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EXTRUSION OF 1/2- AND 3/8-INCH-DIAMETER THIN-WALL TUNGSTEN TUBING IN LENGTHS NEAR 10 FEET

by Charles P. Blankenship and Charles A. Gyorgak

Lewis Research Center

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ABSTRACT

Thin-wall tungsten tubing was extruded in lengths of 7.5 to 10.6 feet (2.3 to 3.2 m) using the floating mandrel technique. Tubing diameters were either 1/2 or 3/8 inch (1.27 or 0.95 cm), and nominal wall thicknesses were 0.020 inch (0.05 cm). In most of the tubes, variations in diameter and wall thickness over a length of 8 to 10 feet (2.5 to 3 m) were less than 0.020 and 0.008 inch (0.05 and 0.02 cm), respectively. Feasibility of warm drawing (1300° F or 700° C) the extruded tubing was demonstrated. Drawing greatly improved tubing surface finish and dimensional tolerances.

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SUMMARY

Small diameter, thin-wall tungsten tubing was extruded in lengths ranging from 7.5 to 10.6 feet (2.3 to 3.2 m) using the floating mandrel technique. Tubing diameters were either 1/2 or 3/8 inch (1.27 or 0.95 cm), and nominal wall thicknesses were 0.020 inch (0.05 cm). Extrusion temperatures ranged from 3500° to 4050° F (1925° to 2230° C), and reduction ratios were varied from 20 to 26.

Dimensional variations were greater than those recorded in an earlier study with shorter lengths of tubing. In addition, the longer tubes were tapered approximately 0.001 to 0.002 inch per foot (0.01 to 0.02 cm/m). The taper resulted from the mandrel taper and from die wear. Dimensional variations over a length of 8 to 10 feet (2.5 to 3 m) were less than 0.020 inch (0.05 cm) on the diameter and 0.008 inch (0.02 cm) on the wall thickness.

The best surface finishes (about 100 μin. or 250 μcm) were obtained at the lower extrusion temperatures. From grain size and microhardness measurements, microstructural uniformity was indicated over the full lengths of the tubing.

Feasibility of reducing the extruded tubing by warm drawing (1300° F or 700° C) was demonstrated. For example, 3/8-inch- (0.95-cm-) diameter tubing was reduced approximately 66 percent to a diameter of 1/4 inch (0.63 cm). Tube drawing greatly improved the outside diameter surface finish (from about 200 to 32 μin. or 500 to 81 μcm) but the surface finish of the inside diameter did not show as much improvement by the drawing procedure used. The diameter and wall thickness of the drawn tubing did not vary more than ±0.001 inch (±0.003 cm).

INTRODUCTION

In a previous study, we showed that small diameter (1/2 and 3/8 in. or 1.27 and

0. 95 cm), thin wall (0. 020 in. or 0. 05 cm), tungsten tubing could be extruded by the floating mandrel technique (ref. 1). In that study, tubing of excellent quality was obtained in lengths of 4 to 5 feet (1. 2 to 1. 5 m). Larger diameter (~3/4 in. or 1. 9 cm), thin-wall-tungsten tubing has been fabricated by others also using the floating mandrel technique (refs. 2 and 3). Another experimental method of making small diameter, wrought tungsten tubing is the filled billet technique used at other laboratories (refs. 2, 4, and 5). However, the length of tubing that can be produced by this method is limited because of the difficulty in removing the solid core material from long lengths of tubing.

The primary objective of the present study was to extend our previous work (ref. 1) to the extrusion of longer lengths of tubing using the floating mandrel technique. This was done by extruding 1/2- and 3/8-inch (1. 27- and 0. 95-cm) diameter, thin-wall tungsten tubing in lengths near 10 feet (3 m). Extrusion conditions were similar to those we used previously except that the reduction ratio was increased from about 18 to greater than 20. Extrusion temperatures ranged from 3500° to 4050° F (1930° to 2230° C). The extruded tubing was evaluated on the basis of surface finish, dimensional variations, and microstructural uniformity.

In addition, in order to demonstrate secondary processing, attempts were made to reduce the extruded tubing by plug drawing. This part of the program was conducted by the Fabrication Technology Group of the Argonne National Laboratory.

