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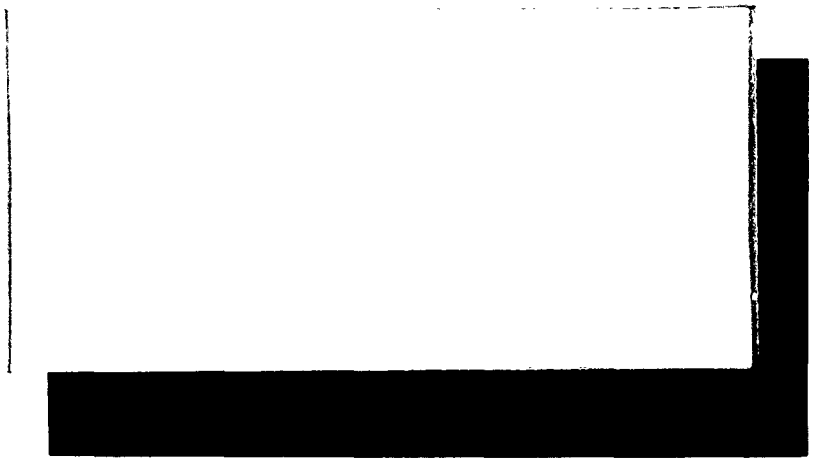

CLIMAX MOLYBDENUM CO.
OF MICHIGAN
Detroit, Michigan

a subsidiary of **AMERICAN METAL CLIMAX, INC.**

THE DEVELOPMENT AND EVALUATION OF TUNGSTEN-BASE ALLOYS

Prepared under Bureau of Naval Weapons
Contract No. NOw 62-0419-c
Third Quarterly Report

15 September 1962 to 15 December 1962

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DETROIT, MICHIGAN

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ABSTRACT

Seven 4-in.-diameter, vacuum-arc-cast tungsten-base alloy ingots, having been successfully extruded following "canning" in molybdenum, were swaged to 1/2-in.-diameter bar stock. Recovery data are reported. Recrystallization temperature determinations were conducted on the extruded billets, as well as on the swaged bar stock.

INTRODUCTION

The objective of Contract No. NOw 62-0419-c is the development of wrought tungsten-base alloys having high elevated temperature strength and adequate ductility at low temperatures.

This report covers the work conducted under the subject contract during the period 15 September 1962 to 15 December 1962.

The following seven tungsten-base alloys were vacuum-arc-cast:

Heat No.	Analysis, %
4136	W + 0.93 Cb + 0.001 C
4138	W + 1.0 Cb + 3.18 Mo + 0.001 C
4137	W + 0.11 Hf + 0.002 C
4139	W + 0.10 Hf + 3.05 Mo + 0.001 C
4140	W + 0.05 Zr + 0.002 C
4142	W + 0.04 Zr + 3.10 Mo + 0.001 C
4141	W + 0.05 Zr + 0.003 B + 0.001 C

All of the ingots were machined, then "canned" in molybdenum in preparation for extrusion.

Details of the primary working of these heats were presented in Progress Report No. 2. At that time, recrystallization data were not available for the extruded billets, consequently this information is presented in Table 1.

Table 1

Hardness of Extruded Billets After Annealing
One Hour at Indicated Temperatures

	W + 0.93% Cb + 0.001% C		W + 1.0% Cb + 3.18% Mo + 0.001% C	
Blank No.	4136-1	4136-2	4138-1	4138-2
Extrusion Ratio	4:1	8.6:1	4:1	8.6:1
Extrusion Temp., F	3800	3800	3800	3800
Condition	DPH	DPH	DPH	DPH
As-Extruded	437	450	446	455
1 hr at 3000 F	437	450	433	437
1 hr at 3200 F	382	383	398	405
1 hr at 3400 F	378	380	370	372
1 hr at 3500 F	375	373*	-	362
1 hr at 3600 F	360*		376	360*
1 hr at 3700 F			358	
1 hr at 3800 F			358*	

	W + 0.11% Hf + 0.002% C		W + 0.10% Hf + 3.05% Mo + 0.001% C	
Blank No.	4137-1	4137-2	4139-1	4139-2
Extrusion Ratio	6.5:1	8.6:1	8.6:1	10:1
Extrusion Temp., F	3600	3600	3600	3600
Condition	DPH	DPH	DPH	DPH
As-Extruded	473	488	459	459
1 hr at 3000 F	468	468	450	425
1 hr at 3200 F	368	368	359	362
1 hr at 3300 F	357	-	356*	353
1 hr at 3400 F	353*	364		353*
1 hr at 3500 F		355*		

* Hardness after annealing at minimum temperature required to produce 100% recrystallized microstructure.

