch	179.4	139.8	1.73
RI-3239		diameter	178.9	142.2	1.35
RI-3240			174.6	129.7	1.22
RI-3241			178.6	145.5	1.20
RI-3242			177.8	137.8	1.20
RI-3243			178.9	142.5	1.29
RI-3244			175.6	144.1	1.00
RI-3245			179.7	137.3	2.04
RI-3246			180.3	140.8	2.28
		Avg. Values	177.4	139.7	1.47

TABLE VI (Continued)

SOME MECHANICAL PROPERTIES OF BERYLLIUM ULTRAFINE WIRE (2-6295) Run at 800°F With Modified Dag 206 (See Run 14 - Table III)

Specimen No.	Drawn Diameter[a] (inch)	Reduction Ratio From Last Anneal	Tensile (Room Temperature) Ultimate[b] ($\times 10^3$ psi)	Yield[c] ($\times 10^3$ psi)	Elong.[d] (%)
RI-3254	0.001848	1120 to 1	202.8	154.0	1.13
RI-3255			205.1	153.6	1.43
RI-3256		Last Anneal	205.1	152.9	1.60
RI-3257		0.062-inch	205.8	154.0	1.69
RI-3258		diameter	204.3	152.1	1.12
RI-3259			205.4	152.1	1.40
RI-3260			205.8	152.9	1.60
RI-3261			202.8	152.5	1.09
RI-3262			205.8	152.1	1.30
RI-3263			203.6	157.7	1.15
RI-3264			190.1	155.1	0.66
		Avg. Values	203.3	153.5	1.29
RI-3325	0.001753	1250 to 1	183.5	138.4	1.74
RI-3327			182.7	142.9	1.26
RI-3328		Last Anneal	179.0	139.6	0.92
RI-3329		0.062-inch	174.8	143.4	0.76
RI-3330		diameter	167.8	140.9	0.58
RI-3331			181.5	143.4	1.26
RI-3332			173.2	143.4	0.67
RI-3333			180.6	131.8	1.23
RI-3334			160.8	140.9	0.40
RI-3335			183.5	136.7	1.67
RI-3336			179.0	143.8	0.90
		Avg. Values	176.9	140.5	1.03
RI-3314	0.001663	1440 to 1	161.1	139.5	0.50
RI-3315			138.0	e	0.18
RI-3316		Last Anneal	174.5	125.7	1.03
RI-3317		0.062-inch	133.5	111.9	0.35
RI-3318		diameter	138.1	e	0.15
RI-3319			173.6	142.7	0.76
RI-3320			170.3	142.7	0.60
RI-3321			135.8	e	0.18
RI-3323			180.9	149.6	0.91
RI-3324			172.6	142.7	0.59
		Avg. Values	157.9		0.53

TABLE VI (Continued)

SOME MECHANICAL PROPERTIES OF BERYLLIUM ULTRAFINE WIRE (2-6295) Run at 800°F With Modified Dag 206 (See Run 14 - Table III)

Specimen No.	Drawn Diameter[a] (inch)	Reduction Ratio From Last Anneal	Tensile (Room Temperature) Ultimate[b] ($x\ 10^3$ psi)	Yield[c] ($x\ 10^3$ psi)	Elong.[d] (%)
RI-3301	0.001497	1720 to 1	132.4	e	0.12
RI-3302			160.8	134.7	0.72
RI-3303		Last Anneal	106.2	e	0.15
RI-3304		0.062-inch	111.9	e	0.10
RI-3306		diameter	120.4	e	0.11
RI-3307			129.5	e	0.18
RI-3308			133.5	e	0.17
RI-3309			159.1	136.4	0.73
RI-3310			151.7	137.5	0.39
RI-3311			149.4	117.6	0.65
RI-3312			143.2	138.1	0.23
		Avg. Values	136.9		0.32

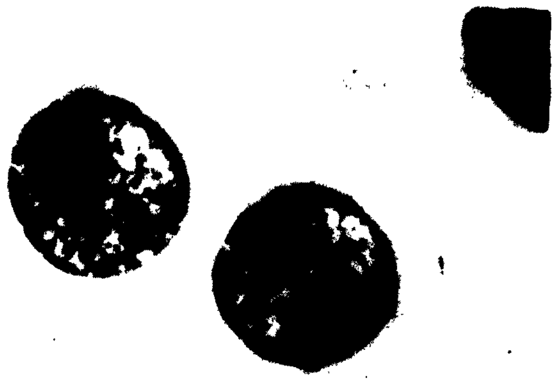
[a]The drawn diameter value was considered equal to the specified die diameter and was used in the calculations of the tensile, ultimate, and yield strength values.

