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FLOATING-MANDREL EXTRUSION OF TUNGSTEN AND TUNGSTEN-ALLOY TUBING

R. E. McDonald
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FEBRUARY 1968

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R. E. McDonald and G. A. Reimann

ABSTRACT

Tungsten and tungsten-alloy tubing were extruded successfully from arc-cast and powder-metallurgy billets by use of the floating-mandrel technique with naturally forming tungsten oxide as a lubricant. Extrusion temperatures ranged between 1650 and 2250°C, and extrusion ratios were in the range of 4 to 9. Satisfactory service was obtained from zirconia-protected dies and mandrels, but surface melting of the container sleeve began when billet temperatures exceeded 1850°C. Rapid extrusion speeds were necessary to minimize heat loss and reduce contact time with the tooling. Thin-walled tungsten tubing was produced with the floating-mandrel technique by reextruding a section of tube shell in a duplex billet.

INTRODUCTION

Tungsten-alloy tubing is of interest because the properties of tungsten-base alloys could satisfy the requirements for very high-temperature reactor applications. The tungsten-rhenium alloys are currently the center of attention because of their high-temperature strength and room-temperature ductility[1] after prolonged heating above their recrystallization temperature. However, the availability of high-quality thin-walled refractory-alloy tubing has been hampered by the lack of processing technology.

Although thin-walled tubing of unalloyed molybdenum has been available since about 1960, the starting blanks for this tubing were made by drilling out solid bar stock to obtain a tube shell suitable for subsequent drawbench reduction. Extruded tube shells of unalloyed molybdenum have been produced on a semicommercial basis since about 1963.

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[1]High-Temperature Materials Program Progr. Rept. May 28, 1965, GEMP-47A, p. 73.

Tungsten and tungsten-base alloys are much more difficult to fabricate than molybdenum and its alloys and have inherent strengths that call for higher processing temperatures than conventional practices can achieve. Extrusion is limited to relatively low reductions, press tooling must be protected from high-temperature billets, and extrusion operations must be rapid to conserve billet heat and minimize contact time with the tooling.

Our objective is to develop commercially adaptable processes and techniques for the production of large- and small-diameter, thin-walled tungsten tubing by extrusion and drawing techniques. This report will be confined to discussing the results of floating-mandrel extrusion.

PROCESS DESCRIPTION

The "filled-billet" technique has been employed as a primary extrusion step by Nuclear Metals, Inc.,[2] Argonne National Laboratory,[3] and General Electric Company.[4–6] A tubular section of tungsten is encapsulated in a molybdenum billet and coextruded, after which acid dissolution of the molybdenum yields the tungsten tube. Quantities of tungsten-alloy tubing have been extruded on a limited-production basis using the filled-billet technique. Oak Ridge National Laboratory has adapted the floating-mandrel technique to refractory-alloy extrusion, utilizing a billet of full cross section for the primary extrusion. This approach

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[2]J. G. Hunt *et al.*, *Development of a Fabrication Process for Seamless Tungsten Tubing, Summary Technical Report to the United States Atomic Energy Commission for the Period July 1, 1962, through June 30, 1963*, NMI-1260.

[3]W. R. Burt, Jr., *et al.*, *Annual Progr. Rept. for 1964, Metallurgy Division*, ANL-7000, pp. 138–142.

[4]*High-Temperature Materials Program Progr. Rept. Jan. 24, 1964*, GEMP-31A, p. 15.

[5]*High-Temperature Materials Program Progr. Rept. Nov. 30, 1964*, GEMP-41A, p. 35.

[6]*High-Temperature Materials Program Progr. Rept. July 28, 1965*, GEMP-49A, pp. 56–60.

has distinct advantages over the filled-billet technique, the most noteworthy being the elimination of jacketing and hence of the attendant waste of molybdenum. Other advantages are the elimination of the awkward step of core removal, a potential for higher output of usable tubing, lower billet machining cost, and more suitable geometry for effective utilization of arc-cast ingot sizes. The floating-mandrel technique has certain disadvantages. Since a billet of 100% tungsten alloy is more difficult to extrude than the filled billet containing 10 to 20% tungsten alloy, higher billet temperatures are necessary to keep pressures required for extrusion within press capacity, and higher temperatures shorten tooling life. Also, a minimum tubing inner diameter of about 3/4 in. is dictated by the ability of the mandrel to withstand the temperatures and stresses of extrusion.

The general scheme followed in producing tungsten-alloy tubing by the floating-mandrel technique is illustrated by a flowsheet shown in Fig. 1. For the primary extrusion, a billet measuring 3 in. in diameter and 5 in. in length is used. A central axial hole of the required size accommodates the mandrel. The billet is induction heated to the desired temperature in argon, inserted into the press, and extruded over the mandrel. Two fabrication routes are available, and the intended route establishes the extrusion ratio to be employed in the primary extrusion. If the tube shell is to be subsequently extruded as a duplex billet, a low ratio (≤ 5) is selected to yield a thick-walled tube shell that can be extruded to the desired wall thickness. If the tube shell is to be plug-and-mandrel drawn, a higher ratio (7 to 9) will be employed to produce a thinner wall and minimize the number of draws.

Extrusion of the duplex billet is a secondary operation, which yields a thin-wall tungsten tube sandwiched between two layers of molybdenum, a configuration less difficult to draw than a full cross section, as-extruded tube shell. The molybdenum cladding may be dissolved before the tube is plug-and-mandrel drawn, or for small-diameter tubing the molybdenum covering may be left intact to conserve heat and protect tungsten from oxidation until the approximate final size is achieved.

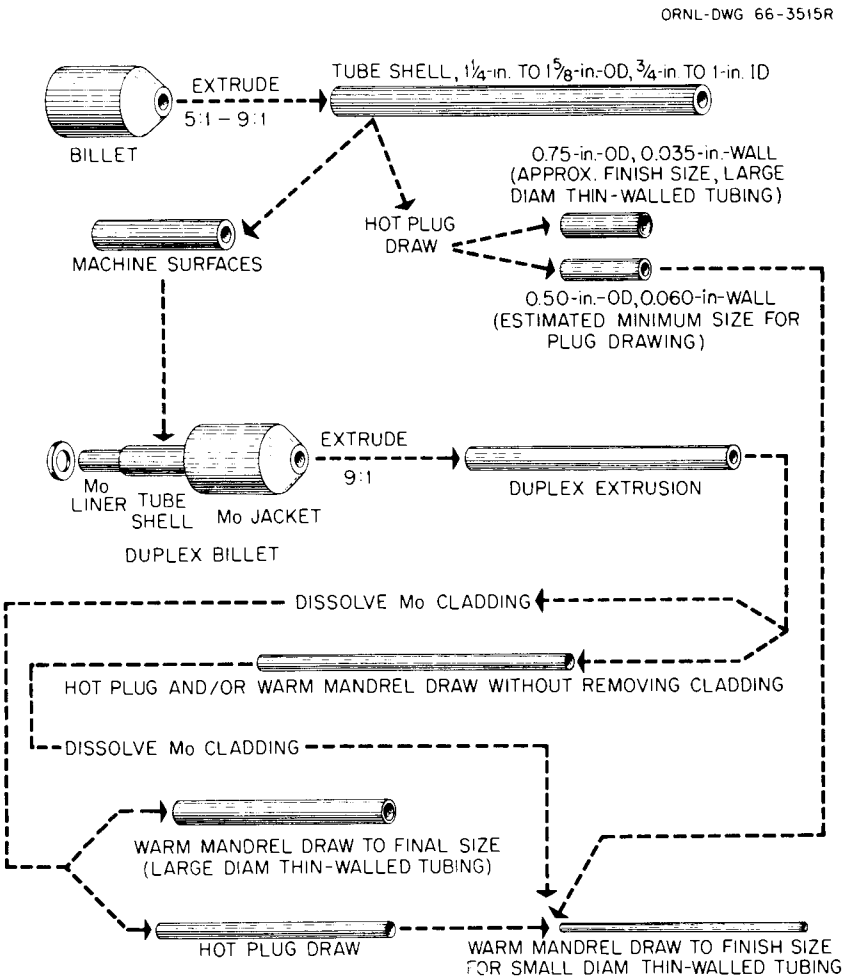

Fig. 1. General Process for Extrusion and Drawing of Tungsten and Tungsten-Alloy Tubing.