EXPERIMENTAL PROCEDURE

Billet Design and Preparation

The billet assembly for extrusion of tubing is shown in figure 1. Billet components, made by powder metallurgy techniques, were obtained from a commercial vendor. The billet materials were of metallurgical grade purity (>99. 9 percent), and component densities were 93 to 95 percent of theoretical. The billet can and core were held together by spot, fusion welding using tantalum pins as a filler (fig. 1). In addition to absorbing any minor surface irregularities associated with the extrusion process, the molybdenum canning material permits direct extrusion of thin-wall tubing at a reasonable reduction ratio compared to an uncanned billet.

Tungsten cylinder dimensions to yield 10-foot- (3-m-) long tubing were calculated assuming fully dense billet components and using a reduction ratio of 25. Cylinder dimensions for 1/2-inch (1. 27-cm) diameter, 0. 020-inch (0. 05-cm) wall tubing were 1. 545 inches (3. 93 cm) outside diameter, 1. 185 inches (3. 05 cm) inside diameter, and 5 inches (12. 7 cm) long. For 3/8-inch (0. 95-cm) diameter, 0. 020-inch- (0. 05-cm-) wall tubing, the corresponding dimensions were 1. 160 inches (2. 95 cm), 0. 800 inch

(2.03 cm), and 5 inches (12.7 cm). Eight extrusion billets were included in this study.

Extrusion Tooling and Procedure

The billets were extruded in a 1020-ton- (9-MN-) vertical-extrusion press equipped with 2-inch- (5-cm-) diameter tooling. Press operation, tooling design, and accessories for extrusion at the relatively high temperatures used in this study are described in reference 6. Figure 2 shows the tooling arrangement for extrusion of tungsten tubing over a mandrel. The mandrels were made of AISI, M-2 tool steel and were coated with zirconia (~0.015 in. or 0.038 cm thick) for thermal protection. After coating, the mandrel diameters were 0.4 inch (1.03 cm) and 0.3 inch (0.76 cm) for extrusion of 1/2-inch- (1.27-cm-) and 3/8-inch- (0.95-cm-) diameter tubing, respectively. The mandrels were tapered 0.002 inch per inch (0.002 cm/cm) over a length of 7.5 inches (19 cm).

The billets were heated by induction to the desired extrusion temperature in a flowing hydrogen atmosphere. Billet temperatures were measured by sighting on a blackbody hole in the top of the billet with an optical pyrometer calibrated to the furnace. Reported extrusion temperatures (billet preheat temperatures) are estimated to be within $\pm 25^{\circ}$ F ($\pm 14^{\circ}$ C). Total time for billet transfer to the press and completion of the extrusion was about 5 seconds. Lubrication consisted of a tungsten disulfide coating on the mandrels and glass cloth (Owens-Corning 173-864 glass cloth) impregnated with tungsten disulfide in the extrusion liner. The billets were not extruded completely to prevent possible damage to the tubing. After extrusion, the molybdenum canning material was removed chemically in a dilute nitric-acid solution. Additional details of the tubing extrusion procedure are outlined in reference 1.

Tubing Evaluation

The extruded tubing was examined for uniformity in dimensions, microhardness, and grain size. The outside diameter was measured at 12-inch intervals over the entire length of the extrusions. Wall thickness measurements were taken from the nose and tail of the extrusions and from sections removed for tube drawing and metallographic studies. Diamond pyramid hardness data (1-kg load) were obtained from metallographic samples taken mostly from the nose and tail sections of the tubing. An average hardness value was obtained from at least three measurements per sample. The grain size of similar samples was determined by a circle intercept method. A profilometer and standard reference blocks were used to measure and estimate the surface finish of the extruded tubing.

Tube Drawing

The objective of the tube drawing experiments was to demonstrate secondary processing of the extruded tubing for final sizing, elimination of minor surface irregularities, and improved dimensional tolerances. No effort was made to optimize drawing parameters or to draw long lengths.

Tube drawing experiments were conducted by the Fabrication Technology Group of Argonne National Laboratory using the procedure described in reference 5. Attempts were made to plug-draw the tubing at temperatures near 1300° F (700° C). Tube pointing was done at 1830° F (1000° C) by swaging.

RESULTS AND DISCUSSION

Extrusion of Tubing

The tubing extrusion data are summarized in table I. Extrusion pressures are the maximum recorded and are given in percent of maximum pressure used for 2-inch- (5-cm-) diameter tooling (200 000 psi or 1380 MN/m^2).