[b]Ultimate strength is computed by dividing the maximum load by the area corresponding to the "specified die diameter".

[c]Yield strength is computed by dividing the yield load (at 0.2% offset) by the area corresponding to the "specified die diameter".

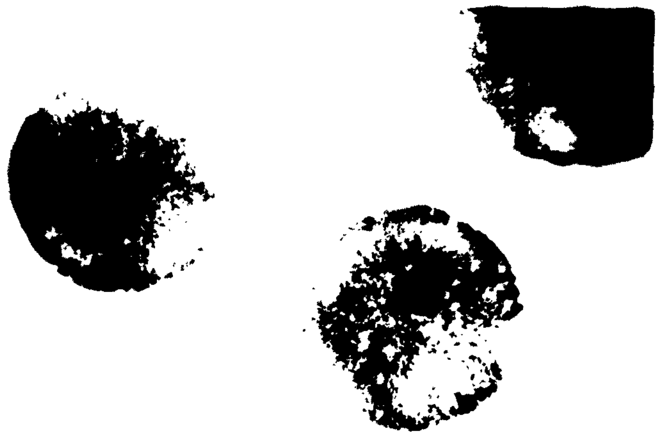
[d]Elongation was graphically measured on the load-deformation curve.

[e]Did not reach 0.2% offset for yield determination.

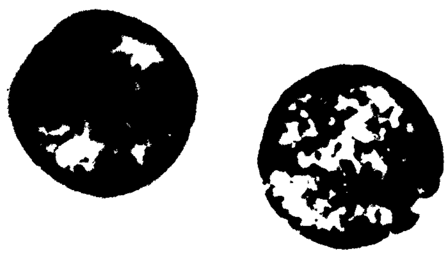


a. 0.00477 inch dia. 1450°F anneal
Lot 8842

b. 0.002164 inch dia. as-drawn from
1450°F annealed 0.0047 inch dia.
Lot 8842



c. 0.00588 inch dia. as-drawn from
0.062 inch dia. Lot 6295



d. 0.00477 inch dia. 1700°F anneal
Lot 8842

e. 0.003663 inch dia. as-drawn from
1700°F annealed 0.00477 inch dia.
Lot 8842

Fig. 2 - Transverse Beryllium Wire
Polarized Light, Magnification 250X

IV. DISCUSSION OF RESULTS

The clad drawing process using mild steel as a clad material was found to be unacceptable for producing ultrafine beryllium wire. From the results of the drawing trials several serious problems appeared and are listed below.

1. The inability to draw "hard" beryllium wire with a mild steel clad.

2. The limited amount of reduction that can be induced in the clad assembly between anneals.

3. Annealing the clad assembly properly so that further drawing may be performed.

4. Obtaining another clad material that will more nearly approach the drawing characteristics of beryllium and is easily removable in acid baths that are passive to beryllium metal.

Of these four major problems, it was felt that the most important are numbers three and four. The solution to problems one and two would probably hinge on the solution of problem number four. However, a substantial amount of time and effort would be required to discover and obtain the best clad material and develop special annealing practices that would react equally on the two different materials involved. It was felt that the scope of both of these problems was not within the range of this program.

The second alternate, conventional warm drawing, proved much more successful. Using this established technique[2] with a change in the lubricating operation, wire sizes down to 0.001848-inch diameter were obtained in relatively long lengths. Drawing difficulties were found to increase under the 0.001848-inch diameter size. However, four different lengths over 25 feet long were fabricated in the 0.001578 and 0.001497-inch size range.

The drawing difficulties encountered during this work were from three sources; die size variance, lubrication breakdown on wire sizes under 0.002-inch diameter, and apparent change of the strength and ductility characteristics of the wire from both material lots as the wire approached its minimum drawn diameter.