(continued)

Table 1 (continued)

	W + 0.05% Zr + 0.002% C		W + 0.04% Zr + 3.10% Mo + 0.001% C	
Blank No.	4140-1	4140-2	4142-1	4142-2
Extrusion Ratio	8.6:1	10:1	8:1	10:1
Extrusion Temp., F	3600	3600	3600	3600
Condition	DPH	DPH	DPH	DPH
As-Extruded	455	478	464	464
1 hr at 2900 F	-	-	464	455
1 hr at 3000 F	450	473	455	433
1 hr at 3100 F	-	-	450	433
1 hr at 3200 F	368	387	356	360
1 hr at 3300 F	-	-	-	360
1 hr at 3400 F	360	380	372	363*
1 hr at 3500 F	361*	358*	350*	

	W + 0.05% Zr + 0.003% B + 0.001% C	
Blank No.	4141-1	4141-2
Extrusion Ratio	10:1	10:1
Extrusion Temp., F	3600	3600
Condition	DPH	DPH
As-Extruded	464	429
1 hr at 2900 F	463	437
1 hr at 3000 F	463	417
1 hr at 3100 F	460	409
1 hr at 3200 F	380	-
1 hr at 3250 F	-	373
1 hr at 3400 F	384	376
1 hr at 3500 F	360*	367
1 hr at 3600 F		360*

* Hardness after annealing at minimum temperature required to produce 100% recrystallized microstructure.

All of the "Mo-canned" extruded billets were cropped to sound stock, and the ends examined for cracks by dye-penetrant inspection methods.

The billets were stress-relieved for one hour at 2700 F in hydrogen, before swaging to 1/2-in.-diameter bar stock. This stress-relief anneal was purely a precautionary measure as the billets had to be shipped to a distant swaging facility.

The sizes, weights, and hardness values of the conditioned extruded billets are given in Table 2. The billets prepared for rolling still contained the molybdenum case.

Table 2

Dimensions and Hardness Values for Extruded and Cropped Tungsten-Base Alloy Billets

Bar No.	Analysis, %	Dia., in.	Length, in.	Weight, lb	DPH	
					As-Extruded	Str.Rel. at 2700F
4136-1	W + 0.93 Cb + 0.001 C	1-1/2	16-3/16	17.25	437	433
-2	"	1-3/32	32	16.46	450	448
4137-1	W + 0.11 Hf + 0.002 C	1-3/16	29-3/4	20.15	473	464
-2	"	1-3/32	39-3/4	20.69	488	473
4138-1	W + 1.0Cb + 3.18Mo + 0.001C	1-9/16	13-1/2	14.92	446	442
-2	"	1-1/16	39-5/16	18.95	455	440
4139-1	W + 0.10Hf + 3.05Mo + 0.001C	1-1/16	39-7/16	19.50	459	450
-2	"	1-1/16	43	20.68	459	430
4140-1	W + 0.05 Zr + 0.002 C	1-1/16	39-5/8	20.27	455	459
-2	"	1-1/16	40-7/8	20.38	478	475
4141-1	W + 0.05Zr + 0.003B + 0.001C	1	45-7/16	20.50	464	460
-2	"	1	39-9/16	17.16	429	431
4142-1	W + 0.04Zr + 3.10Mo + 0.001C	1-1/16	39-3/16	20.06	464	464
-2	"	1	44-15/16	20.32	464	457

For swaging, the billets were heated to 3000 F, held for ten minutes, then swaged through a series of round dies to 1/2-in.-diameter stock. Swaging of bar numbers 4136-1, 4138-1, 4137-1, 4139-1, and 4140-1 was reported in Progress Report No. 2.

A photograph illustrating typical swaged bars is shown in Figure 1.

The total recovery data was obtained using "Mo-canned" extrusion blank weights and the cropped 1/2-in.-diameter bar stock weights. These results are listed in Table 3.

Studies of Swaged Bars

To date, recrystallization data have been obtained for the swaged bars representing each of the seven alloy compositions.

