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Technical Progress Report

INVESTIGATION OF THE TECHNICAL FEASIBILITY OF COLD EXTRUSION FOR ZIRCALOY-2 TUBING PRODUCTION

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UNITED STATES-EURATOM JOINT RESEARCH AND DEVELOPMENT PROGRAM

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DISCLAIMER

INTRODUCTION

This report summarizes progress to date on the cold-extruded Zircaloy-2 tubing program. The over-all objective of the program is to establish the feasibility of using cold extrusion to produce Zircaloy-2 tubular products. The first phase, now in progress, is concerned with determining basic feasibility and evaluating lubricants.

PROGRESS DURING SEPTEMBER

Forty-eight additional regular extrusion tests were carried out during September at reductions of 50, 65, and 80%. Failure of the 80% die prevented the completion of that series of tests.

The plotted pressure-stroke curve of each test was examined, and the maximum pressure obtained from the plot was compared to the pressure obtained from the pressure gauge. The plotted pressure was determined to be more accurate and reliable, since the pressure gauge does not register instantaneous peak pressure surges. Therefore, all of the extrusion tests were re-evaluated on the basis of the maximum plotted pressure. Results are tabulated below. All specimens used the high-temperature fluoride-phosphate base coating.

A number of tests were carried out using lubricants consisting of various amounts of lead sulfide (PbS) and antimony sulfide (Sb_2S_3) added to a suspension of molybdenum disulfide (MoS_2) in resin. As seen in the tabulation, when 10% of these additions are used, the effectiveness of the lubricant is greatly increased. It is planned to continue the exploration of these lubricant systems in order to determine the optimum concentration of the additivies.

Reduction (%)	Specimen Length (in.)	Lubricant	Maximum Pressure (psi)	Efficiency, η (%)
50	1-1/4	Moly-Spray-Kote	148,000	40
50	2-1/2	MolyKote X-106M	135,000	44
		10% graphite in resin	137,000	43
		Moly-Spray-Kote	159,000	37
		10% MoS_2 + 10% Sb_2S_3 in resin	171,000	34
		Johnson 700	184,000*	32
65	1-1/4	10% MoS_2 + 10% PbS in resin	150,000	63
		10% MoS_2 + 10% Sb_2S_3 in resin	153,000	62
		10% graphite in resin	153,000	62
		5% graphite + 5% MoS_2 in resin	160,000	60

Reduction (%)	Specimen Length (in.)	Lubricant	Maximum Pressure (psi)	Efficency η (%)
		Amchem Granolube 10	162,000	59
		MolyKote X-106M	166,000	57
		Dag 47	167,000	57
		10% MoS_2 in resin	172,000	55
		10% MoS_2 + 1/2% PbS in resin	172,000*	55
		Moly-Spray-Kote	174,000	55
		10% MoS_2 + 1% PbS in resin	177,000*	54
		10% MoS_2 + 1% Sb_2S_3 in resin	179,000*	53
		Poxylube 75	186,000*	51
		10% MoS_2 + 1/2% Sb_2S_3 in resin	198,000*	48
65	2-1/2	MolyKote X-106M	174,000	55
		5% graphite + 5% MoS_2 in resin	199,000	48
		Moly-Spray-Kote	208,000	46
		Amchem Granolube 10	214,000	44
80	1-1/4	5% graphite + 5% MoS_2 in resin	189,000*	83
		10% MoS_2 in resin	199,000*	79
		10% graphite in resin	213,000*	74
		MolyKote X-106M	224,000*	70
		Moly-Spray-Kote	232,000*	68

* Only one valid test.

Seven specimens were extruded, each using a ½-inch-long type 2024 aluminum follower. The objective was to minimize Zircaloy scrap loss by completely extruding the billet. The aluminum used a chromate-phosphate conversion coating and the same lubricant as the Zircaloy billet.

In the first series, using annealed followers, the billets extruded satisfactorily but had a pipe or extrusion defect extending about 1 inch into the extruded bar at the butt end. By changing to followers in the hardened T-4 condition, the properties of the follower were made to closely match those of the billet and the length of pipe was reduced to 1/2 inch. The peak extrusion pressure for samples coated with 5% graphite + 5% MoS_2 in resin was about 5% higher than without a follower. For samples coated with Moly-Spray-Kote, the pressure was about 15% higher. Further work will be done with followers in an attempt to reduce the defect length in the extrusion.

Work was continued on the economic evaluation of cold extrusion. The results of this study will be included in the Phase I final report.

SUMMARY AND CONCLUSIONS

Phase I of the subject investigation is nearing completion. Sufficient progress has been made to indicate clearly the basic feasibility of cold extruding Zircaloy-2.

Lubrication systems, composed of a lubricant and a conversion coating, were developed and evaluated for the current application. On the basis of this work, a fluoride-phosphate base coating and a number of promising lubricants were selected for actual extrusion tests.

Bars of Zircaloy-2 were successfully cold-extruded to reductions of 50, 65, and 80%. The best lubricants provided excellent surface finish, and no evidence of cracks or other defects could be found in the specimens. Annealed extruded specimens exhibited the same tensile properties as annealed raw stock. Deformation efficiency was found to be in the same range as for cold-extruded aluminum, titanium, and steel.

A review of the economic potential of this process for tubing production has shown that:

1) Cold extrusion of Zircaloy-2 heavy-walled tube shells is economic if sufficient production volume exists. The increased quality and closer tolerances associated with cold-extruded shells would be helpful in subsequent tubing-manufacture steps.
2) Cold extrusion 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.

FUTURE WORK

Assuming that the required approval to proceed with Phase II of the program is received, the following work will be conducted.

1) Evaluation of lubricants will continue, especially of MoS_2 with additions of PbS or Sb_2S_3.
2) The effect of increased extrusion temperatures up to about 400°C, surface finish, annealing cycle, etc., will be investigated.
3) The technique and limits of making Zircaloy-2 tubular extrusions will be investigated; piercing (cupping) of round specimens will be attempted at various reductions up to about 70%. The effect of various punch configurations will be evaluated.

4) Forward extrusion of open-end, closed-end tubes will be made at reductions up to about 75%, and various die configurations will be evaluated to minimize the extrusion pressure and provide a smooth surface. The lower limit on wall thickness will also be determined.

PROJECT PERSONNEL

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

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