Distribution of this document is unlimited.





# CONVAIR

A DIVISION OF GENERAL DYNAMICS CORPORATION
SAN DIEGO

CONVAIR-SD
Applied Manufacturing Research
Department 190-2

No.: PR 951

Date: April 1961

Ref.: PR 951, W.O. 27093

# FEASIBILITY OF STABILIZING HEAT-TREATED ALUMINUM ALLOY FORGINGS



FINAL REPORT



Prepared by: L. J. Mattek
L. J. Mattek
Mfg. Development Engineer

Approved by: W. E. Wise
Dr. E. L. Armi, Chief
Applied Mfg. Research



Distribution List: 1.0 b

Convair-San Diego

# FEASIBILITY OF STABILIZING HEAT-TREATED ALUMINUM ALLOY FORGINGS


## ABSTRACT

Aluminum forgings were stabilized by super cooling with liquid nitrogen followed by rapid heating with high pressure steam immediately after solution heat-treat quenching. Distortion, during subsequent machining, was not reduced in the stabilized forgings in relation to non-stabilized forgings. The large variation in the forging contour apparently was a critical deterrent to reduction of residual stresses by this method of stabilizing.

Convair-San Diego

1. PROJECT TITLE: FEASIBILITY OF STABILIZING HEAT-TREATED ALUMINUM ALLOY FORGINGS.

2. STATEMENT OF PROBLEM:

Heat-treated aluminum alloy forgings tend to warp erratically, as machining removes portions of metal containing high degrees of residual stresses. The residual stresses were introduced in the forgings by thermal gradient action during the water quenching phase of the heat-treatment.

3. OBJECTIVE:

To stabilize aluminum alloy forgings by the Alcoa method during heat-treatment and measure the amount of distortion which occurs during machining of the stabilized forgings in comparison to forgings which were not stabilized.

4. PURPOSE:

To evaluate the degree of distortion reduction, if any, during machining of the stabilized forgings and to determine the feasibility of adapting the stabilizing treatment on a production basis.

5. CONCLUSION:

Forgings stabilized by the Alcoa method distorted overall as extensively as the non-stabilized forgings during the machining operations. The forgings tested contained large, heavy walled pockets with thin walled liners at the base of the pockets. Apparently, the thin walled sections yield to a degree seconds prior to the yielding in the heavy section. The yielding in the heavy sections at a later time interval then promotes additional stresses in the thinner sections. The resulting complex nature of yielding in one area developing new stresses in other areas tends to result in negligible stress relief

5. CONCLUSION:

overall in the final condition.

6. RECOMMENDATIONS:

(1) Conduct stabilization on the same type forgings by a heat flash method which operates at temperatures roughly 300 to 400°F higher than the temperatures of the Alcoa method. At these higher temperatures, the yield strength may be only 1/8 to 1/2 the value at the lower temperatures. The higher relief temperatures should result in a very much lower level of net residual stresses.

(2) Conduct stabilizing by both the Alcoa and the heat flash methods on forgings of relatively uniform cross sections in order to determine if either process is applicable to forgings limited to uniform sections only. (This P.R. would be undertaken only if the investigation proposed in Item 1 turned out negative.)

7. PROCEDURE:

7.1 Background:

The Alcoa Corporation[1] has applied for a patent on stabilizing of heat-treated aluminum alloy forgings. Stabilizing is intended to reduce residual stresses which were introduced by the thermal gradient action of water quenching during heat-treatment. The residual stresses promote erratic warpage of the parts as subsequent machining removes portions of the stressed metal. Alcoa's process reverses the quenching action by super cooling the parts followed by rapid heating with high pressure live steam. This reverse thermal action is intended to reverse the quench stresses with a net result that most residual

---

1 The Thermo-Mechanical Method of Relieving Residual Quenching Stresses in Aluminum Alloys. By H.N. Hill and L.A. Willey, ASM Transaction V-52, pages 657-674.

7. PROCEDURE:

7.1 Background: (Cont'd)

stresses are cancelled out.