To determine the uniformity of the swaged bars, as-received hardness values were determined at selected intervals along each bar. The results obtained indicated that the variations were relatively small, therefore alleviating difficulties in subsequent sampling for metallurgical and mechanical property determinations.

Hardness and percent recrystallization data as a function of annealing temperature for the 1/2-in.-diameter bars are given in Table 4.

Elevated temperature tensile and creep-rupture strengths and tensile transition temperature determinations have been initiated on the 1/2-in.-diameter bar stock.

Table 3

Recovery Data After Swaging Tungsten-Base Alloys to 1/2-in.-Diameter Rounds

Bar No.	Analysis, %	Cropped Extruded Bar			Swaged Bar			*Cropped Bar Stock			% Total Recovery
		Dia., in.	Length, in.	Weight, lb	Dia., in.	Length, in.	Weight, lb	Dia., in.	Length, in.	Weight, lb	
4136-1	W + 0.93 Cb + 0.001 C	1-1/2	16-3/16	17.25	----------	Cracked	----------				0
-2	"	1-3/32	32	16.46	1/2	61-5/8	7.75	1/2	57-1/2	7.39	34.9
4138-1	W + 1.0Cb + 3.18Mo + 0.001C	1-9/16	13-1/2	14.92	----------	Cracked	----------				0
-2	"	1-1/16	39-5/16	18.95	1/2	135-3/8	17.45	1/2	110	14.09	57.7
4137-1	W + 0.11 Hf + 0.002 C	1-3/16	29-3/4	20.15	9/16	133-1/2	19.40	9/16	124-5/8	18.08	70.9
-2	"	1-3/32	39-3/4	20.69	1/2	153	20.00	1/2	146-1/2	19.19	75.3
4139-1	W + 0.10Hf + 3.05Mo + 0.001C	1-1/16	39-7/16	19.50	1/2	141-1/4	18.88	1/2	135-11/16	18.07	72.0
-2	"	1-1/16	43	20.68	1/2	157-5/8	20.15	1/2	151-11/16	19.36	77.8
4140-1	W + 0.05 Zr + 0.002 C	1-1/16	39-5/8	20.27	1/2	141-7/8	19.24	1/2*	135-3/8	18.34	71.9
-2	"	1-1/16	40-7/8	20.38	1/2	151-3/4	19.70	1/2	145-5/8	19.03	74.6
4141-1	W + 0.05Zr + 0.003B + 0.001C	1	45-7/16	20.50	1/2	99-1/8	12.80	1/2	92-3/8	12.03	48.1
-2	"	1	36-9/16	17.16	1/2	136-5/8	17.65	1/2	127-3/4	16.62	75.6
4142-1	W + 0.04Zr + 3.10Mo + 0.001C	1-1/16	39-3/16	20.00	1/2	152-1/4	19.30	1/2	146	18.50	74.6
-2	"	1	44-15/16	20.32	1/2	153-1/4	19.50	1/2	148-1/4	18.80	75.2

Table 4

Recrystallization of Swaged 1/2-in.-Diameter Bars

Bar No.	4136-2		4137-1		4138-2		4139-1		4140-1		4141-1		4142-1	
Composition,%	W + 0.93Cb + 0.001 C		W + 0.11Hf + 0.002 C		W + 1.0 Cb + 3.18Mo + 0.001C		W + 0.10 Hf + 3.05Mo + 0.001C		W + 0.05Zr + 0.002 C		W + 0.05 Zr + 0.003B + 0.001C		W + 0.04 Zr + 3.10Mo + 0.001C	
	DPH	% Rec.	DPH	% Rec.	DPH	% Rec.	DPH	% Rec.	DPH	% Rec.	DPH	% Rec.	DPH	% Rec.
As-Swaged	467	0	483	0	468	0	468	0	478	0	514	0	464	0
1 hr at 2700F	458	0			466	0	-	-			516	0	456	0
1 hr at 2900F	459	0	457	0	459	0	437	5	462	1	493	0	456	1
1 hr at 3000F	457	1	455	2	459	0	425	20	459	1	498	2	445	5
1 hr at 3100F	453	25	454	5	445	2	413	40	455	10	444	70	416	30
1 hr at 3200F	384	90	388	70	405	40	350	100	395	60	378	100	376	100
1 hr at 3250F	-	-	387	80	-	-			-	-				
1 hr at 3300F	383	95	357	99	385	80			363	98				
1 hr at 3350F	-	-	360	100	-	-			362	100				
1 hr at 3400F	373	99			368	99								
1 hr at 3500F	374	100			373	100								