Billet lubrication appeared to be adequate in all of the extrusions, and, in general, the extruded surface finishes were better than those obtained in the previous study. Only in two of the extrusions did the die wear exceed 0.010 inch (0.03 cm). This was considered excellent in view of the relatively high reductions and working temperatures. The mandrels remained intact during all of the normal extrusion trails. Even a 0.3-inch- (0.76-cm-) diameter mandrel performed satisfactorily at an extrusion temperature of 3600° F (1980° C). A similar size mandrel failed in the previous study at an extrusion temperature of 3500° F (1930° C) and at maximum extrusion pressure. Other than the temperature difference, perhaps the thinner zirconia coating used on the mandrels in this study was a factor since the mandrel load supporting area was about 18 percent greater.

As noted in table I, the reduction ratio was varied from about 20 to 26. This was accomplished by changing the size of the die orifice in order to obtain longer lengths of tubing. In addition to changes in reduction ratio, variations in butt length also affected the total length of extruded tubing.

Evaluation of Extruded Tubing

All the tubes extruded successfully were fully dense, integrally sound, and fairly uniform in size. The extruded tubes, after removal of the molybdenum canning material, are shown in figure 3. As shown, the tubes are fairly straight with only minor bowing at the ends of two tubes removed from the catcher device immediately after extrusion. Surface finish, dimensional variations, and microstructural uniformity of the extruded tubing are discussed in the following sections. Tube W2-17 was not included in the evaluation studies.

Surface finish. - As found previously, surfaces of the extruded tubes were striated parallel to the extrusion direction. The striations were moderate to excessive depending upon the extrusion temperature. Tubing extruded at temperatures near 4000° F (2200° C) exhibited average root-mean-square (rms) finishes of about 200 to 300 microinches (500 to 760 μcm). Average root-mean-square finishes for tubing extruded at the lower temperatures were about 100 to 130 microinches (250 to 330 μcm). These results are in general agreement with those of our previous work and indicate more compatible flow at the molybdenum-tungsten interface at temperatures near 3500° F (1925° C) and lower. The effect of extrusion temperature on surface finish is illustrated in figure 4.

In addition to the striations, some of the tubes exhibited rippled areas. However, the ripples were hardly noticeable in all but two of the extruded tubes. These tubes (W2-16 and W3-7) had a few rippled areas in which the wall thickness was nearly half that of the uniform sections. The ripples did not extend over one-third of the tube circumference, and they were about 1/4 inch (0.6 cm) long. The ripples were at random locations along the tube lengths. In comparing rippled sections to the uniform areas of the tubing, no differences in grain size, microhardness, or density were observed. In our previous work, similar defects were associated with extrusion surface defects in the molybdenum canning material. However, the as-extruded surfaces in this study were much better and did not exhibit surface tears or other defects. Therefore, assuming streamline flow, the rippled areas probably resulted from low density areas in the sintered, billet components.

Dimensional variations. - Dimensional data for the extruded tubing are summarized in table II. In general, the variations in outside diameter and wall thickness are greater than those we reported previously for shorter lengths of extruded tubing (ref. 1). In addition, the longer tubes were tapered approximately 0.001 to 0.002 inch per foot (0.01 to 0.02 cm/m). The taper resulted from mandrel taper and from die wear. In most of the tubes, variations in diameter and wall thickness over a length of 8 to 10 feet (2.5 to 3 m) were less than 0.020 and 0.008 inch (0.05 and 0.02 cm), respectively. These variations are not considered to be excessive for the current state of development, and they can be improved by secondary processing as demonstrated in this study.

About 80 to 90 percent of the extruded material containing tungsten tubing was uniform and considered usable except for tubes W2-16 and W3-7. The usable lengths are listed in table II. In addition to areas not considered usable, the variations in length resulted from different reduction ratios and from the amount of billet extruded. Only one tube (W3-8) had a usable length greater than 10 feet (3 m). However, sufficient data are presented herein to demonstrate that tubing lengths of 10 feet (3 m) can be obtained by direct extrusion. If required, the reduction ratios can be increased (at 26 only 77 percent of the available extrusion pressure was required) or longer tungsten cylinders might be used in the extrusion billets.

Hardness and grain size. - The results of the grain size and microhardness tests are summarized in table III. Microstructural uniformity in the extruded tubes is evident from the relatively small variations in microhardness and grain size from nose to tail of the extruded tubes. The equiaxed grain structure was similar to that observed in our previous study with no evidence of porosity.