7.2 Forging Treatments:

Four forgings, Part No. 8-18782 rib wing parts of 7075-T6 aluminum alloy were selected for testing. Parts number 1 and 2 were stabilized as follows:

a. Solution heat-treated per MPS 51.01.

b. After water quenching at 160°F, the parts were cooled to -280° to -290°F, first in cold water, then trichlorethylene and dry ice, then in a liquid nitrogen cell. The cooling took approximately four hours.

c. The parts were then heated rapidly with 375°F live steam for 45 minutes.

d. The parts were aged per MPS 51.02.

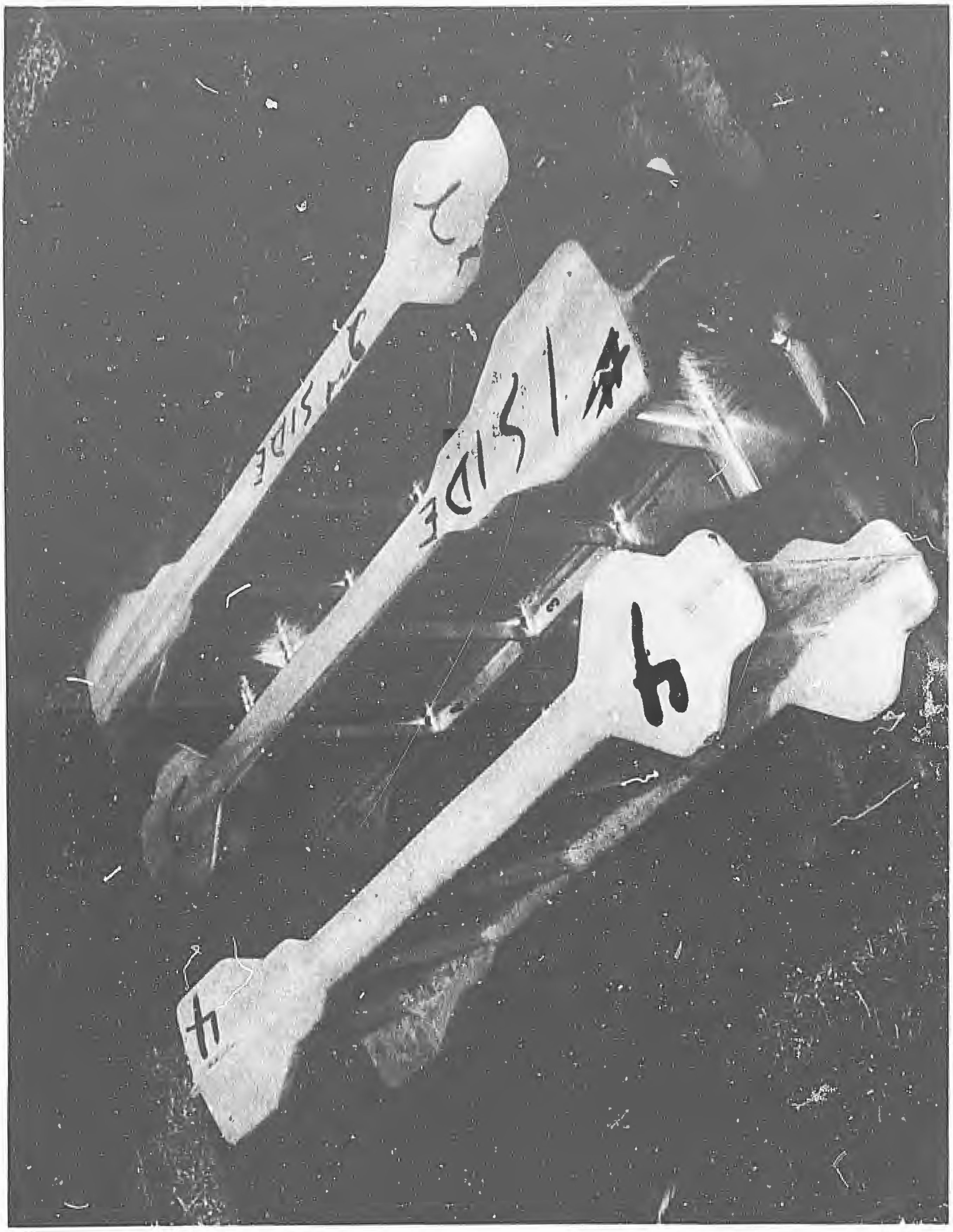
Part #3 was reheat-treated per MPS 51.01 and 51.02, but was not stabilized per steps b and c above.

