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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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Submitted by:
F. E. Weil

Approved by:
H. R. Hulett
D. D. Foley

ADVANCED TECHNOLOGY LABORATORIES
A Division of American-Standard
369 Whisman Road
Mountain View, California

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STATEMENT OF PROBLEM

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 was concerned with evaluating lubricants and determining the basic feasibility of cold-extruding Zircaloy-2. The relative costs of the process were also 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

The basic feasibility of cold-extruding Zircaloy-2 was demonstrated during Phase I, through examination of a number of important variables.

Lubrication systems composed of a lubricant and a conversion coating were developed and evaluated by a special compression test. Based on the results obtained, a fluoride phosphate conversion coat and a number of lubricants were chosen for the extrusion tests. Bars of Zircaloy-2 extruded at reductions of 50, 65, and 85% exhibited excellent surfaces with no evidence of cracks or other defects. The fluoride phosphate conversion coat in connection with a lubricant containing 8 w/o MoS_2 and 2 w/o Sb_2S_3 in resin provided the best results.

Preliminary extrusions were initiated on $1\frac{1}{4}$" diameter billets to provide an accurate basis for determining tool design for the actual fuel-element-size tube extrusions. Billets were pierced using eight different punch profiles, with a 140-degree conical punch profile producing the best results. Open-end tubes (approx. 1-inch OD) were extruded successfully with maximum reductions of 80% and final wall thicknesses down to 0.024 inch. Again the 8 w/o MoS_2 and 2 w/o Sb_2S_3 in resin lubricant provided the best results and was chosen as the lubricant for the small-size tube-extrusion tests.

A series of bar extrusions was performed to evaluate tensile properties of specimens given various annealing treatments. For commercial Zircaloy-2 (containing 1200 ppm oxygen), a short-time treatment (20 minutes at 660°C) provided tensile results comparable to those obtained from the standard treatment of 6 hours at 800°C. The purpose of the short-time annealing treatment, other than the obvious time saving, was to minimize grain growth during the annealing treatments.

Tools for extruding fuel-element-size tubing (0.560" OD × 0.030" wall) were designed, fabricated, tested, modified as indicated, and finalized. The tubing is produced from 1-inch-diameter billets in one piercing and two forward-extrusion steps. Short lengths of tubing have been extruded, and tube quality appears to be excellent. Wall thickness has a maximum variation of only 0.001 inch on the most recently extruded specimens. No cracks or other defects have been found in the extruded tubing. Minor tooling difficulties prevented the production of tubing in quantities large enough to permit performance of adequate evaluation studies.

Pole figures depicting the preferred orientation of commercial* and cold-extruded Zircaloy-2 tubing were completed. Results indicate that cold-extruded tubing should exhibit greater burst strength than drawn tubing because of the more favorable orientation of its slip planes.

A preliminary analysis of the economic potential of this process for Zircaloy-2 tubing production has shown that the cold extrusion of heavy-walled tube shells is economic, and production of thin-walled fuel-containing tubes with integral end caps is definitely promising because a better product can be obtained at considerably lower cost than that currently associated with reactor-grade plain tubing.