Tube Drawing

Successful tube drawing was accomplished by leaving the molybdenum canning material on the inside diameter of the tubing and using the following schedule:

Drawing temperature, ^{o}F (^{o}C)	1300^{o} (700^{o})
Die preheat temperature, ^{o}F (^{o}C)	930^{o} (500^{o})
Reduction per pass, percent	10

Two pieces of drawn tubing from extrusion W3-7 are shown in figure 5. The shorter length of tubing (~8 in. or 20 cm) (fig. 5(a)) was drawn from the 3/8-inch- (0.95-cm-) outside diameter to an outside diameter of 0.280 inch (0.71 cm). The wall thickness after removal of the molybdenum was 0.013 inch. Total reduction in area was about 58 percent. The longer piece of tubing (~14 in. or 36 cm) (fig. 5(b)) was reduced about 66 percent to a final outside diameter of 0.248 inch (0.63 cm) and a wall thickness of 0.011 inch (0.028 cm). Dimensional variations did not exceed ±0.001 inch (0.003 cm) on either tube diameter or wall thickness, and they are well within the recommended tolerances for refractory metal tubing (ref. 7).

Finishes of the outer surfaces of the as-drawn tubing were considered excellent (about 32 μin. or 81 μcm). The longer length of tubing shown in figure 5(b) was lightly belt-sanded to a finish of about 16 microinches (41 μcm). The inner surfaces of the drawn tubing still exhibited some striations, but these were markedly improved from the as-extruded condition (about 80 μin. or 200 μcm compared to about 200 μin. or 500 μcm for tube W3-7).

Improvement in the surface finish from extruded to drawn tubing can be noted by comparing figure 4(b) to the inset of figure 5(a). Some remnants of the original striated surface were still present on this drawn tubing; but after further reduction to a 0.248-inch (0.63-cm) diameter, the striations were hardly noticeable and could be removed easily by light belt-sanding.

Nondestructive testing (eddy current) of the drawn tubing indicated that defects, if present, were less than 10 percent of the wall thickness. Only a small area on one end of the longer tube in figure 5(b) gave indications of defects greater than 10 percent of the wall thickness. This was related to slightly deeper striations on the tube inner surface.

Attempts to draw the tubing without molybdenum on the inside diameter were unsuccessful. The outer surfaces were smooth, but the striations could not be removed from the inner surfaces and eventually led to cracking after only a few passes. Additional development efforts are required to improve the inner-surface finish of the tubing by plug-drawing.

SUMMARY OF RESULTS

In this study, attempts were made to extrude tungsten tubing in lengths near 10 feet (3 m). The results are summarized as follows:

1. Small-diameter, thin-wall-tungsten tubing was extruded in lengths ranging from 7.5 to 10.6 feet (2.3 to 3.2 m) using the floating mandrel technique. Nominal tubing diameters were either 1/2 or 3/8 inch (1.27 or 0.95 cm), and nominal wall thicknesses were 0.020 inch (0.05 cm). Extrusion temperatures ranged from 3500° to 4050° F (1925° to 2230° C), and reduction ratios were varied from 20 to 26.

2. Dimensional variations over a length of 8 to 10 feet (2.5 to 3 m) were less than 0.020 inch (0.05 cm) on the outside diameter and 0.008 inch (0.02 cm) on the wall thickness. Better surface finishes (about 100 μin. or 250 μcm) were obtained at the lower extrusion temperatures. From grain size and microhardness measurements, microstructural uniformity was indicated over the full lengths of the tubing.

3. Feasibility of reducing the extruded tubing by warm drawing (1300° F or 700° C) was demonstrated. Variations in diameter and wall thickness of the drawn tubing did not exceed ±0.001 inch (±0.003 cm). Tube drawing greatly improved the finish of the outer surface from about 200 microinches (500 μcm) to about 32 microinches (81 μcm). The finish of the inner surface (about 80 μin. or 200 μcm) did not show as much improvement by the drawing procedure used.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, April 25, 1968,
129-03-14-03-22.