TOOLING AND LUBRICATION

The floating-mandrel technique[7] is illustrated in Fig. 2. The term "floating mandrel" is used because the mandrel is not attached to the stem. This technique has an advantage of simplified tooling arrangements, as less retooling change is required for changing from tube-shell extrusion to sheet bar or rounds. The graphite follower ejects the extrusion from the die. Dies and mandrels are machined from H-12 tool

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[7]R. E. McDonald and C. F. Leitten, Jr., "Production of Refractory-Metal Tube Shells by Extrusion and Flow-Turning Techniques," pp. 85–92 in Refractory Metals and Alloys III; Applied Aspects, Vol 30, ed. by Robert I. Jaffee (Proceedings of the Third Technical Conference, AIME), Gordon and Breach Science Publishers, New York, 1966.

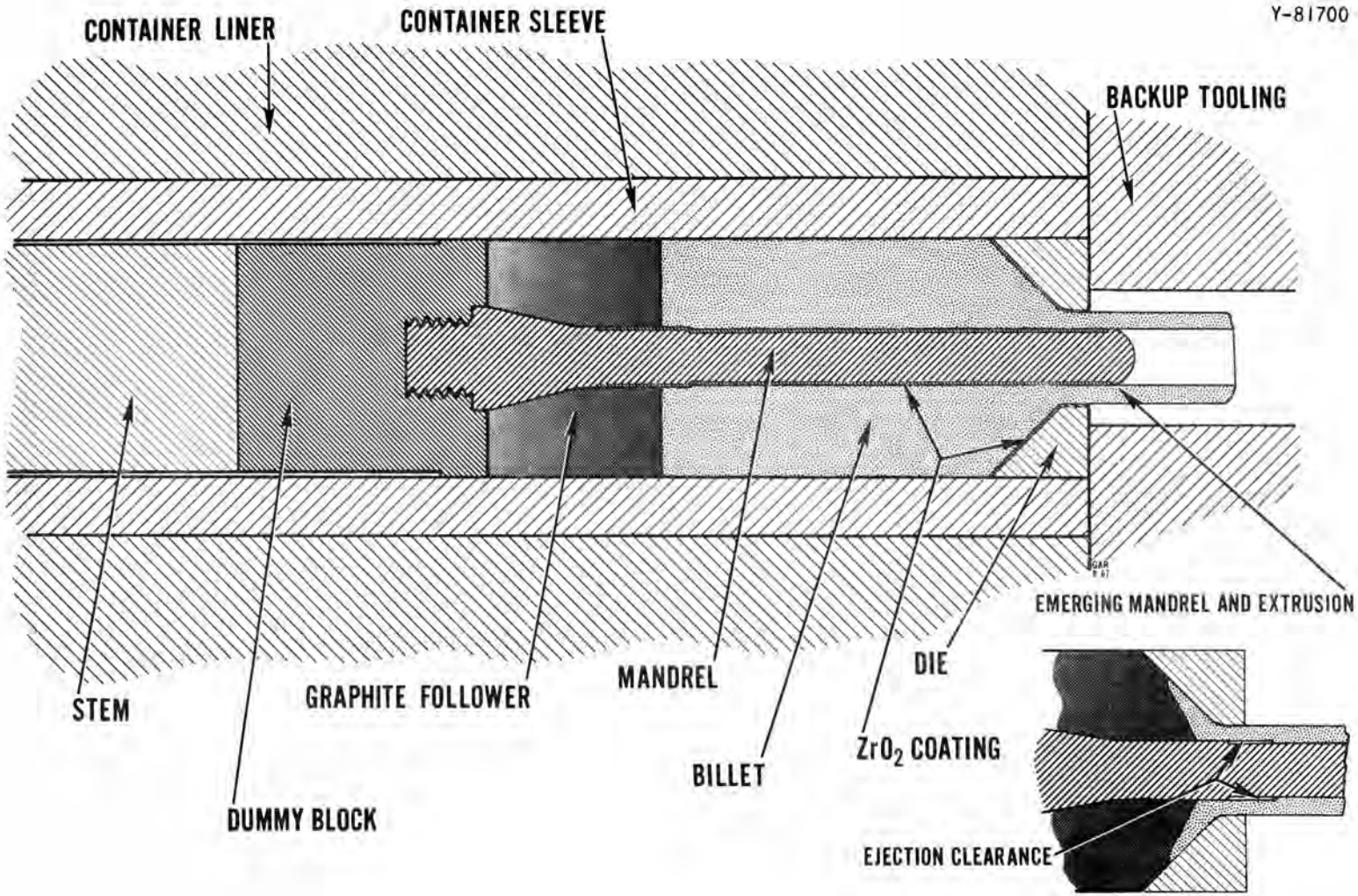

Fig. 2. Schematic of Floating-Mandrel Extrusion Technique.

steel and are hardened to 46 to 50 Rockwell C. A flame-sprayed zirconia coating 0.030 in. thick protects the working surfaces of dies and mandrels from temperatures required for refractory-metal extrusion. No satisfactory method has been found to protect the steel container sleeve; however, this area is less critical and the sleeve will withstand 40 or more extrusions unless billet temperatures consistently exceed 1850°C. Mandrel coating wear has been negligible, but several mandrel failures were encountered when slow ram speed caused prolonged contact with the billet and overheated the mandrel.

The coefficient of friction is significant in any extrusion process, and much effort has been expended by the industry to diminish its effect. Lubrication at temperatures required for refractory-metal extrusion is particularly difficult. In our work, the lubricity of the naturally forming molybdenum and tungsten oxides (melting points 795 and 1473°C, respectively) was exploited and none of the various grades of lubricating glasses was used, because until recently we believed that glass contributed to extrusion surface defects. Billet oxidation is inhibited by the argon atmosphere in the induction heater, but when the furnace is opened and the hot billet is transferred to the press, the exposure to atmosphere produces copious quantities of the lubricating oxide.

The W–25% Re billets generated insufficient oxide for adequate lubrication, and a process was devised to apply a 0.010-in. layer of chemically vapor deposited (CVD) tungsten onto the billet surface to ensure that the desired quantity of oxide was formed.

Inability to minimize the wear of tooling because of poor tooling materials or insufficient lubrication will result in nonuniformity of extrusion dimension. Using the above techniques of zirconia coatings for the tooling and CVD lubrication, we can predict the extrusion diameters to ±0.010 in. over a 30-in. length.

EXTRUSION RESULTS AND DISCUSSION

Sixteen tungsten and tungsten-alloy tube shells have been extruded by the floating-mandrel technique. The extrusion data are summarized in Table 1. Billet types are separated into three groups: (1) unalloyed

Table 1. Conditions and Results of Tungsten and Tungsten-Alloy Tube-Shell Extrusions[a]

Extrusion	Billet Weight (lb)	Extrusion Conditions					Tube-Shell Dimensions (in.)	
		Temperature (°C)	Reduction Ratio[b]	Breakthrough Force (tons)	Speed (in./sec)	Extrusion Index, K (psi)	Outer Diameter	Inner Diameter
Unalloyed Tungsten (Powder-Metallurgy Billets)						$\times 10^3$		
1190	16.1	1870	5.0	480	7.0	89.9	1.625	0.978
1191	16.1	1760	5.0	405	6.5	75.8	1.622	0.986
Unalloyed Tungsten (Wrought Billets)								
1362	18.6	1650	5.0	600	5.5	112.8	1.621	0.984
1363	18.6	1760	5.0	555	5.5	104.0	1.624	0.980
1449	20.4	1980	8.8	580	3.0	76.5	1.255	0.755
1451	19.9	1925	8.7	600	4.5	79.9	1.260	0.752
0004	20.2	1750	6.4	690	0.7	100.0	1.410	c
0031	14.9	1770	4.0	550	1.0	90.0	1.707	0.735
W-25% Re (Arc-Cast Billets)								
1592	17.2	2100	4.9	550	9.5	95.1	1.639	0.978
1593	17.4	2250	4.8	530	10.3	97.3	1.653	0.981
Molybdenum-Clad Tungsten (Duplex Billets)								
1637	14.8	1650	8.8	435	5.5	57.4	1.252	0.774
0037[c]	14.2	1900	8.8	505	1.1	63.0	1.257	0.740

[a]Floating-mandrel technique and base-metal oxide lubricant used.

[b]Based on ratio cross sections of upset billet and extrusion.