Figs. 3, 4, and 5 show the change in mechanical properties with the drawn diameter of wire from Lot No. 2-8842 for the three processes used. The plotted values are taken from the calculated average values listed in Table IV. It is interesting to note that as the minimum drawn diameter of the "hard" wire is approached, the values of the ultimate, yield, and elongation are at a minimum. Comparing the ultimate and yield curves of Figs. 3

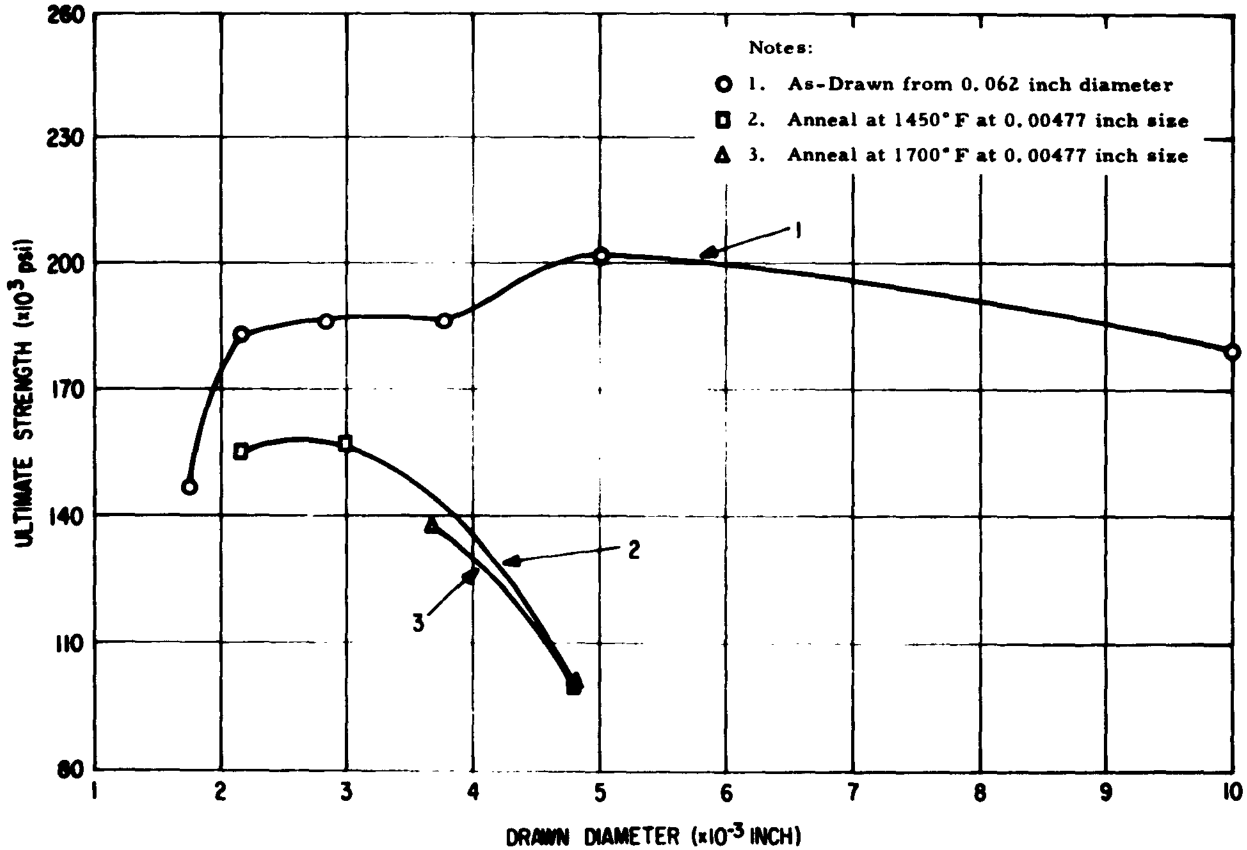


Fig. 3 - The Change in Ultimate Strength With Drawn Diameter For Lot No. 2-8842

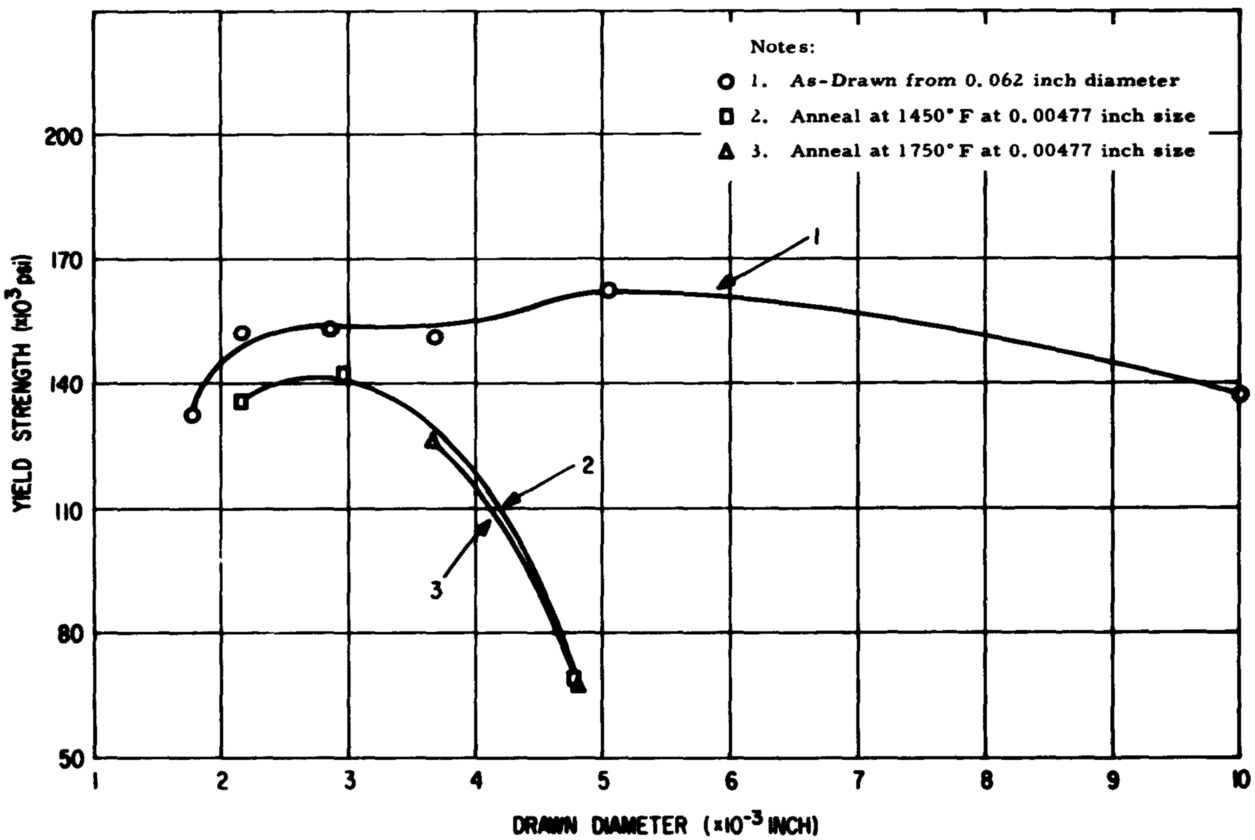


Fig. 4 - The Change in Yield Strength With Drawn Diameter For Lot No. 2-8842

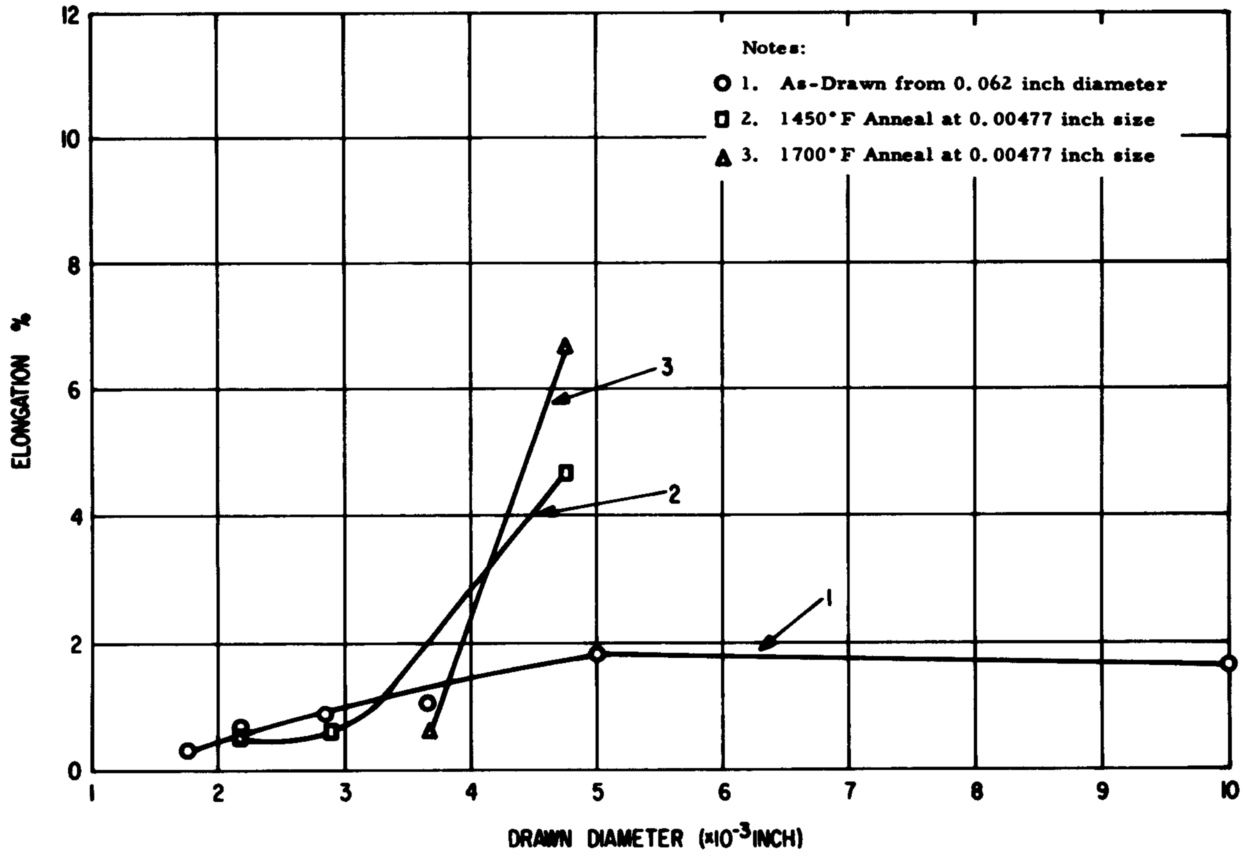