PROGRESS OCTOBER-DECEMBER 1961

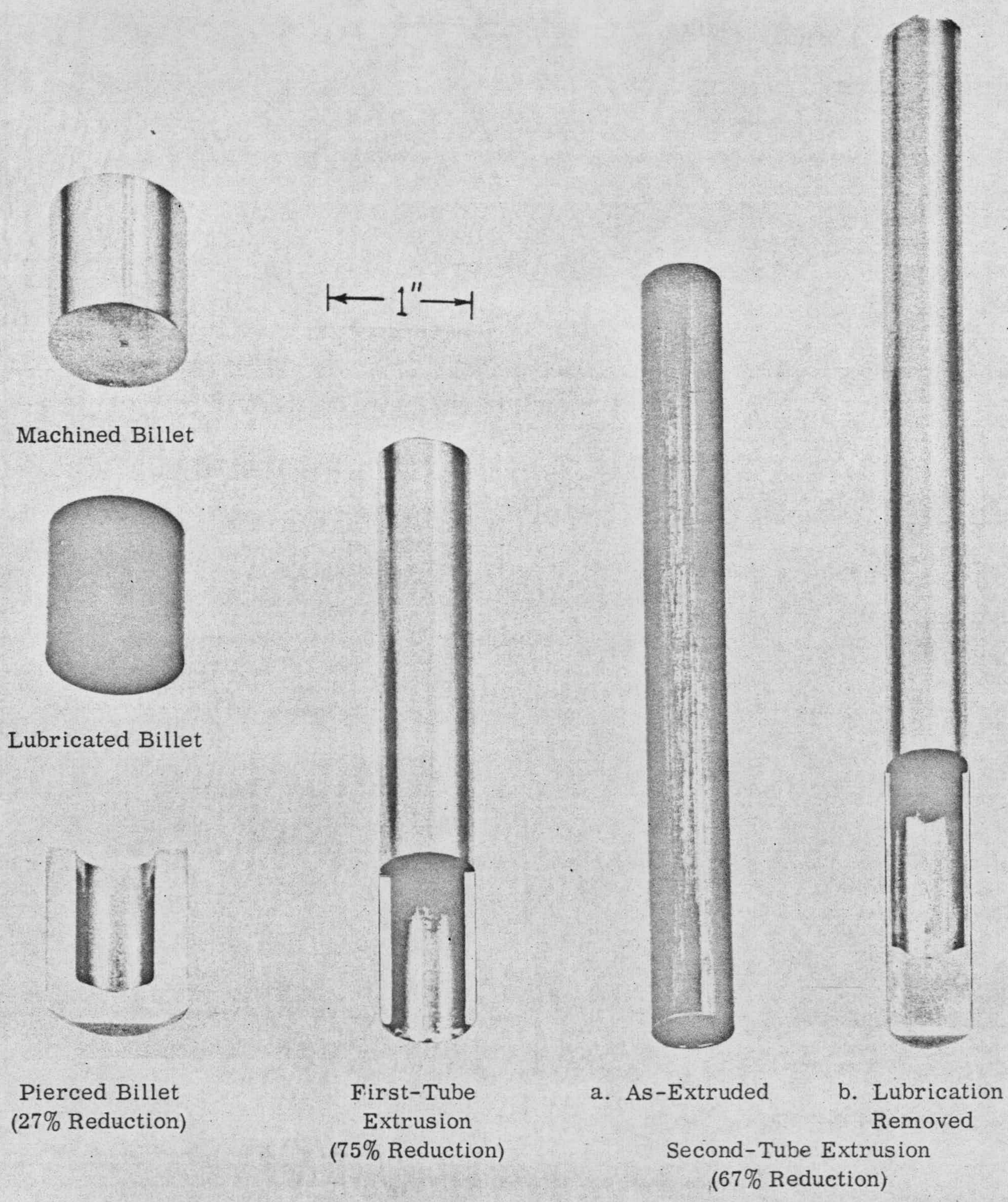
A. Extrusion of Small Tubes

The extrusion of fuel-element-size tubing was continued this quarter, with emphasis on finalizing tool-design requirements for the one piercing and two forward-extrusion steps. Figure 1 shows the product at each stage of the sequence of operations required to produce the final tubing.