Part #4 was retained in the original T-6 condition.

The reheat-treatment and stabilizing was subcontracted and conducted by Cal Doran, Los Angeles.

7.3 Machining:

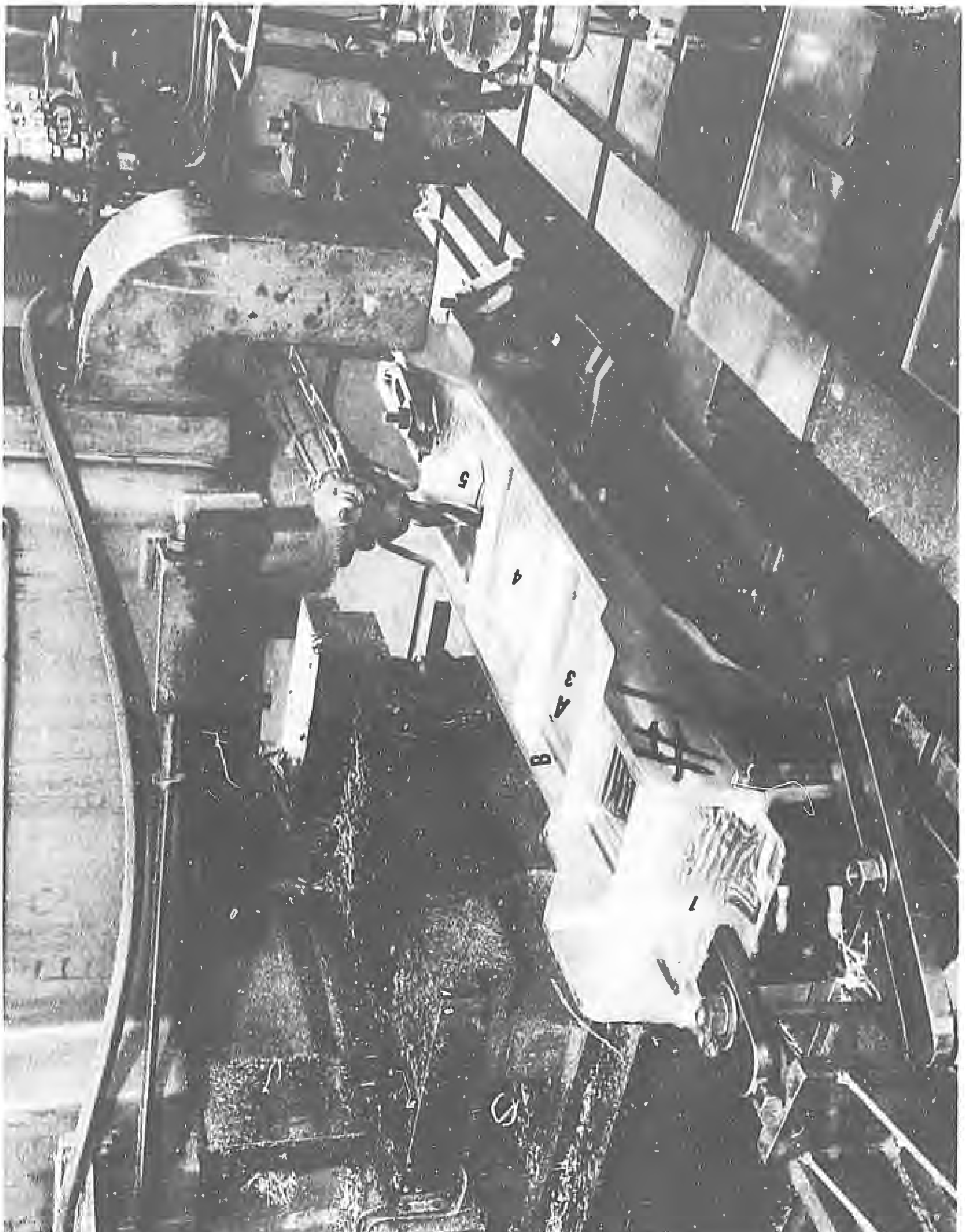
Photographs of the forgings taken during the machining operations are as shown in Figures 1 and 2. Forging #4 in Figure 1 has not been machined. The edges of the forgings are marked 1st or 2nd as the machining sequence proceeded. The pockets in the forgings are identified by numbers from 1 to 5 in each photograph. The pocket sides were also identified as first or second to denote the machining sequence.