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TABLE I. - TUNGSTEN TUBING EXTRUSION DATA

Billet	Nominal tubing diameter		Extrusion temperature		Reduction ratio[a]	Maximum extrusion pressure,[b] percent	Average ram speed		Extruded length		Die wear	
	in.	cm	^oF	^oC			in./sec	cm/sec	ft	m	in.	cm
W2-13	1/2	1.27	3500	1925	21	95	3.3	8.4	9.4	2.9	0.017	0.043
W2-16	↓	↓	4000	2200	23	80	7.5	19.0	9.7	3.0	.004	.012
W2-17	↓	↓	3600	1980	23	97	3.2	8.1	9.1	2.8	.008	.020
W3-6	3/8	0.95	4050	2230	20	66	7.7	19.5	9.5	2.9	.024	.061
W3-7	↓	↓	4050	2230	22	70	7.7	19.5	9.7	3.0	.010	.025
W3-8	↓	↓	4050	2230	26	77	6.7	17.0	11.8	3.6	.002	.005
W3-9	↓	↓	4050	2230	24	83	8.6	21.8	11.8	3.6	.007	.018
W3-10	↓	↓	3600	1980	25	94	6.7	17.0	10.5	3.2	.002	.005

[a]Calculated from original billet and average extruded tubing dimensions.
[b]Percent of maximum pressure available, 200 000 psi (1380 MN/m^2).

TABLE II. - DIMENSIONAL VARIATIONS OF EXTRUDED TUNGSTEN TUBING

Tube identity	Reduction ratio	Outside diameter				Wall thickness				Usable length	
		Nose		Tail		Nose		Tail			
		in.	cm	in.	cm	in.	cm	in.	cm	ft	m
W2-13	21	0.482/0.488	1.22/1.24	0.505/0.507	1.28/1.29	0.023/0.027	0.058/0.068	0.023/0.025	0.058/0.064	7.5	2.3
W2-16	23	0.488/0.492	1.24/1.25	0.498/0.506	1.27/1.28	0.019/0.022	0.048/0.056	0.022/0.025	0.056/0.064	[a]8.0	2.4
W3-6	20	0.358/0.359	0.91	0.373/0.377	0.95/0.96	0.023/0.027	0.058/0.068	0.024/0.029	0.061/0.074	8.0	2.4
W3-7	22	0.361/0.365	0.92/0.93	0.378/0.379	0.96	0.020/0.024	0.051/0.061	0.022/0.028	0.056/0.071	[a]8.0	2.4
W3-8	26	0.362/0.368	0.92/0.94	0.375/0.377	0.95/0.96	0.018/0.026	0.046/0.066	0.020/0.028	0.051/0.071	10.6	3.2
W3-9	24	0.348/0.353	0.88/0.90	0.358/0.363	0.91/0.92	0.018/0.021	0.046/0.053	0.023/0.026	0.058/0.066	8.2	2.5
W3-10	25	0.356/0.362	0.91/0.92	0.374/0.378	0.95/0.96	0.020/0.023	0.051/0.058	0.019/0.023	0.048/0.058	9.1	2.7

[a]Includes a few areas with severe ripple defects.

TABLE III. - GRAIN SIZE AND MICROHARDNESS OF EXTRUDED TUNGSTEN TUBING

Tube identity	Extrusion temperature		Sample location	Average grain diameter, mm	Diamond pyramid hardness, 1-kg load
	^{o}F	^{o}C			
W2-13	3500	1925	Nose Tail	0.015 .008	371 411
W2-16	4000	2200	Nose Tail	0.016 .014	372 372
W3-6	4050	2230	Nose Tail	0.021 .021	399 373
W3-7	4050	2230	Nose Tail	0.021 .016	379 386
W3-8	4050	2230	Nose Tail	0.020 .018	373 377
W3-9	4050	2230	Nose Tail	0.021 .018	363 383
W3-10	3600	1980	Nose Tail	0.011 .012	376 395

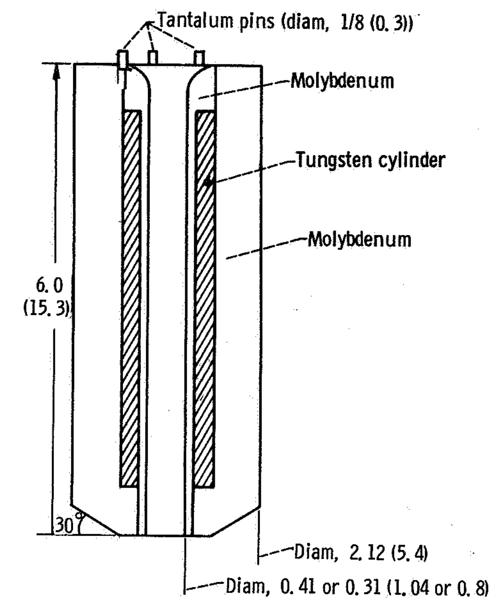


Figure 1. - Schematic of billet assembly for extrusion of tungsten tubing. (Dimensions are in inches (cm).)