1. Piercing

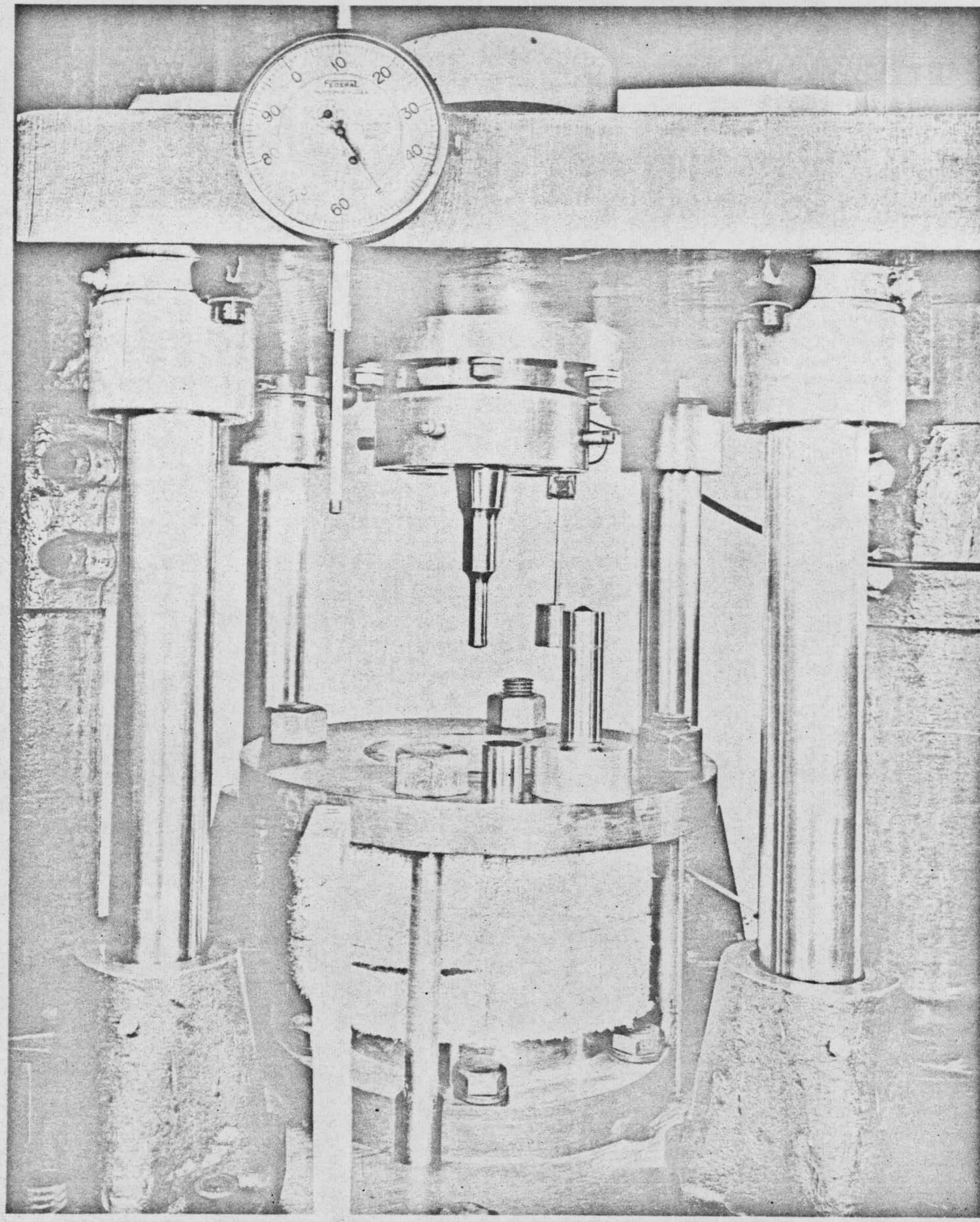
The precision die set for piercing was completed, and 50 billets were pierced. Figure 2 shows the die set installed in the extrusion press. The apparatus consists of normal piercing tooling accurately assembled in a precision die set. The wall thickness of cups pierced with this die set varied by 0.002 inch, compared with as much as 0.010 inch in cups pierced with the original tooling. This non-concentricity is reduced appreciably in the subsequent extrusion steps.

* Commercial tubing is standard hot-extruded, rocked, and cold-drawn seamless tubing.



EXTRUSION SAMPLES IN STAGES OF TUBING DEVELOPMENT

FIGURE 1



PRECISION DIE SET WITH PIERCING TOOLING INSTALLED
(Piercing anvil and coining punch shown in foreground.)

FIGURE 2

The anvils designed to form the final outside diameter during the piercing operation were not successful. The pierced cups could not be removed from the anvil economically, and the remaining surface was badly galled. Additional anvils of regular design were fabricated to reduce the bottom thickness of the pierced billets.

