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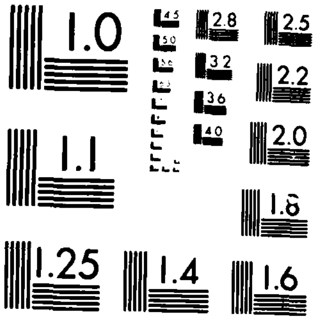

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TECHNICAL REPORT ARCCB-TR-85001

# MATERIAL PROPERTY AND FRACTURE TESTING OF 7075-T6 EXTRUDED ALUMINUM

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NOVEMBER 1985

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

The results of an experimental investigation into the material properties of 7075-T6 extruded aluminum used in the production of sabots for kinetic energy projectiles are presented. A comparison is made of two suppliers' materials, and a test is described that will show a difference exists in the two suppliers' materials.

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# INTRODUCTION

In the Spring of 1984 during acceptance testing of the M833 projectile, severe breakup of the aluminum discarding sabot was observed. This breakup had not been noted previously. The acceptance tests were being conducted because a new supplier of extruded 7075-T6 aluminum was being used. The task of this unit was to determine if there were any differences in the material properties of the two suppliers' materials. Since both materials obviously met the specifications (tensile strength and elongation), a different series of tests was considered and conducted. Fracture toughness was considered because brittle, fragmentation failures were observed. Also, tests were mainly conducted at -40°F because the breakups occurred at this temperature; however, testing was conducted at room temperature for information and for determining trends in the data.

We conducted two types of toughness tests in two orientations. The toughness tests were the traditional $K_{Ic}$ test described in ASTM Method (ref 1) E-399 and a test described as Slow Notch Bend Energy (SNBE). The second test measures the total energy-to-failure for a notched Charpy specimen. The specimen orientations studied were the longitudinal and transverse directions, that is, the L-R and R-L orientations of Reference 1. Two groups of materials were investigated, one with no observed failures from supplier number 2, the other with many observed failures from supplier number 1.

Our investigation also included metallography, chemistry, and scanning

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[1] "Standard Test Method for Plane-Strain Fracture Toughness of Metallic Materials," 1985 ASTM Annual Book of Standards, Vol. 03.01, ASTM, Philadelphia, PA, 1985, pp. 547-582.

electron microscopy (SEM) observations. In this report, we will touch on those areas as well as the mechanical properties testing.

## MATERIALS

The materials were supplied as extruded sectors and finish-machined petals from the extrusion. The materials from both suppliers met the established requirements in terms of the yield strength, elongation, and chemistry. There may have been some differences in the type and amount of plastic work in the materials of each supplier. The material will be described as supplier number 1 and supplier number 2 material.

## SPECIMENS

The specimens were removed from the material as described in ASTM E-399 (ref 1) and as shown in Figure 1. The specimens were machined using the same equipment and, as much as possible, the same machinist. In the case of the SNBE test, the notch was put in using the same equipment (a broach) and thus, should have only minor variations from one supplier to the other.

## TESTS AND APPARATUS

Figure 2a is a schematic of the SNBE test. It shows a standard Charpy (ref 2) sized bend specimen mounted for a three-point bend test. The tests were conducted in a servo-hydraulic tensile test machine. The tensile machine

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[1] "Standard Test Method for Plane-Strain Fracture Toughness of Metallic Materials," 1985 ASTM Annual Book of Standards, Vol. 03.01, ASTM, Philadelphia, PA, 1985, pp. 547-582.

[2] "Standard Methods for Notched Bar Impact Testing of Metallic Materials," 1985 ASTM Annual Book of Standards, Vol. 03.01, ASTM, Philadelphia, PA, pp. 235-258.

was run in the stroke control mode and the time to fail a specimen was approximately 1.5 minutes. The deflection of the specimen was measured slightly offset from the midpoint of the beam, and the conversion to load-line displacement is shown. Figure 2b shows a load deflection curve where the deflection has been converted to load-line deflection and the area under the curve is the energy-to-failure of a specimen.

The other tests such as tensile and $K_{Ic}$ tests were conducted according to the applicable ASTM specification.

## DISCUSSION AND PRESENTATION OF RESULTS

### General

In the beginning of the testing, a distinct difference existed in the two suppliers' materials, but as testing was continued on materials produced later in the cycle of production, the lower results of the tests from the better supplier began to fall into the range of the higher results of the other supplier. Metallographic results also showed some phenomena that were unexpected. The experimental test results will generally be presented chronologically to show how the data gathering progressed, and then conclusions will be drawn from the entire data base.

### Tensile Tests

Table I presents the yield and ultimate strength results for the two suppliers' materials measured in the two orientations. The longitudinal tests were conducted on specimens 0.550 inch in diameter and the transverse tests were conducted on specimens 0.160 inch in diameter. These were standard and small-size specimens from ASTM Method E-8 (ref 3). The results of the tensile strength tests are inconclusive as one supplier was higher at times, while the other supplier was higher at other times. The trend that strength increases with lower temperatures was expected.