Machined Forgings Nos. 2 and 3 Unmachined Forging No. 4

Figure 1

Convair Print 70078




Convair Print 70076

Machining Forging No. 1

Figure 2

7. PROCEDURE:

7.3 Machining: (Cont'd)

The forgings were machined in a Sunstrand Profiler, part of which is visible in Figure 2. The edges of the forgings were machined with a 10" face mill, with a 0.060" radius. The pockets, as shown in Figure 2, were milled out with a 1-1/4" flute end mill with a 0.125" radius run at 180 rpm. The pockets were flooded with spray mist coolant during milling to assure that the forging remained cool in order to avoid distortion from hot spots caused by milling.

8. RESULTS:

8.1 Distortion During Machining:

Distortion measurements taken as each machining sequence was completed are tabulated in Table I.

The degree of twist in the over-all forging was measured as each machining sequence was completed. The bottom of each pocket was measured for distortion after the final machining operation.

Each forging was machined similarly, except forging 4 which contained a rather drastic "oil canning" in pocket 2 before the machining operation started. During the first side machining of the pockets, the "oil canning" of the #2 pocket became so bad that the machining tool went right through the pocket before the first rough machining of the pockets could be accomplished. The twist of the number 4 forging was similar to the number 3 forging up to that point. Further machining of number 4 forging was then discontinued.

When the average distortion twist in each forging was compared,

TABLE I

DISTORTION MEASUREMENTS TAKEN AS MACHINING PROCEEDED

| Sequence of Machining | #1 Forging (Stabilized) | #2 Forging (Stabilized) | #3 Forging (Not Stabilized*) | #4 Forging (Not Stabilized*) |
|---|---|---|---|---|
| Mill Edge 1 | 0.014" Twist on Edge 1 | 0.012" Twist on Edge 1 | Flat | Flat |
| Mill Edge 2 | 0.006" Twist on Edge 2 | Flat | Flat | 0.006" Twist on Edge 2 |
| Rough Pocket Side 1 | 0.036" Twist on Edge 1<br>1.054" Twist on Edge 2 | 0.068" Twist on Edge 1<br>0.047" Twist on Edge 2 | 0.010" Twist on Edge 1<br>0.008" Twist on Edge 2 | 0.010" Twist on Edge 1<br>0.008" Twist on Edge 2 |
| Rough Pockets Side 2 | 0.020" Twist on Edge 1<br>0.012" Twist on Edge 2 | 0.029" Twist on Edge 1<br>0.015" Twist on Edge 2 | 0.013" Twist on Edge 1<br>0.010" Twist on Edge 2 | Oil Canning Caused<br>Tool to go throuh Plt.2 (Machining Discontinued) |
| Rough Finish Pocket Side 1 | 0.041" Twist on Edge 1<br>0.023" Twist on Edge 2 | 0.054" Twist on Edge 1<br>0.041" Twist on Edge 2 | 0.023" Twist on Edge 1<br>0.015" Twist on Edge 2 | |
| Average Twist | 0.026" | 0.033 | 0.010" | |
| Rough Finish Pocket Side 2 | CONCAVITY MEASURED FROM ONE SIDE. | | | |
| Pocket 1<br>2<br>3<br>4<br>5 | 0.020" Concave<br>O.K.<br>0.100" Concave<br>0.070" Convex<br>0.150" Concave | O.K.<br>0.150" Concave<br>0.140" Concave<br>0.030" Convex<br>0.010" Concave | 0.050" Concave<br>0.140" Concave<br>0.090" Convex<br>0.090" Concave<br>0.110" Convex | |
| Av. Pocket Distortion | 0.068" | 0.066" | 0.096" | |

