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Quarterly Technical Progress Report
INVESTIGATION OF
THE TECHNICAL FEASIBILITY OF COLD EXTRUSION
FOR ZIRCALOY-2 TUBING PRODUCTION

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STATEMENT OF PROBLEM

The over-all objective of the investigation is to establish the feasibility of using cold extrusion to produce Zircaloy-2 tubular products. The first phase was concerned with the determination of the basic feasibility of cold extruding Zircaloy-2 and the evaluation of lubricants. The economic feasibility of this process also was investigated. The second phase, now in progress, is concerned with the technique and limitations of making Zircaloy-2 tubular extrusions.

SUMMARY OF PROGRESS TO DATE

Lubrication systems composed of a lubricant and a conversion coating were developed and evaluated for the cold extrusion of Zircaloy-2. A fluoride-phosphate base coating and several lubricants were selected for actual extrusion tests. Bars of Zircaloy-2 were successfully extruded at room temperature to reductions of 50, 65, and 80%. Successful extrusions also have been made at temperatures up to 400°C. Excellent surface finish was obtained, and no evidence of cracks or other defects could be found. Fully annealed extruded specimens exhibited the same tensile properties as similarly treated raw bar stock. Deformation efficiencies were found to be in the same range as for cold-extruded aluminum, titanium, and steel, varying from 40% for the lowest reductions to 80% for the highest reductions. Billets have been pierced successfully to 50% reduction at 300 C. Various punch profiles were investigated, the best being selected for further work.

A preliminary analysis of the economic potential of this process for Zircaloy-2 tubing production has shown that:

1. The cold extrusion of heavy-walled tube shells is economic if sufficient production volume exists.
2. Production of thin-walled fuel-containing tubes with integral end caps appears promising because a better product can be obtained at considerably lower cost than that currently associated with reactor-grade plain tubing.

PROGRESS OCTOBER-DECEMBER 1960

The final report on Phase I was completed and submitted for approval during this period.

Room-temperature extrusion tests on bar, using a 120-degree die angle, were completed. The averaged results are given in Table I. The "A" surface samples had a surface finish of about 32 microinches rms after removal of lubricant but before pickling. The lubricant was easily removed with a hot 30% nitric acid solution.

A number of billets have been extruded with 50% reduction at temperatures up to 400 C. Excellent surfaces were obtained on all extrusions. The maximum pressure decreases greatly with temperature, as shown in Table II. The deformation efficiency, η , was calculated by using the properties of Zircaloy-2 at the extrusion temperature. The efficiency remained essentially constant up to 400 C, where it decreased because of lubricant breakdown at that temperature. On the basis of these tests, 300 C was chosen as the temperature to be used for initial piercing experiments.

Billets have been pierced successfully at 300 C with a reduction of 50%. Two lubricants, Moly-Spray-Kote and 5 w/o graphite + 5 w/o MoS_2 in the resin, were used, along with five different punch profiles. The maximum pressure using the resin-carrier lubricant was less in each case. Results are shown in Table III.

CONCLUSIONS

At this point in the experimental program, production of capped Zircaloy tubes by cold extrusion looks quite promising, both technically and economically. All types of extrusions attempted to date have been successful. Technical feasibility is indicated especially by the current results of piercing (cupping) experiments. However, final judgement as to the suitability of this process for nuclear applications cannot be made until tubes have been extruded.

PLANS FOR FUTURE WORK

Additional elevated-temperature extrusion of bar will be carried out, and the product will be tensile tested both before and after annealing. Billets will be pierced at other reductions ranging from about 35 to 80% and with additional punch profiles.

Forward extrusion of open- and closed-end tubes will be carried out at reductions up to about 80%, and various die configurations will be investigated. Other extrusion variables, including temperature (up to 400 C), surface finish, and annealing cycle, will be studied experimentally. Wall thickness and reduction limitations will be established for tubular products.

PRINCIPAL INVESTIGATORS

Investigators on this project include: F. E. Weil, Metallurgist and Project Leader; J. G. Hill, Associate Metallurgist; R. C. Blair, Assistant Metallurgist. Over-all supervision is exercised by Dr. D. R. Mash, Manager, Materials Department.

TABLE I

AVERAGED RESULTS FOR FORWARD EXTRUSION OF
1¼-INCH-DIAMETER ZIRCALOY-2 BAR

Note: All specimens used the high-temperature fluoride-phosphate undercoat.