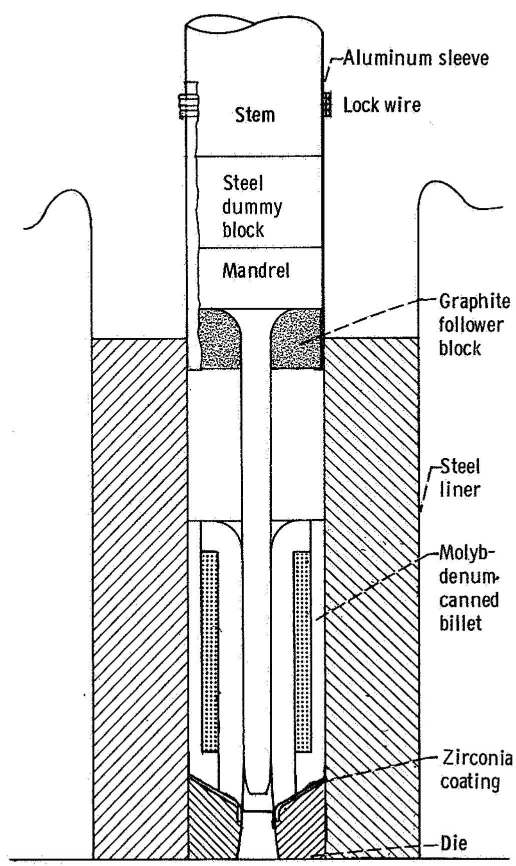


Figure 2. - Schematic of tooling arrangement for extruding tungsten tubing over a floating mandrel.