[c]Mandrel failed.

tungsten, (2) W–25% Re, and (3) duplex billets. The reduction ratio is determined by the relative cross-sectional areas of the upset[8] billet and the extrusion product; the breakthrough tonnage is the force required to start the billet through the die and generally corresponds to the peak pressure of the extrusion stroke; the speed is the rate of ram advance after breakthrough occurs; and the extrusion index, or constant K is computed from the relation

$$F/A_b \ln(A_b/A_x) \ ,$$

where F is the total force in pounds on the press ram at breakthrough, A_b is the cross-sectional area of the upset billet in square inches, and A_x is the cross-sectional area of the extrusion in square inches. A low extrusion index indicates that larger reduction ratios can be achieved.

Extrusion of Unalloyed Tungsten

The initial tungsten tube-shell extrusions were produced from unalloyed tungsten billets, and three typical billets are shown in Fig. 3. Nine unalloyed tungsten tube shells were extruded from billets of this configuration. Two of the unalloyed billets were extruded in the "as-sintered" condition. The others were machined from 3 1/4-in.-diam bar stock that had been extruded from 6-in.-diam as-sintered billets by E. I. duPont de Nemours and Company, Metals Center, Baltimore, Maryland. The designation "wrought" in Table 1 refers to the 3-in.-diam billets that were machined from this high-density recrystallized bar stock.

Unalloyed tungsten tube shells were extruded at billet temperatures between 1650 and 1980°C and extrusion ratios from 4.0 to 8.8. Examples of unalloyed tungsten tube shells are shown in Fig. 4. Notice the

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[8]Extrusion billet diameters are machined slightly undersize to facilitate insertion into the press. Extrusion begins when the force applied to the billet base is sufficient to start the front of the billet through the die. Before this occurs, the billet distorts, or upsets, until it completely fills the container. Thus, the upset billet diameter or the container sleeve inside diameter must be used to compute the actual extrusion ratio.

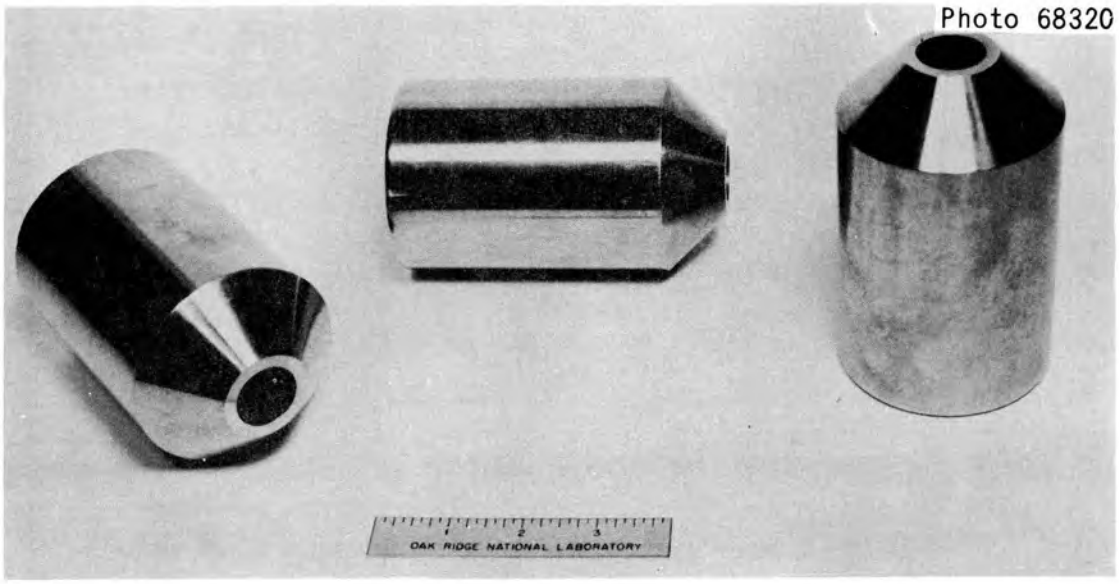

Fig. 3. Typical Tungsten Billets for Floating-Mandrel Extrusion.

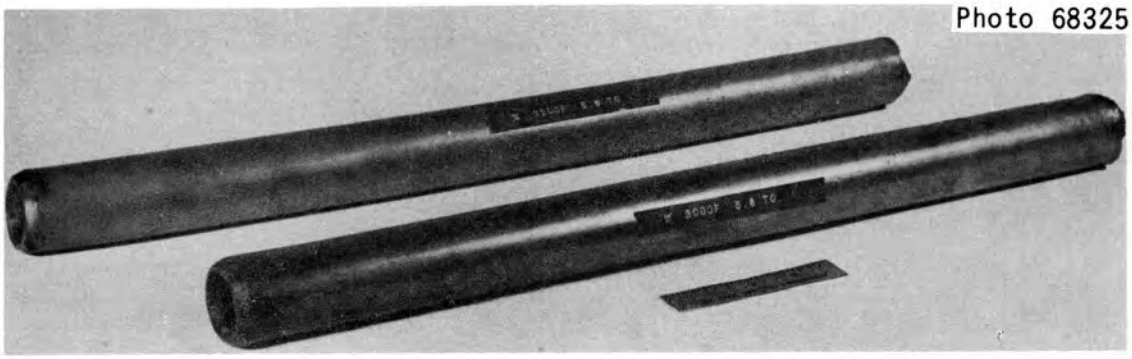

Fig. 4. As-Extruded Unalloyed Tungsten Tube Shells 1362 (Bottom) and 1363. Both extrusions utilized naturally forming tungsten oxide as a lubricant.

excellent as-extruded surfaces. Representative billet and extrusion microstructures of unalloyed tungsten are compared with W–25% Re structures in Fig. 5.