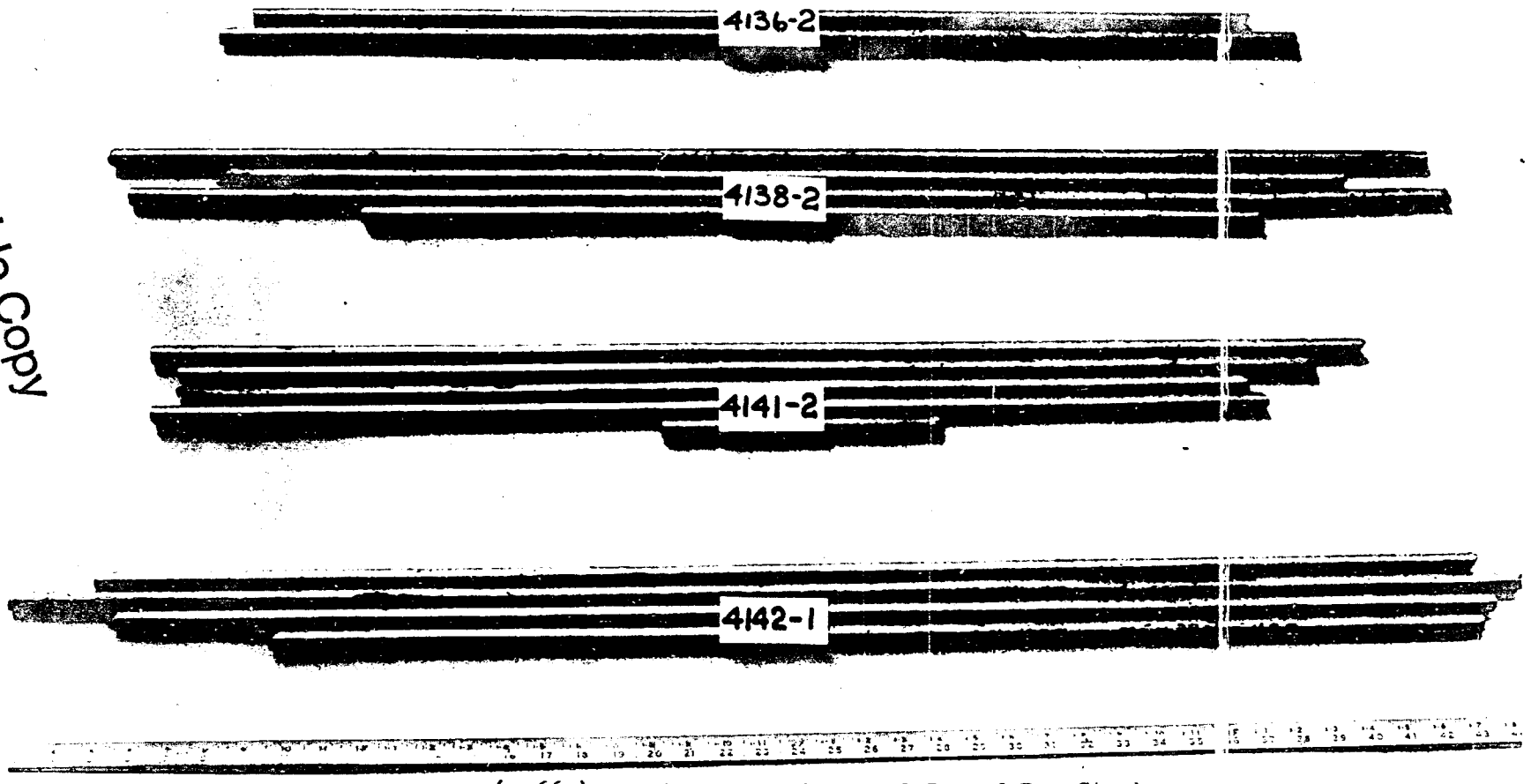

FIGURE 1 (P2663) - As-Received Canned-Swaged Bar Stock
Heat 4136 - W + 0.93% Cb + 0.001% C
Heat 4138 - W + 1.0% Cb + 3.10% Mo + 0.001% C
Heat 4141 - W + 0.05% Zr + 0.003% B - 0.001% C
Heat 4142 - W + 0.04% Zr + 3.10% Mo + 0.001% C