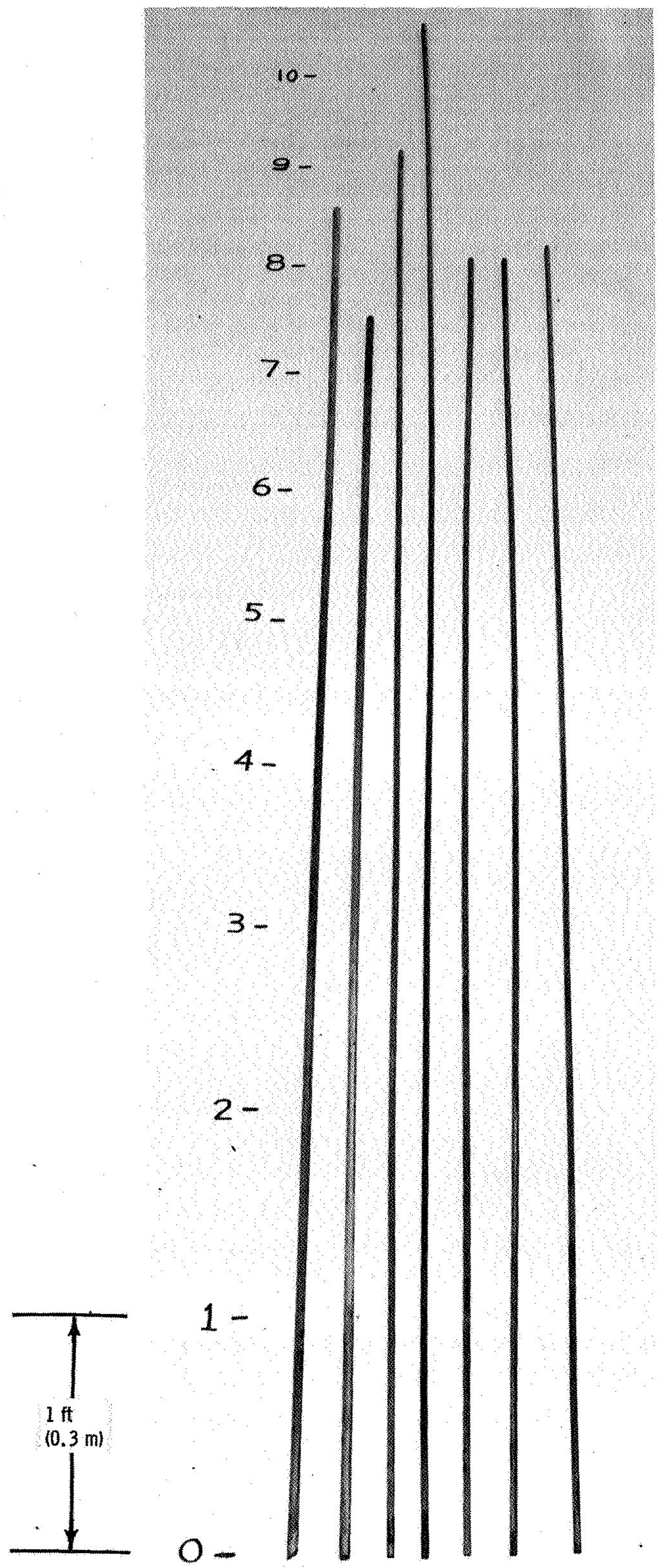
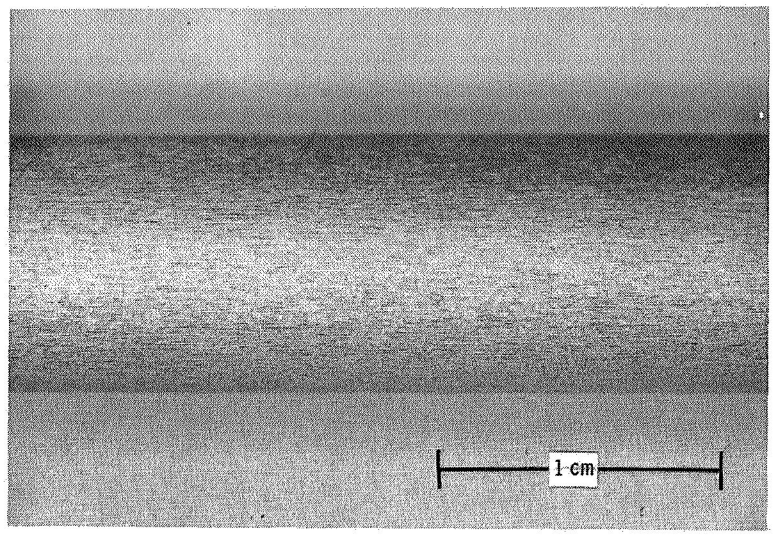
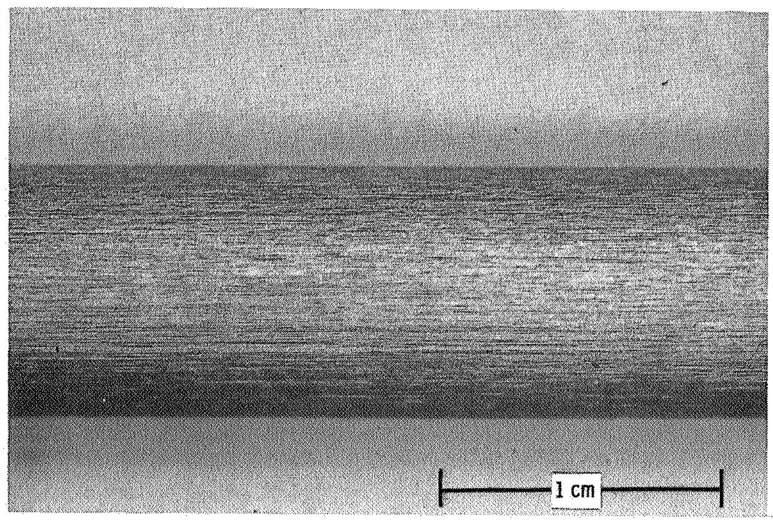


Figure 3. - Extruded tungsten tubing, 1/2- and 3/8-inch diameter (1.27 and 0.95 cm).



(a) Tube W3-10 extruded at 3600° F (1980). Surface finish, approximately 100 microinches (250 μcm); X3.7.