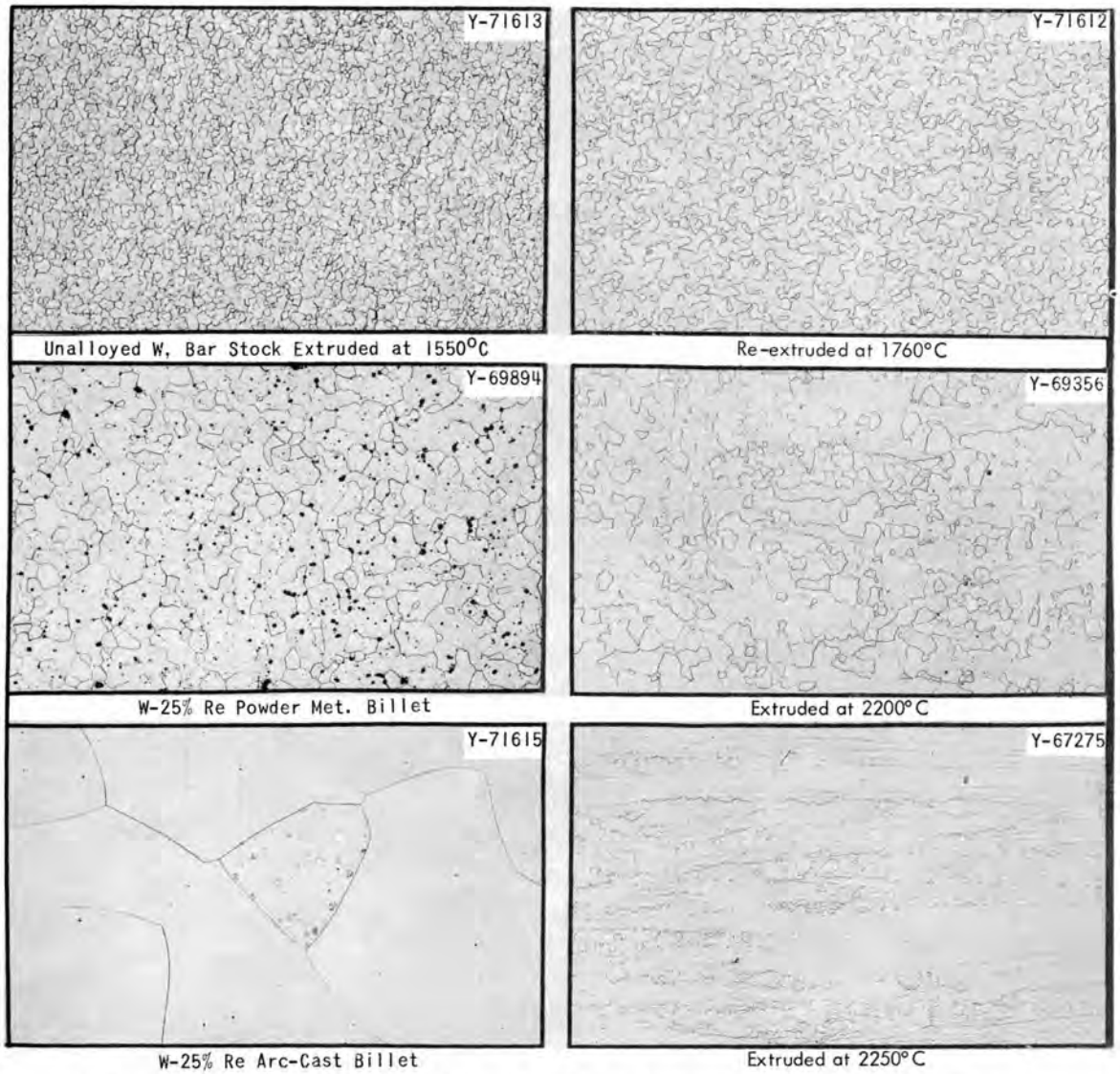

Fig. 5. Comparison of Billet and As-Extruded Structures of Unalloyed Tungsten and W–25% Re. 100×.

Extrusion of W–25% Re

Two tube shells of W–25% Re were extruded from arc-melted billets and are shown in Fig. 6. Extrusion data are listed in Table 1. The as-extruded surfaces were reasonably good, considering the extrusion temperature, although some fissures are evident and some taper exists because of die wear.

Billet and extrusion microstructures are compared in Fig. 5. The first microstructures compare unalloyed tungsten extruded as bar stock at 1550 °C with the same material reextruded into a tube shell at 1760 °C. The recrystallized grain size is slightly larger in the tube shell because of the higher reextrusion temperature. The voids observed in the structure of the W–25% Re billet are typical of this powder-metallurgy product. After extrusion one observes a mixed recrystallized and cold-worked structure with no evidence of the voids previously observed in the billet. The arc-cast W–25% Re billet has a very coarse grain size, typical of arc-cast products. Much less recrystallization is evident after extrusion, even though billets were heated and extruded with very similar temperatures and ratios.

Fig. 6. Tungsten–25% Rhenium Tube Shells 1592 and 1593 (see Table 1). The billets were lubricated by tungsten oxide formed from a coating of chemically vapor deposited tungsten on the billet surface.

Structural homogeneity may be achieved by a 1-hr postextrusion anneal at 1800°C. The response of extruded arc-cast and powder-metallurgy W–25% Re billets to 1-hr vacuum anneals at temperatures between 1700 and 2000°C is compared in Fig. 7. The 1700°C anneal is not sufficient to complete recrystallization in either sample, while the 2000°C anneal produces grain growth in only the arc-cast sample.

Development of Improved Mandrel

Some difficulty was encountered when the extrusions would not completely clear the mandrel at the end of the extrusion stroke. This was an undesirable situation because it caused difficulty in clearing the press tooling, and it contributed to cracking in the extrusion. This problem had been encountered in previous work with molybdenum and was attributed to the fact that the graphite follower was no longer confined when the extrusion left the die and therefore could not push the tube shell free of the mandrel. Inserting a 1-in.-thick heated (1000 to 1100°C) molybdenum follower ahead of the graphite reduced the problem to the extent that the molybdenum follower became lodged on the mandrel instead of the extrusion.

Mandrel redesign eliminated this difficulty altogether, and the use of a heated molybdenum follower was discontinued. The redesign employed a slight taper along the mandrel and a 0.030-in. increase in diameter at the base (see Fig. 2), so that the last 3 to 4 in. of extrusion had an internal diameter large enough for "ejection clearance" (see Fig. 2), to preclude its clinging to the front of the mandrel. The mandrel design change was effective to the extent that extrusions cleared the mandrel with sufficient velocity to strike the end of the runout tube. The slight mandrel taper produced no significant taper on the finished tube product.

Mandrel separations were encountered when extrusion temperatures and pressures were increased to produce the thinner walled tungsten tubing. Additional mandrel separations were prevented by increasing the ram speed from 3 or 4 in./sec to more than 8 in./sec to reduce the time of contact between the mandrel and the hot billet.

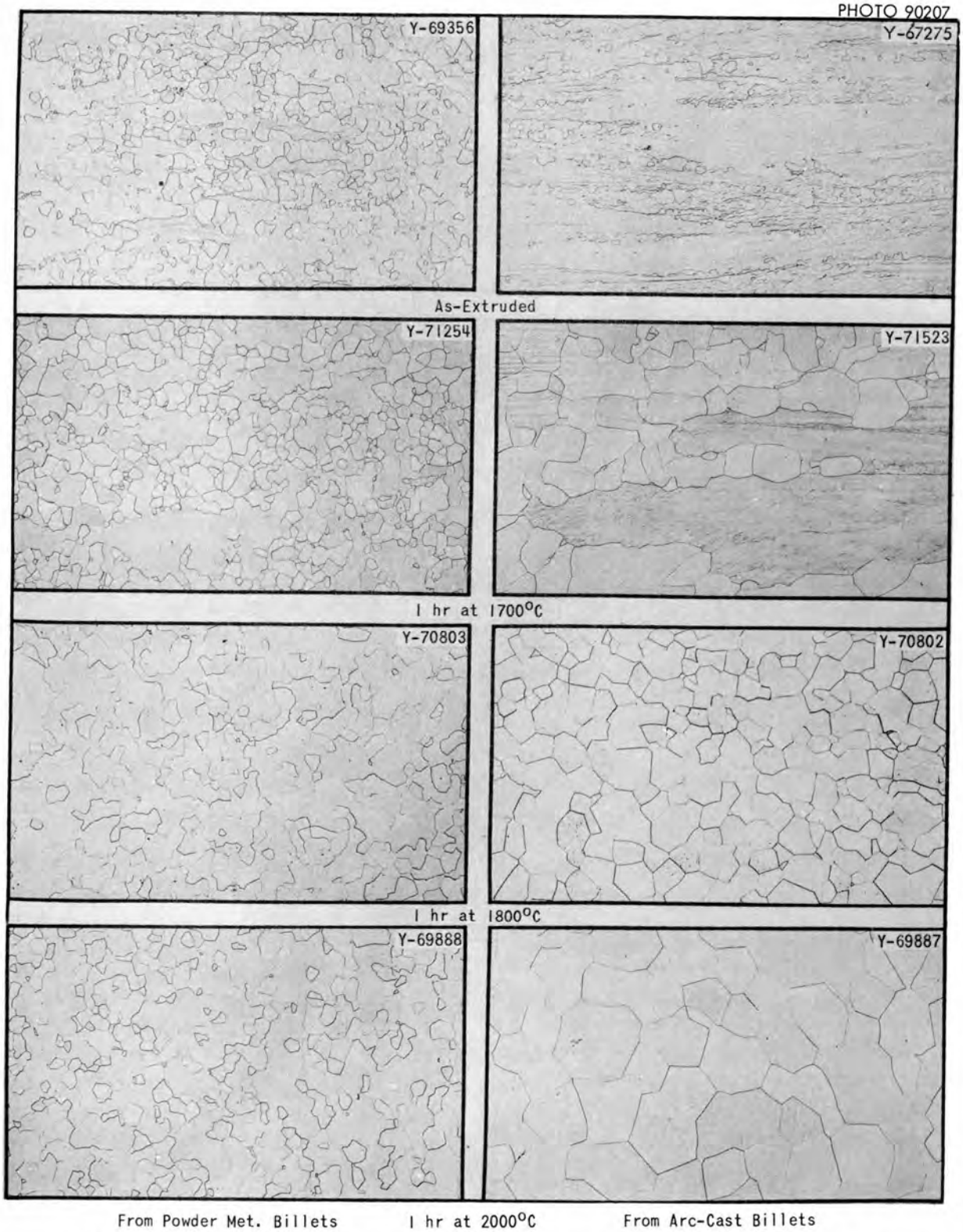

Fig. 7. Comparison of Structural Response to Vacuum Annealing of Extrusions from Powder-Metallurgy and Arc-Cast Billets of W–25% Re. 100×.