Reduction (%)	Specimen Length (in.)	Lubricant	Maximum Extrusion Pressure (psi)	Deformation Efficiency, η (%)	Surface Finish *
50	1¼	Moly-Spray-Kote	148,000	40	B
50	2½	MolyKote X-106M	135,000**	44	B
		10 w/o Graphite in Resin	137,000	43	CD
		Moly-Spray-Kote	159,000	37	B
		10 w/o MoS ₂ + 10 w/o Sb ₂ S ₃ in Resin	171,000	34	B
		Johnson 700	184,000**	32	D
65	2½	MolyKote X-106M	174,000	55	B
		5 w/o Graphite + 5 w/o MoS ₂ in Resin	196,000	49	BC
		Moly-Spray-Kote	208,000	46	A
		Amchem Granolube 10	214,000	44	CD
65	1¼	10 w/o MoS ₂ + 10 w/o PbS in Resin	150,000	63	B
		10 w/o MoS ₂ + 10 w/o Sb ₂ S ₃ in Resin	153,000	62	B
		10 w/o Graphite in Resin	153,000	62	B
		5 w/o Graphite + 5 w/o MoS ₂ in Resin	160,000	60	B
		Amchem Granolube 10	162,000	59	B
		MolyKote X-106M	166,000	57	AB
		Acheson Dag 47	167,000	57	AB
		10 w/o MoS ₂ in Resin	172,000	55	B
		10 w/o MoS ₂ + ½ w/o PbS in Resin	172,000**	55	B

See next page for footnotes.

TABLE I
(concl.)

Reduction (%)	Specimen Length (in.)	Lubricant	Maximum Extrusion Pressure (psi)	Deformation Efficiency, η (%)	Surface Finish*
65	$1\frac{1}{4}$	Moly-Spray-Kote	174,000	55	AB
		10 w/o MoS_2 + 1 w/o PbS in Resin	177,000**	54	B
		10 w/o MoS_2 + 1 w/o Sb_2S_3 in Resin	179,000**	53	B
		Poxylube 75	186,000	51	BC
		10 w/o MoS_2 + $\frac{1}{2}$ w/o Sb_2S_3 in Resin	198,000**	48	B
80	$1\frac{1}{4}$	10 w/o Graphite in Resin	199,000	79	BC
		5 w/o Graphite + 5 w/o MoS_2 in Resin	211,000	75	BC
		MolyKote X-106M	221,000	71	CD
		10 w/o MoS_2 in Resin	222,000	70	C
		Moly-Spray-Kote	226,000	69	AB
		10 w/o MoS_2 + 10 w/o Sb_2S_3 in Resin	232,000	68	B
		Amchem Granolube 10	244,000	65	AB
		Acheson Dag 47	246,000	64	B
		10 w/o MoS_2 + 10 w/o PbS in Resin	257,000	61	BC
80	$2\frac{1}{2}$	Moly-Spray-Kote	272,000	58	D
Specimens with $\frac{1}{2}$ -inch-long Type 2024 Aluminum Followers.					
65	$1\frac{1}{4}$	5 w/o Graphite + 5 w/o MoS_2 in Resin	166,000	57	B
		Moly-Spray-Kote	196,000	49	B

* Surface-quality grading system: A = Smooth, no scratches or scoring; B = Smooth, few light scratches; C = Slightly scored; D = Badly scored.

** Only one valid test.

TABLE II
EXTRUSION PRESSURES AND EFFICIENCIES WITH
50% REDUCTION, USING 2½-INCH SPECIMENS

Notes: All specimens used the high-temperature fluoride-phosphate undercoat.
All specimens had "A" surfaces.

Temperature (°C)	5 w/o Graphite + 5 w/o MoS ₂ in Resin		Moly-Spray-Kote	
	Maximum Pressure (psi)	Efficiency, η (%)	Maximum Pressure (psi)	Efficiency, η (%)
Room temp.	--	--	159,000	37
100	126,000	43	138,000	39
200	90,000	42	96,000	39
300	72,000	41	78,000	38
400	66,000	37	93,000	36

TABLE III
PIERCING-EXPERIMENT RESULTS WITH 50% REDUCTION AT 300° C

Note: All specimens used the high-temperature fluoride-phosphate undercoat.

Punch Profile	Maximum Pressure (psi)	
	5 w/o Graphite + 5 w/o MoS ₂ in Resin	Moly-Spray-Kote
Spherical, 140° included angle	235,000	246,000
Flat	236,000	242,000
Conical, 140° included angle	245,000	248,000
Hemispherical, 180° included angle	254,000	267,000
Conical, 170° included angle	263,000	266,000

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