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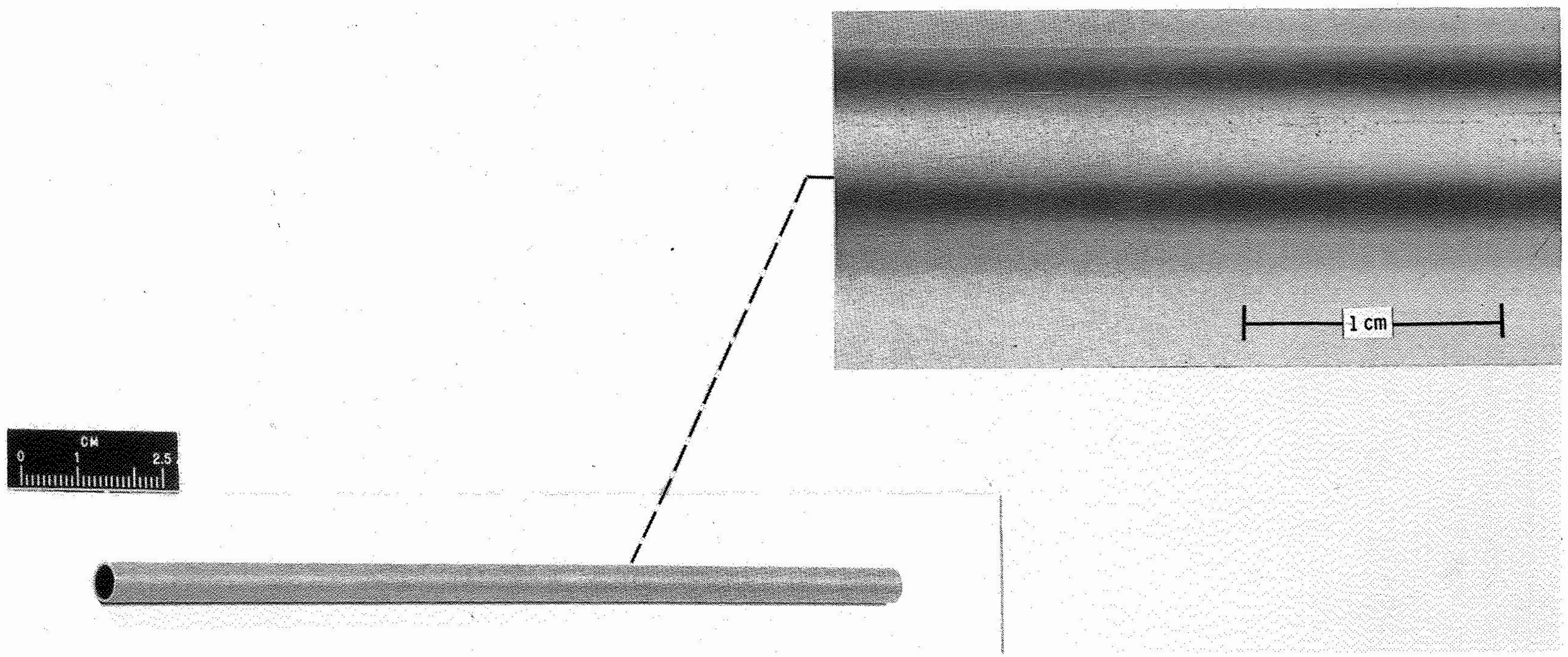
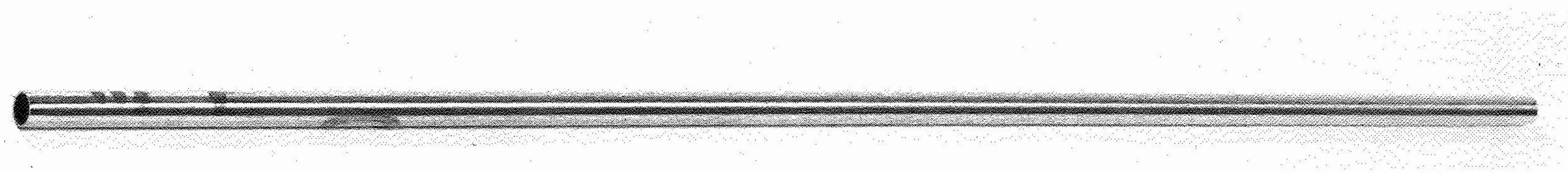
(b) Tube W3-7 extruded at 4050° F (2230° C). Surface finish, approximately 200 microinches (500 μcm); X3.7.

Figure 4. - Effect of extrusion temperature on surface finish of extruded tungsten tubing.



(a) Reduced 56 percent to diameter of 0.280 inch (0.71 cm); as drawn.



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(b) Reduced 66 percent to diameter of 0.248 inch (0.63 cm); lightly belt-sanded.

Figure 5. - Drawn tungsten tubing from W3-7 extruded at 4050° F (2230° C).

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