Examination of Extrusion Surface Defects

No convenient means is available to protect the container sleeve of H-12 tool steel from tungsten billets heated in excess of 1850 °C, where sleeve attrition becomes a serious problem. Rapid billet handling and high extrusion speeds reduce the severity of the problem without eliminating it. The most troublesome aspect of the surface melting of the sleeve is the reaction of the molten steel with hot tungsten.

An example of severe surface defects in W–25% Re extruded at 2160 °C is shown in Fig. 8. The as-extruded surface was sandblasted clean, but a hard deposit remained in and around the fissures and became rust-colored when swabbed with dilute HCl. The microstructures in Fig. 8 show a longitundinal section near the surface in an area of severe intergranular penetration. Some portions of the intruded material became dislodged during mechanical polishing.

Earlier we thought that the extrusion surface defects, which were more numerous and increasingly severe as billet temperatures were raised above 1850 °C, resulted from reaction of the billet surface with glass lubricants in use at the time. We discovered that extrusions defects previously attributed to reaction with the lubricating glass occurred under similar extrusions conditions when our oxide lubrication was used. The absence of lubricating glass on the as-extruded surface facilitated the observation that a liquid had been present in and around surface defects and that this substance was rich in iron. Since the die was protected by a ZrO_2 coating, the only source of this much iron was the container sleeve.

Iron concentration was determined by microprobe analysis, traversing a 3-μ spot across the areas of interest. Iron concentrations up to 45% were determined in some areas, with concentration varying roughly according to the width of the deposit and the distance from the surface of the extrusion. Two examples of microprobe traverses are shown in Fig. 9, with the corresponding concentration plots aligned to match the traverses shown in the photomicrographs. The deepest penetrations contain up to 15% Fe. Vanadium and chromium, alloying elements in H-12 tool steel, were sought but not detected.

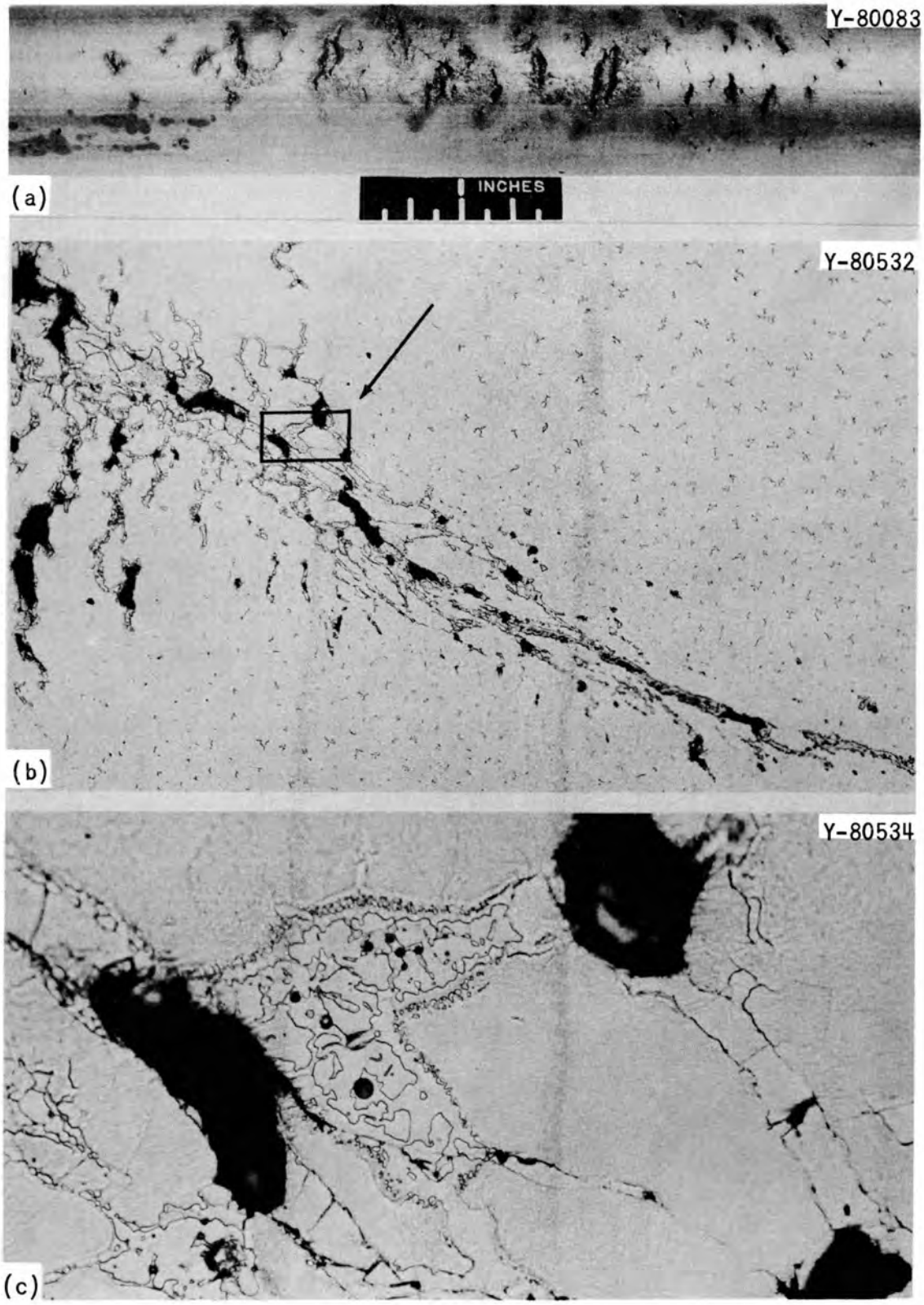

Fig. 8. Defects in Extruded W–25% Re. (a) View of as-extruded surface. (b) Microstructure of longitudinal section near surface. 100×. (c) Close-up of indicated areas in (b). 1000×.