* Although forging #3 was not stabilized, it was re-heat-treated along with forgings #1 and #2. Forging #4 was not re-heat-treated.

8. RESULTS:

8.1 Distortion During Machining: (Cont'd)

it was found that the two stabilized forgings twisted an average 0.030" for each measurement. The number 3 forging, not stabilized, twisted an average of 0.010" per reading. The number 4 forging twisted similarly to forging number 3, as far as the machining was conducted.

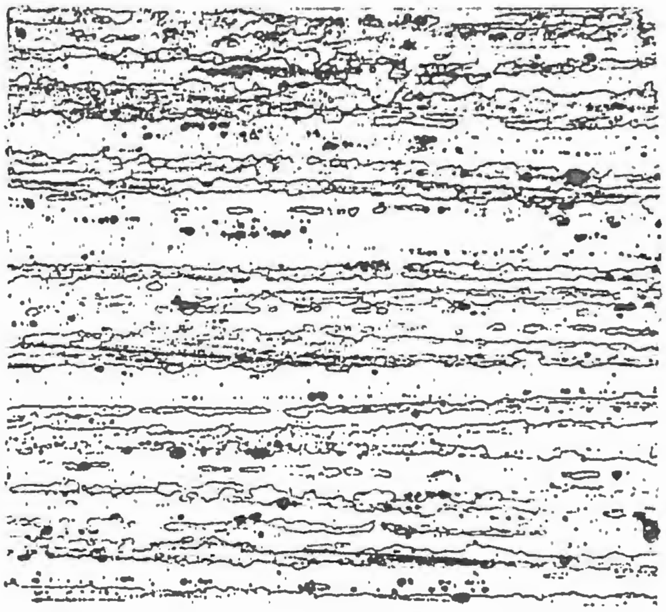
The degree of "oil Canning" distortion at the bottom of each pocket for the two stabilized forgings averaged 0.067". The non-stabilized forging number 3 "oil canned" 0.096" average. Forging 4 was not measured for "oil canning" because the machining operations could not be fully accomplished.

It is evident from the above measurements that the degree of distortion over-all was not improved by the stabilizing treatment. The wide variation from heavy to thin sections probably was a decisive factor in the erratic distortions that resulted.

8.2 Metallographic Examination:

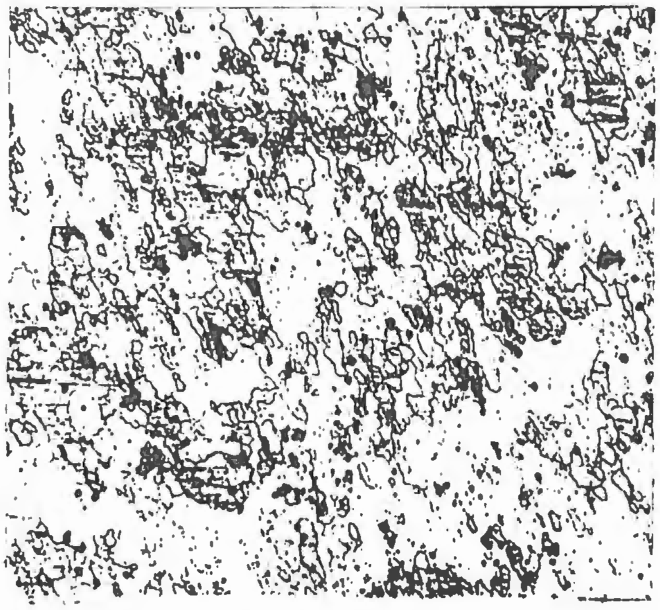
Metallographic examinations were made of the thin pocket liner areas and the heavier edge section of each forging as located at A and B, respectively, in pocket 3 of the forging of Figure 2. There was no apparent difference in microstructure of the stabilized forging shown in Figures 3 and 4, compared to the non-stabilized forgings of Figures 5 and 6.