Fig. 5 - The Change in Elongation With Drawn Diameter For Lot No. 2-8842

and 4 of the "hard"drawn wire, a sudden decrease in the difference of the values is noted under 0.002-inch diameter.

Figs. 6, 7, and 8 show the trends of the average mechanical properties of Lot 6295 from Table V and VI. A sharp decline in strength and ductility is again noted.

Little difference is noted in the strength characteristics of the wires drawn at two temperature levels (700°F and 800°F) down to 0.002164-inch diameter. Ductility values from both wires (Fig. 8) indicated the same decreasing trend as their minimum drawn (0.001578-inch) diameter is approached.

The draw results of all the heat-treated wires were disappointing. This condition was thought to be partly due to excessive surface injury during the controlled pickling operations preceding annnealing. The strength levels of the drawn wire having a 1450°F anneal, seem to reach a peak before an overall reduction of 5:1 is obtained. Elongation of wire from both anneals decrease rapidly and approach lower values than those obtained from the "as-drawn" wire. Since the ductility characteristics and strength levels of the heat-treated wires were lower than the values of the "as-drawn" wire, the drawing performance of the heat-treated wire could not be expected to approach that of the "as-drawn" wire. Because of this experience, further drawing work of annealed wire at 0.005 inches in diameter was abandoned.