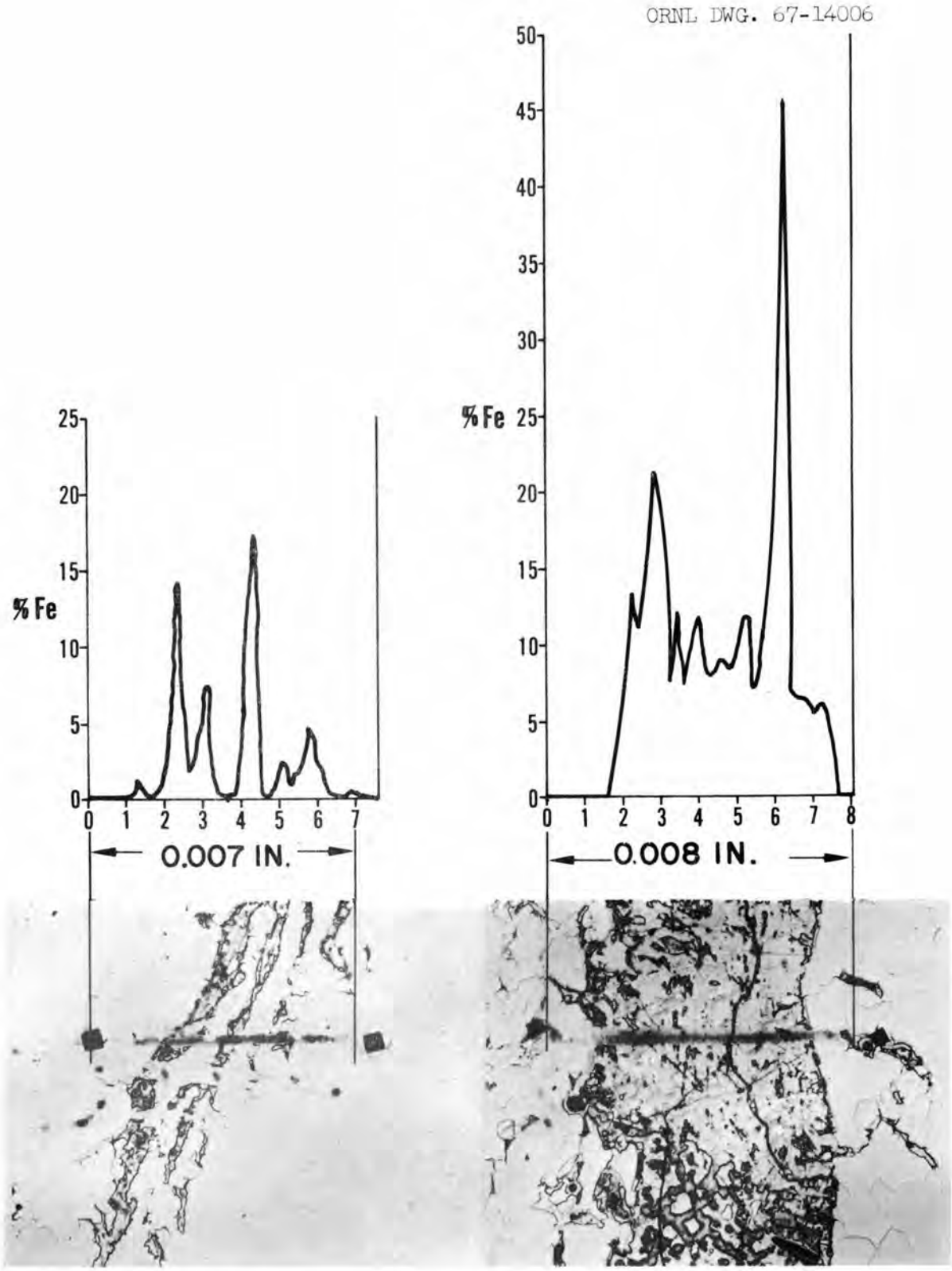

Fig. 9. Microprobe Scans and Corresponding Plots of Iron Concentration at Root of Penetration (Left) and Near Extrusion Surface.

The mechanism of extrusion defect formation is not clearly understood. We believe that molten iron is forced under high pressure into small fissures that develop in the highly deformed billet surface during the extrusion stroke. This molten iron wets freshly fractured surfaces and produces rapid intergranular attack in areas under tensile stress, resulting in severe defects in the extrusion surface.

Alternate Container Sleeve Materials

At study of container sleeve designs and materials[9] produced no results that would be useful for tungsten-alloy extrusion above 2000°C. An obvious approach to prevent iron contamination of the billet was to use a nonferrous alloy as a container sleeve. A candidate material in this application was TZM molybdenum alloy, which has been employed as a die insert for the hot extrusion of steel. The hot hardness and wear resistance were outstanding in this instance, although the high thermal conductivity of this alloy is not considered an asset when tungsten is to be extruded. Its contribution to billet heat loss places a premium on speed of handling and extrusion.

A TZM sleeve was obtained and installed, but an attempt to extrude a 2100°C tungsten billet was not successful. The oxide lubricating layer was not adequate to prevent galling and seizing between billet and sleeve. Also, the strength of TZM stock at this diameter was not sufficient to prevent plastic deformation, and the container liner was not strong enough to give the TZM sleeve proper support. Fragments of the sleeve and the unextruded portion of the billet are shown in Fig. 10, where evidence of surface tearing is obvious. Notice also that the lip of the die was pressed deeply into the sleeve.

Few materials can be obtained in a size sufficient for a container sleeve that will withstand an excess of 200,000-psi pressure along with the temperatures exceeding 2000°C that are encountered in this work. A possible candidate is vitrified stabilized zirconia, which can be procured in fairly large sizes without prohibitive cost. It can easily withstand

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[9]S. R. Spachner, Final Report on Development of Improved Liner for Extrusion Billet Containers, ML-TDR-64-194 (May 1964).

Fig. 10. Fragments of TZM Sleeve with Die and Partially Extruded Billets.

2200 or 2300°C; it has very poor heat conductivity, which would minimize billet heat loss; and it presents a relatively low-friction surface to heated tungsten. While its 350,000-psi compressive strength is an outstanding asset, its 20,000-psi tensile strength is a serious handicap. The latter property requires that the sleeve be placed under heavy compression to ensure that the greatest force that can be exerted by the extrusion press is not sufficient to induce any tensile stresses in the zirconia sleeve. Herein lies the difficulty in utilizing zirconia, as the design and choice of material for the compression sleeve must ensure restraint both circumferentially and longitudinally under dynamic nonuniform elastic loading of the support tooling. Up to this time, no practical proposals have been volunteered that would permit utilization of a ZrO_2 sleeve.

Extrusion of Duplex Billets

Drawbench techniques are not sufficiently developed to produce thin-wall tubing from low-ratio extrusions of high-strength tungsten alloys.

To bypass this technological problem, a duplex billet was designed to accommodate a tube shell section from a previous extrusion. Reextrusion of the tube shell in the duplex billet achieves a greater total ratio by compounding reduction and permits production of thin-walled tubing. The concept of reextrusion of tungsten alloy tubing in a "filled billet" has been employed for a number of years by others.[10-14] The filled billet and our duplex billet are compared in Fig. 11. The designs are the same in principle, yet essential differences are apparent. The duplex billet is designed for extrusion over the floating mandrel, whereas the filled billet contains its own mandrel consisting of either graphite, calcium carbide, or other suitable core material. The duplex billet mandrel does not deform upon extrusion as the tubular product is developed, whereas the core of the filled billet undergoes a reduction proportional to the extrusion ratio and must be removed from the extrusion before much further processing can proceed. The duplex billet requires less machining and uses considerably less molybdenum for a given weight of tungsten tube shell.

The products of filled- and duplex-billet extrusion are compared in Fig. 12, where the ease of producing large-diameter, thin-walled tubes by use of the duplex billet is illustrated. For identical starting blanks passing through the same diameter extrusion die, a larger diameter, thinner tube shell can be obtained by the duplex-billet.

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[10] J. G. Hunt *et al.*, Development of a Fabrication Process for Seamless Tungsten Tubing, Summary Technical Report to the United States Atomic Energy Commission for the Period July 1, 1962, through June 30, 1963, NMI-1260.

[11] W. R. Burt, Jr., *et al.*, Annual Progr. Rept. for 1964, Metallurgy Division, ANL-7000, pp. 138–142.

[12] High-Temperature Materials Program Progr. Rept. Jan. 24, 1964, GEMP-31A, p. 15.

[13] High-Temperature Materials Program Progr. Rept. Nov. 30, 1964, GEMP-41A, p. 35.

[14] High-Temperature Materials Program Progr. Rept. July 28, 1965, GEMP-49A, pp. 56–60.

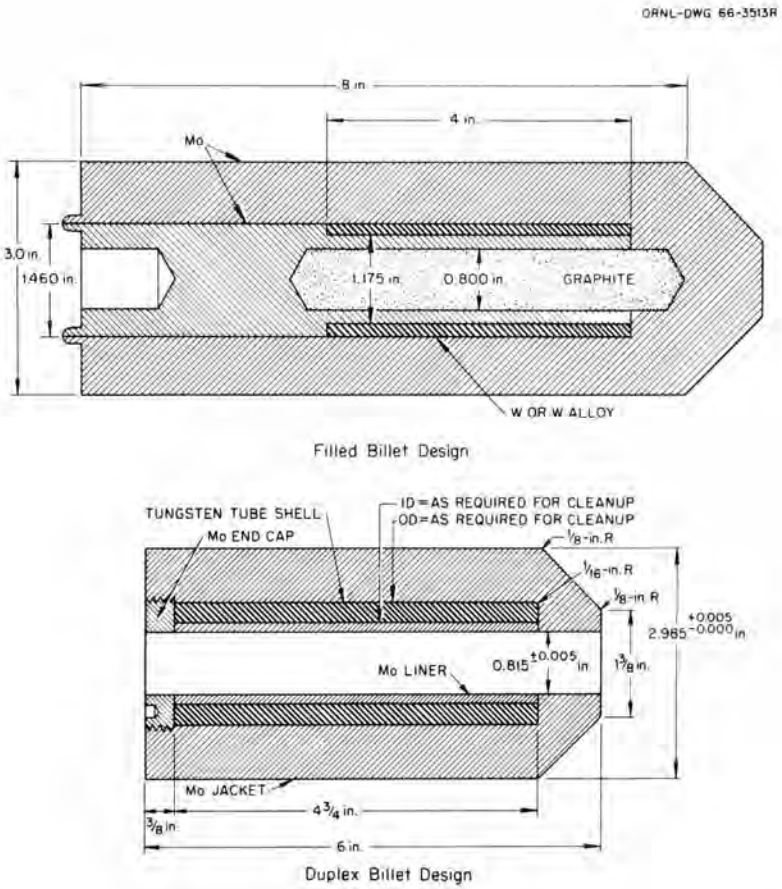


Fig. 11. Comparison of Filled- and Duplex-Billet Designs.