## Toughness Tests

Table II presents the results of $K_{Ic}$ testing conducted on the two suppliers' materials. The only significant difference that can be seen is from tests conducted in the R-L direction where the supplier number 2 material was 15 percent better at room temperature and 19 percent better at -40°F.

Table III presents the results of SNBE tests conducted on the two suppliers' materials. Here we can see that the supplier number 2 results are superior in both the L-R and R-L orientations. The SNBE test results at -40°F showed that the supplier number 2 materials are 20 percent better. Since the failures occurred at -40°F and the rear skirt failure and parts of the other failures were considered to be basically R-L in nature, the SNBE test in the R-L orientation conducted at -40°F was chosen as the test to be concentrated on for future testing.

It is worthy of note that in prior work (ref 4) SNBE tests gave a better description of the ability of a notched component to survive launch loading than did the $K_{Ic}$ tests. Thus, the prior work and the current work gave

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[3] "Standard Methods of Tension Testing of Metallic Materials," 1985 ASTM Annual Book of Standards, Vol. 03.01, ASTM, Philadelphia, PA, 1985, pp. 130-151.

[4] J. H. Underwood and M. A. Scavullo, "Fracture Behavior of a Uranium or Tungsten Alloy Notched Component With Inertia Loading," Fracture Mechanics: Sixteenth Symposium, ASTM, STP 868, (M. F. Kanninen and A. T. Hopper, eds.), ASTM, 1985, pp. 554-568.

similar results in this respect, and the basic reason is believed to be the same. Since the component in both cases was notched and was not believed to be cracked, the SNBE test of a notched specimen gave better results than the $K_{Ic}$ test of a precracked specimen.

Table IV presents the results of additional SNBE testing conducted on the two materials. For the R-L tests at -40°F the materials of supplier number 2 show a clear advantage over those of supplier number 1, although due to the range of the data, some of the supplier number 2 material falls into the high range of supplier number 1. This could be a reflection of the fact that not all items produced using supplier number 1 material fail.

Table V presents the results of the SNBE test conducted at -40°F on the most recent material produced by supplier number 2. An interesting result is that a sample taken from either side of an extrusion can produce different measurements. Figure 3 shows an extruded section with the test samples shown penciled in at either side. At the top are photomicrographs taken perpendicular to the extrusion direction showing considerably more aligned second phase particles on one side of the extrusion than on the other. This can also be detected ultrasonically as shown by the two ouptuts of an ultrasonic sensor. Figures 4a, 4b, and 4c show photomicrographs of actual specimens. Figure 4a shows an extrusion that had equal properties from side to side, and the photomicrographs show equal distribution of second phase particles on both sides. Figures 4b and 4c depict the case of unequal test results and unequal photomicrograph results. The specimens showing the least amount of aligned structure orientation also demonstrate the lower SNBE.

## CONCLUSIONS

1. $K_{Ic}$ shows only slight differences between the two suppliers' materials in both orientations and at both temperatures. Only the the R-L orientation fracture toughness could be used to separate the two materials.

2. SNBE in both orientations and at both temperatures demonstrates a difference in the two suppliers' materials.

3. Later in the material production cycle, supplier number 2 (the seemingly better supplier) supplied material with SNBE nearly as low as supplier number 1 and with side to side variations not previously observed.

# REFERENCES

1. "Standard Test Method for Plane-Strain Fracture Toughness of Metallic Materials," 1985 ASTM Annual Book of Standards, Vol. 03.01, ASTM, Philadelphia, PA, 1985, pp. 547-582.
2. "Standard Methods for Notched Bar Impact Testing of Metallic Materials," 1985 ASTM Annual Book of Standards, Vol. 03.01, ASTM, Philadelphia, PA, pp. 235-258.
3. "Standard Methods of Tension Testing of Metallic Materials," 1985 ASTM Annual Book of Standards, Vol. 03.01, ASTM, Philadelphia, PA, 1985, pp. 130-151.
4. J. H. Underwood and M. A. Scavullo, "Fracture Behavior of a Uranium or Tungsten Alloy Notched Component With Inertia Loading," Fracture Mechanics: Sixteenth Symposium, ASTM, STP 868, (M. F. Kanninen and A. T. Hopper, eds.), ASTM, 1985, pp. 554-568.