It is thought that the decreasing trend of the strength and ductility values of "as-drawn" wire from both material lots below 0.001848-inch diameter, could well be associated with the relatively rough surface condition that exists on products made with solid film lubricants. Since the surface to unit volume ratio of wire increases as the diameter decreases, the surface, its condition, and resulting frictional forces; become increasingly more important to the success or failure of the draw pass. It is felt that the slight lubrication breakdown that was observed in the small die sizes would have increased surface roughness and frictional forces causing a higher rate of tensile failures during the draw pass. During this program, the 0.001753-inch diameter die, giving the wire a surface to unit volume ratio of 2250 to 1, was the size where a definite increase in rate of failures was noted. This can also be seen by observing the drastic decrease of obtainable drawn lengths and their diameter sizes mentioned earlier.

However, since one wire was drawn through a 0.00115-inch diameter die for a length of 2 feet, it is strongly felt that with improved lubrication longer lengths of wire should be obtainable well below the diameters produced during this work.

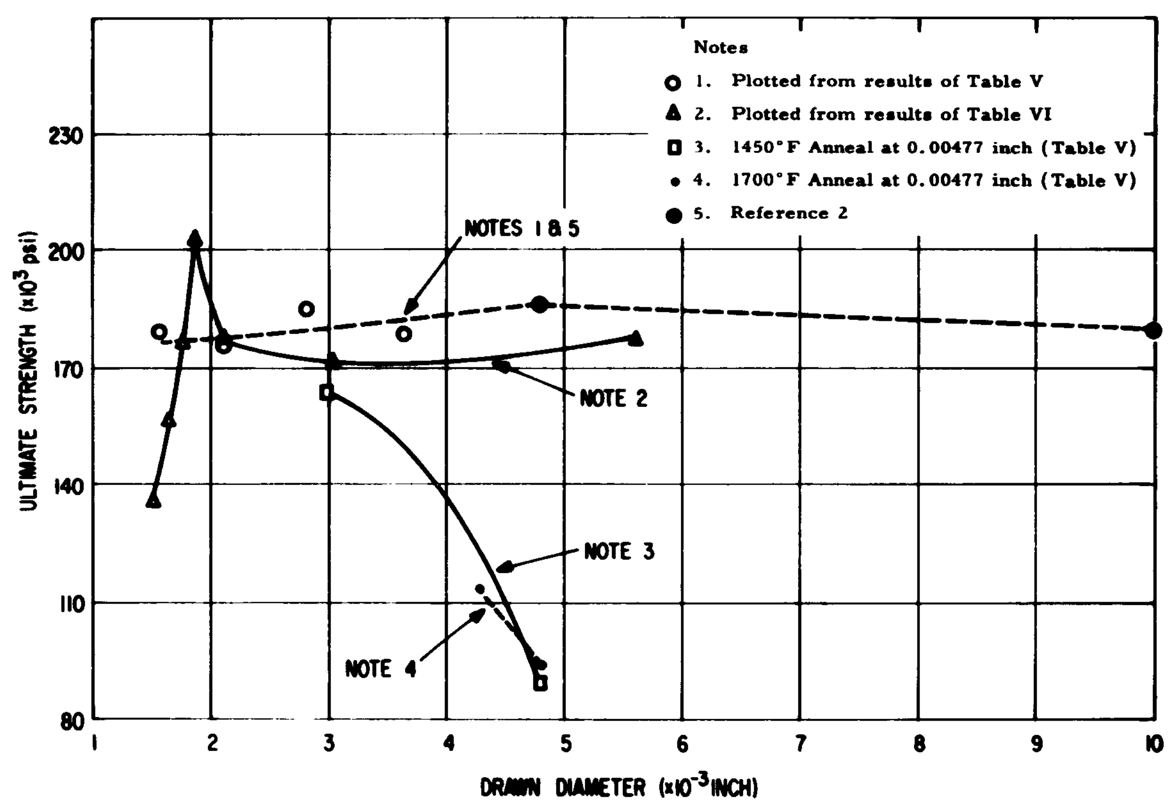


Fig. 6 - The Change in Ultimate Strength With Drawn Diameter for Lot No. 2-6295

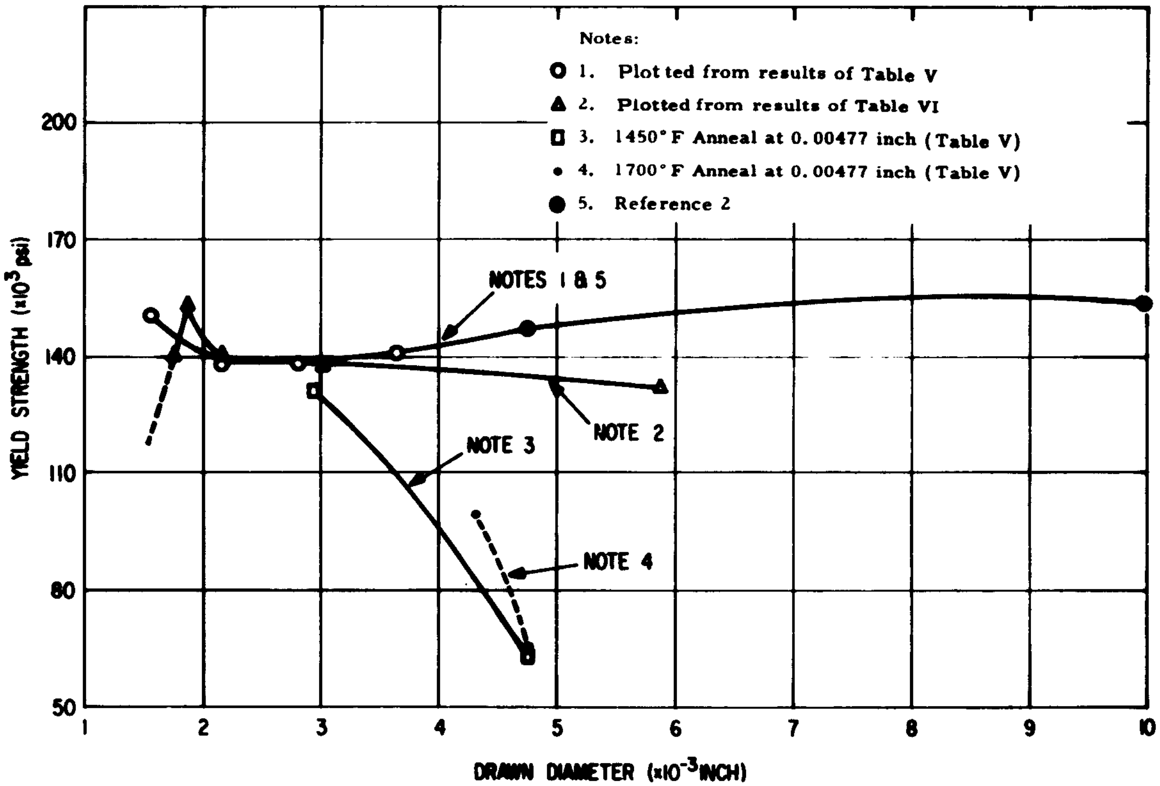


Fig. 7 - The Change in Yield Strength With Drawn Diameter for Lot No. 6295

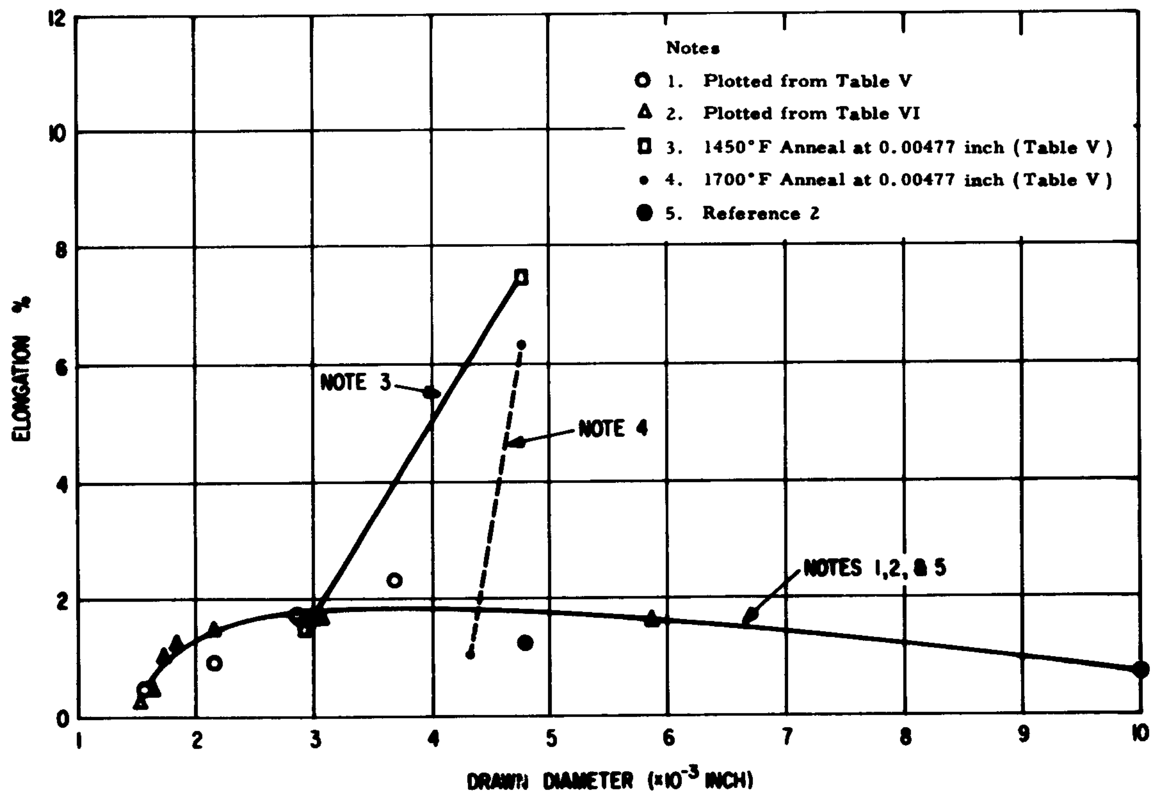


Fig. 8 - The Change in Elongation With Drawn Diameter for Lot No. 2-6295

V. CONCLUSIONS AND RECOMMENDATIONS

1. The clad draw process is unacceptable for producing ultrafine beryllium wire.

2. Using the conventional warm drawing technique and the lubrication procedure described herein, 100 to 200 foot lengths of 0.001848-inch diameter, and short lengths (25 to 50 feet) of 0.001578 to 0.001497-inch diameter can be produced. The following beryllium wire coils were shipped to complete the contract requirements.

   25 feet of 0.001497-inch diameter (Run 14)
   25 feet of 0.001578-inch diameter (Run 14)
   35 feet of 0.001578-9nch diameter (Run 14b)
   30 feet of 0.001578-inch diameter (Run 15)
   71 feet of 0.001848-inch diameter (Run 9)

3. The wire produced during this work showed a definite decrease in strength and ductility levels between the 0.001848 and 0.001497-inch diameters.

4. Operating temperatures of 700°F and 800°F showed little effect on the mechanical properties of Lot 6295.

5. Ultrafine wire produced by conventional warm draw techniques exhibits usable structural tensile properties at room temperature for diameters of 0.001848 and larger.

6. Future work should consider further investigation on such parameters as:

   (a) Effect of an improved lubricant on drawability below 0.002-inch diameter.

   (b) Effect of improved surface condition on drawability below 0.002-inch diameter.

VI. REFERENCES

1. A. G. Gross, Jr., R. G. O'Rourke, and W. W. Beaver, "Fabrication of Beryllium Wire" - Final Report for Navy - Contract NOas-59-6030-c, November 28, 1959.

2. A. G. Gross, Jr., R. G. O'Rourke, and W. W. Beaver, "Fabrication of Beryllium Fine Wire" - Final Report for Navy - Contract NOas-60-6108-c, April, 1961.

3. A. G. Gross, Jr., R. G. O'Rourke, "Development of Fine Diameter High-Purity Wire From Zone-Refined Beryllium" - Final Report for Navy - Contract NOw-62-0067-c, December, 1962