Figure 13 shows the component parts of the duplex billet before assembly, as well as a partially assembled billet. Figure 14 shows the cross section of a duplex extrusion produced at 1650°C at 8.8 extrusion ratio before and after removal of the molybdenum coating. The convolutions in the tungsten tube are common with filled-billet and duplex extrusions.

Eliminating the molybdenum sleeve from the duplex billet and extruding the tube shell directly against the mandrel produced the unexpected benefit of an improved surface, which is shown in Fig. 15 along with microstructures produced in unalloyed tungsten by duplex extrusion. The mandrel presents a harder surface to the inside of the tube shell than does the heated molybdenum sleeve, preventing the uneven surface from developing. Also, the cold mandrel tends to chill the tube shell, producing more wrought

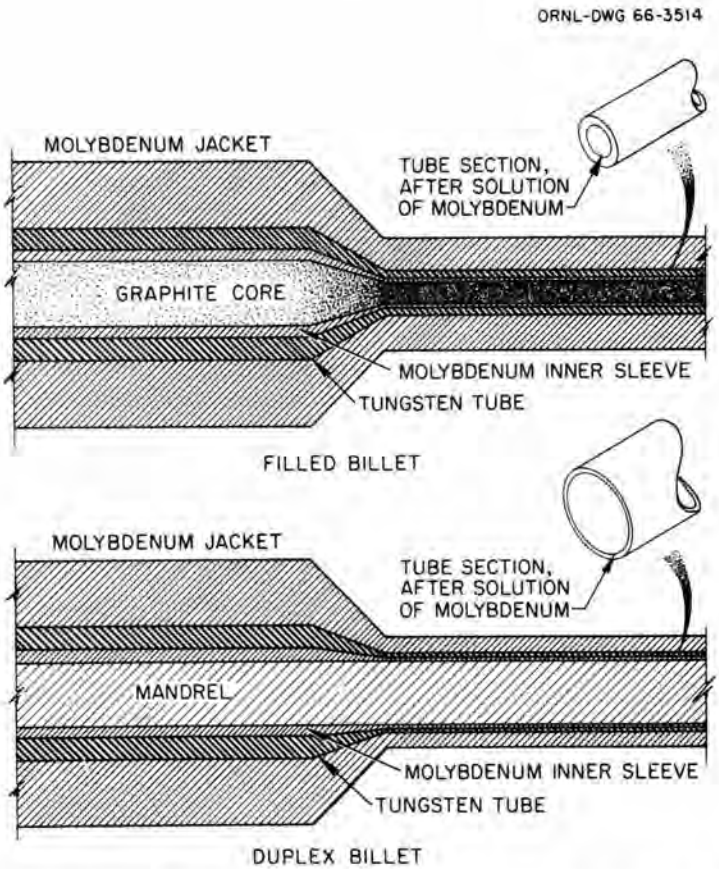
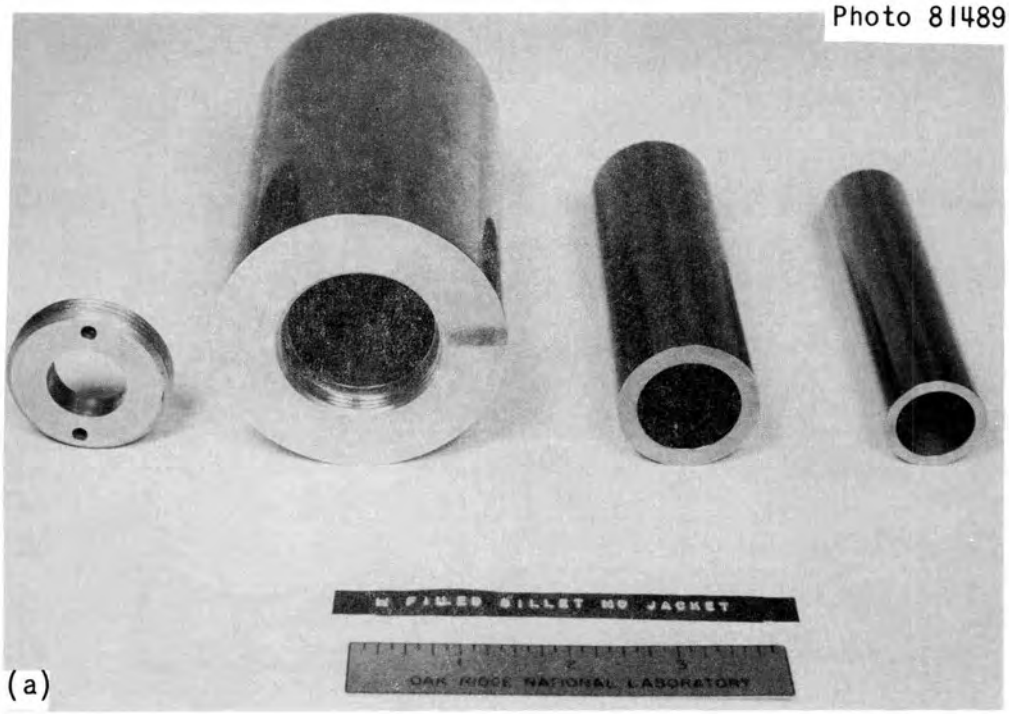


Fig. 12. Relative Size of Reextruded Tungsten Tubing Produced from Filled- and Duplex-Billets from Identical Starting Blanks.

structure. Since the bulk of the duplex billet cross section is molybdenum, this configuration is extruded with relative ease, allowing more latitude with regard to combinations of extrusion temperature and ratio. Wall thickness may be controlled by choice of extrusion dies, and microstructure may be controlled to some degree by varying billet temperature.



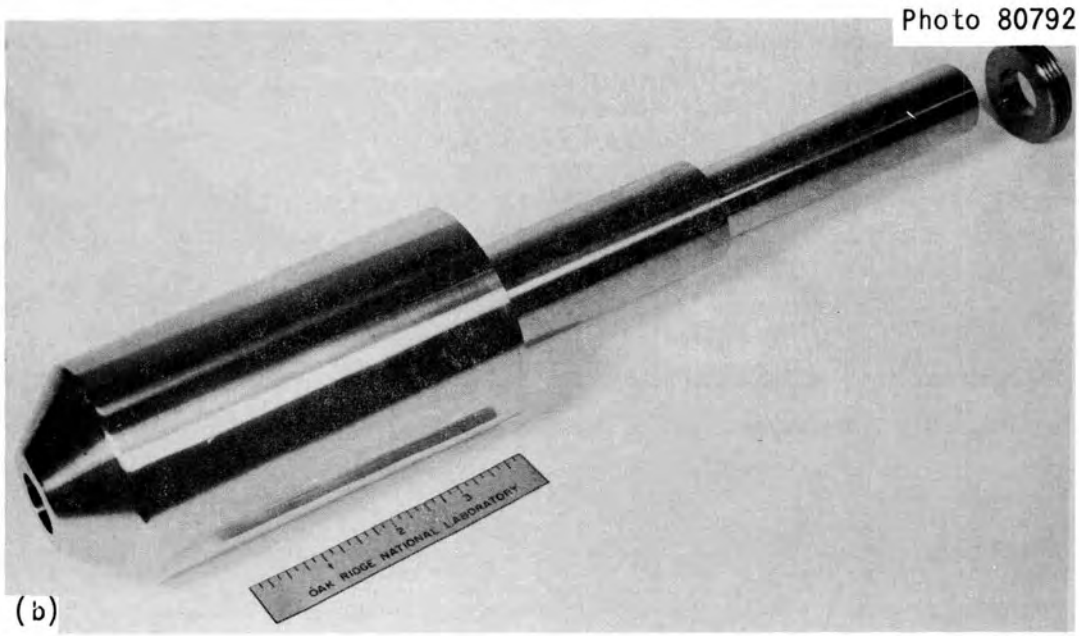


Fig. 13. Component Parts of, and Partially-Assembled Duplex Billet.