Material & Process Lab. Print 2768



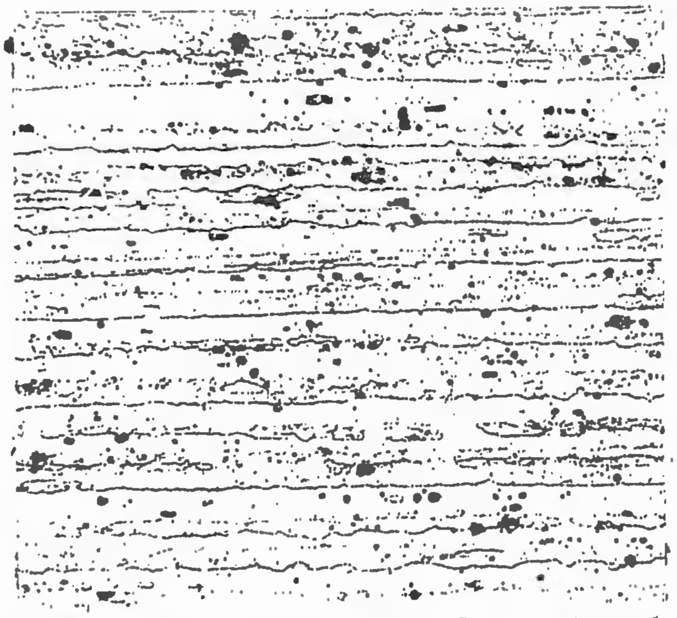
Stabilized Forging No. 1 Area A
Kellers Etch 200X
Figure 3

Material & Process Lab. Print 2770



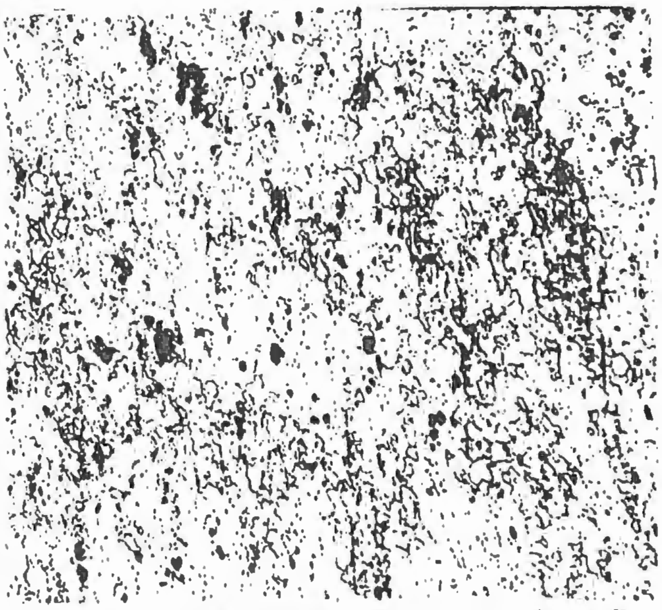
Stabilized Forging No. 1 Area B
200X
Figure 4

Material & Process Lab. Print 2769



Unstabilized Forging No. 3 Area A
Kellers Etch 200X
Figure 5

Material & Process Lab. Print 2771



Unstabilized Forging No. 3 Area B
Kellers Etch 200X
Figure 6