The completion of these piercing tests finalized tool design and extrusion procedures for the piercing operation. Measurements of the as-pierced cups indicate that the die set will provide the alignment needed to produce tubing with wall-thickness variances less than 0.001 inch.

2. First-Tube Extrusions

During this quarter, 50 first-tube extrusions were performed, all with an integral-mandrel-type punch; therefore, the tube caps still separated from the wall. Floating-mandrel punches have been fabricated and will be used on subsequent first-tube extrusions, to prevent end-cap separation.

Ten of the extrusions were performed on machined rather than as-pierced billets, but no difference in quality was apparent. As expected, wall-thickness variances of the as-pierced cups were decreased to 0.0008 to 0.0010 inch by the 75% reduction of this extrusion. Initial extrusions of this series exhibited galled and gouged surfaces, because the lubrication had broken down completely. The surface became too hot during extrusion, causing the lubricant to decompose. The die was re-ground, and the remaining extrusions were performed at a much slower speed. No burning was evident, and the resulting surfaces were excellent.

A few specimens were extruded with sprayed, instead of dipped, lubricant coatings. No appreciable difference was noticed, except that the dipped coating, being thicker, had a tendency to strip from the specimen under extreme conditions.

3. Second-Tube Extrusions

Tooling difficulties have prevented consistent successful results on the final tube extrusion. Only eight second-tube extrusions were completed this quarter because of faulty punches and a delay in receipt of replacement punches. The extrusions that were completed exhibited excellent surfaces and varied in wall thickness by less than 0.001 inch. Since tooling difficulties apparently have been solved, a number of final tubes should be fabricated during the coming quarter.

B. Tubing Evaluation

The lack of adequate quantities of finished tubing has delayed the evaluation studies. The pole-figure work on preferred orientation was completed, but no tensile, burst, or stress-rupture tests were performed.

1. Pole-Figure Studies

Pole figures comparing the preferred orientation of commercial and ATL cold-extruded Zircaloy-2 tubing were completed. The tests were performed with a Schulz Modified Pole-Figure Device manufactured by the Phillips Electronic Co. Results were compared against a standard random zirconium sample.

The general texture of the ATL cold-extruded tubing can be described as having the basal plane (0001) parallel to the extrusion direction and rotated about 15 degrees out of the plane of the tube surface. The texture of the commercial tubing is the same; however, the basal plane (0001) is rotated about 70 degrees to the tube surface. In each case, the direction $[10\bar{1}0]$ is parallel to the extrusion direction. This indicates that ATL tubing should exhibit greater burst strength, since the primary slip planes, the $\{10\bar{1}0\}$ system, are 75 degrees away from the direction for slip in the tubing for extruded tubing and only 20 degrees away for drawn tubing. The results from the pole-figure studies will be reported in greater detail in the final report.

2. Burst Tests

No burst tests were performed this quarter; however, the equipment has been designed and fabricated and is ready whenever sufficient tubing is available for test. The commercial tubing will be compared to the cold-extruded tubing.

CONCLUSIONS

It has been shown that short-length reactor-size (0.560" OD × 0.030" wall) Zircaloy-2 tubing can be cold-extruded from 1-inch-diameter bar stock. Tubing quality is excellent, with no evidence of cracks or other defects. The maximum length that can be produced directly by cold extrusion is probably about 2 to 3 feet, but this can be increased by using a final cold-drawing operation. The main advantages of the cold-extrusion process (compressive forming, low scrap loss, dimensional accuracy, low cost, elimination of the tube rocking process) would still be present. According to preliminary analysis, the cold-extrusion process should be economic for production of tubing, and a better product should result than that obtained from conventional methods.

FUTURE WORK

The extrusion of small-size tubing will be continued, with program emphasis on evaluation of tube quality. Tubes will be tensile tested, burst tested, and stress-rupture tested. A final report will be submitted at the end of the next quarter. A proposal for the investigation of drawing cold-extruded tubes is being submitted.

PRINCIPAL INVESTIGATORS

Investigators on this project include: F. E. Weil, Section Supervisor and Project Leader; J. G. Hill, Associate Metallurgist. Over-all supervision is exercised by Dr. D. D. Foley, Manager, Materials Laboratory.

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