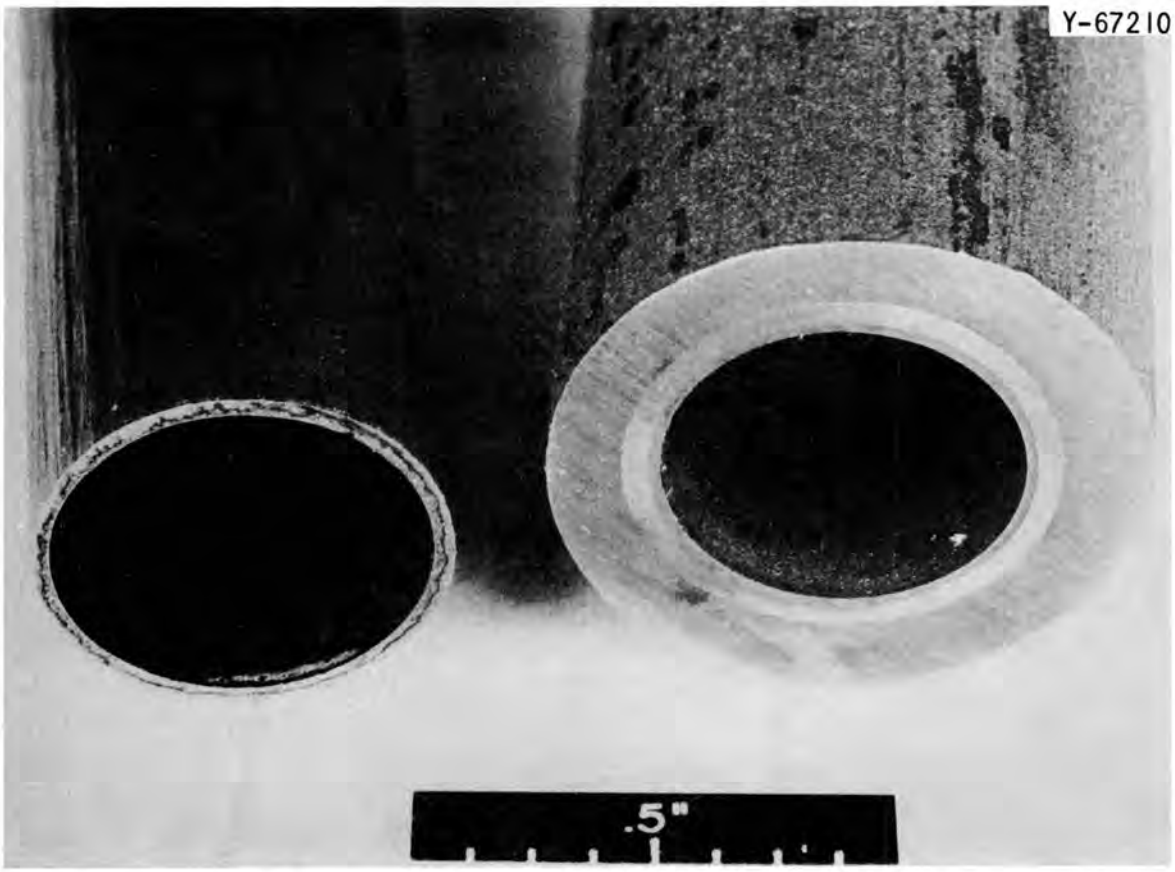


Fig. 14. Cross Sections of Duplex Extrusions Before and After Solution of Molybdenum Jacketing.

SUMMARY

The floating-mandrel technique, not used conventionally for refractory-metal extrusion, has been adapted by ORNL to the production of tungsten-base tube shells and large-diameter, thin-wall tubing. The primary extrusion is produced from a 3-in.-diam billet approximately 5 in. long that has been bored axially to accommodate the mandrel of desired size.

Unalloyed tungsten tube shells have been produced with billet temperatures between 1650 and 1980°C and reduction ratios between 4.0 and 8.8. Short transfer times (less than 10 sec) and rapid extrusion speeds are required at higher temperatures and reduction ratios to avoid overheating and failure of the mandrel. The addition of 25% Re to tungsten increases its resistance to deformation to the extent that, with billet

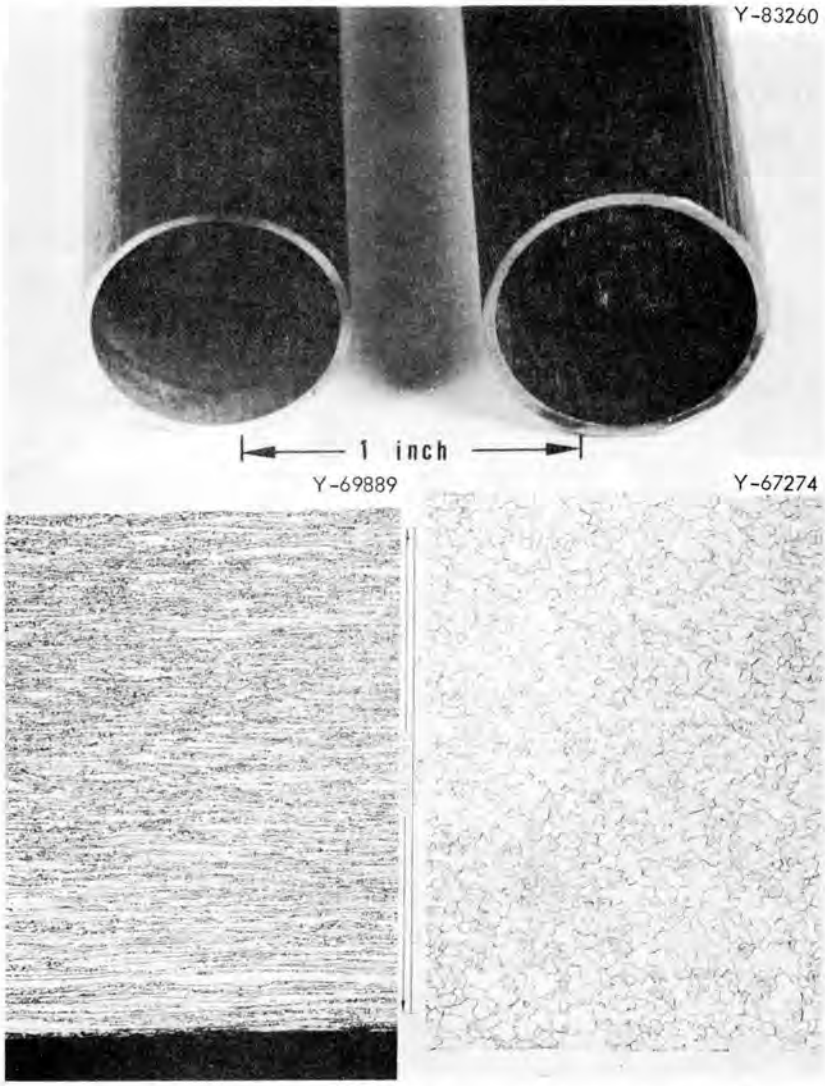


Fig. 15. Comparison of Duplexed Tube Surfaces When Extruded Without Molybdenum Sleeve (Left) and with Sleeve. Wrought microstructure develops when tungsten is extruded directly against cold mandrel.

temperatures of 2100 to 2250 °C, reduction ratios have been limited to about 5. Extrusion temperatures above 1850 °C greatly increase the tendency toward surface defects resulting from iron contamination.

The billet is lubricated by the tungsten oxide layer that forms naturally during transfer from billet heater to press, and excellent extrusion surfaces are obtainable. The W–25% Re alloy does not form sufficient oxide for satisfactory lubrication, so a process has been devised to chemically vapor deposit a 0.010- to 0.020-in. layer of unalloyed tungsten on the billets to ensure adequate lubrication.

The cross sections of many as-extruded tungsten alloy tube shells are too heavy to permit subsequent drawing by available techniques. Therefore, to produce large-diameter thin-walled tubing from the tube shell sizes that are limited by extrusion press capacity, a duplex billet was developed whereby a section of extrusion is jacketed in molybdenum and reextruded over a floating mandrel. Several thin-walled tubes have been produced by this method. Since the cross section of the duplex billet is mostly molybdenum, a greater latitude in billet temperature and extrusion ratio is possible, so a greater range of wall thicknesses and microstructures can be obtained. After acid dissolution of the molybdenum covering, the tungsten tube may be drawbench finished to either large- or small-diameter, thin-walled tubing.

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