TABLE I. MEASURED YIELD AND ULTIMATE STRENGTHS FROM M833 SABOTS

| | Yield Strength, Ksi | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Longitudinal, L | | | | | | Short Transverse, R | | | | | |
| | +70°F | | | -40°F | | | +70°F | | | -40°F | | |
| Supplier | Range | n | Avg | Range | n | Avg | Range | n | Avg | Range | n | Avg |
| 1 | 89-91 | 3 | 89.3 | 89-94 | 4 | 91.9 | 70-77 | 3 | 72.3 | 71-79 | 9 | 75.3 |
| 2 | 84-94 | 4 | 88.9 | 92-95 | 4 | 93.0 | 78-80 | 3 | 79.1 | 67-75 | 3 | 70.8 |
| | Ultimate Strength, Ksi | | | | | | | | | | | |
| 1 | 94-97 | 3 | 95.3 | 95-100 | 4 | 97.8 | 80-81 | 4 | 80.4 | 82-85 | 9 | 83.0 |
| 2 | 97-100 | 4 | 96.3 | 99-101 | 4 | 99.4 | 86-87 | 3 | 86.6 | 77-88 | 3 | 81.2 |

n = number of samples

TABLE II. MEASURED PLANE-STRAIN FRACTURE TOUGHNESS FROM M833 SABOTS

| | Fracture Toughness ($K_{Ic}$), Ksi(in.)$^{1/2}$ | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L-R Orientation | | | | | | R-L Direction | | | | | |
| | +70°F | | | -40°F | | | +70°F | | | -40°F | | |
| Supplier | μ | n | σ | μ | n | σ | μ | n | σ | μ | n | σ |
| 1 | 29.6 | 8 | 1.6 | 29.7 | 8 | 2.9 | 19.2 | 6 | 2.0 | 17.2 | 8 | 1.3 |
| 2 | 32.4 | 4 | 3.0 | 31.5 | 4 | 2.9 | 22.7 | 2 | 2.4 | 21.3 | 4 | 1.5 |

μ = mean
n = number of samples
σ = standard deviation

TABLE III. MEASURED SLOW NOTCHED BEND ENERGY FROM M833 SABOTS

| | Slow Notched Bend Energy, in.-lb. | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L-R Orientation | | | | | | R-L Direction | | | | | |
| | +70°F | | | -40°F | | | +70°F | | | -40°F | | |
| Supplier | μ | n | σ | μ | n | σ | μ | n | σ | μ | n | σ |
| 1 | 37.6 | 7 | 1.9 | 28.7 | 8 | 3.3 | 21.2 | 8 | 3.0 | 19.2 | 8 | 1.7 |
| 2 | 48.7 | 4 | 3.6 | 40.8 | 4 | 2.7 | 28.9 | 4 | 2.8 | 24.0 | 2 | .6 |

μ = mean
n = number of samples
σ = standard deviation

TABLE IV. MEASURED SLOW NOTCHED BEND ENERGY FROM M833 SABOTS

| | Slow Notched Bend Energy, in.-lb. | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Longitudinal, L-R Span = 1.58 in. | | | | | | Short Transverse, R-L Span = 1.20 in. | | | | | |
| | +70°F | | | -40°F | | | +70°F | | | -40°F | | |
| Supplier | Range | N | Avg | Range | N | Avg | Range | N | Avg | Range | N | Avg |
| 1 | | | | | | | | | | | | |
| Group 1 | 36-41 | 7 | 37.6 | 24-38 | 10 | 30.4 | 17-27 | 8 | 21.2 | 17-23 | 8 | 19.0 |
| Group 2 | - | - | - | - | - | - | - | - | - | 12-18 | 17 | 15.7 |
| Group 3 | - | - | - | - | - | - | - | - | - | 13-21 | 16 | 17.8 |
| 2 | | | | | | | | | | | | |
| Group 1 | 45-53 | 4 | 48.7 | 38-44 | 4 | 40.8 | 25-31 | 4 | 28.9 | 24-28 | 3 | 25.3 |
| Group 2 | - | - | - | - | - | - | - | - | - | 21-26 | 7 | 22.7 |
| Group 3 | - | - | - | - | - | - | - | - | - | 23-24 | 7 | 23.6 |

TABLE V. MEASURED SLOW NOTCHED BEND ENERGY FOR R-L SAMPLES TAKEN FROM RECENT SUPPLIER NUMBER 2 EXTRUSIONS

| Identification Number* | SNBE in.-lbs. (at -40°F) |
|---|---|
| L2 | 26.0 |
| L3 | 26.7 |
| L3· | 22.2 |
| L1 | 25.2** |
| L1· | 16.2** |
| K1 | 22.9 |
| K1 | 22.5 |
| K1· | 21.5 |
| K3 | 25.1** |
| K3 | 26.0** |
| F3 | 17.6 |
| F2 | 19.9 |
| F2· | 18.7 |
| F1 | 17.5** |
| F1· | 25.7** |

*The letter indicates a heat number and the number indentifies a sector from a matched set to provide a sabot. The dot indicates a sample taken from the opposite side of the extrusion as shown in Figure 3.

**Indicates micrographs are shown in Figures 4a, b, and c.

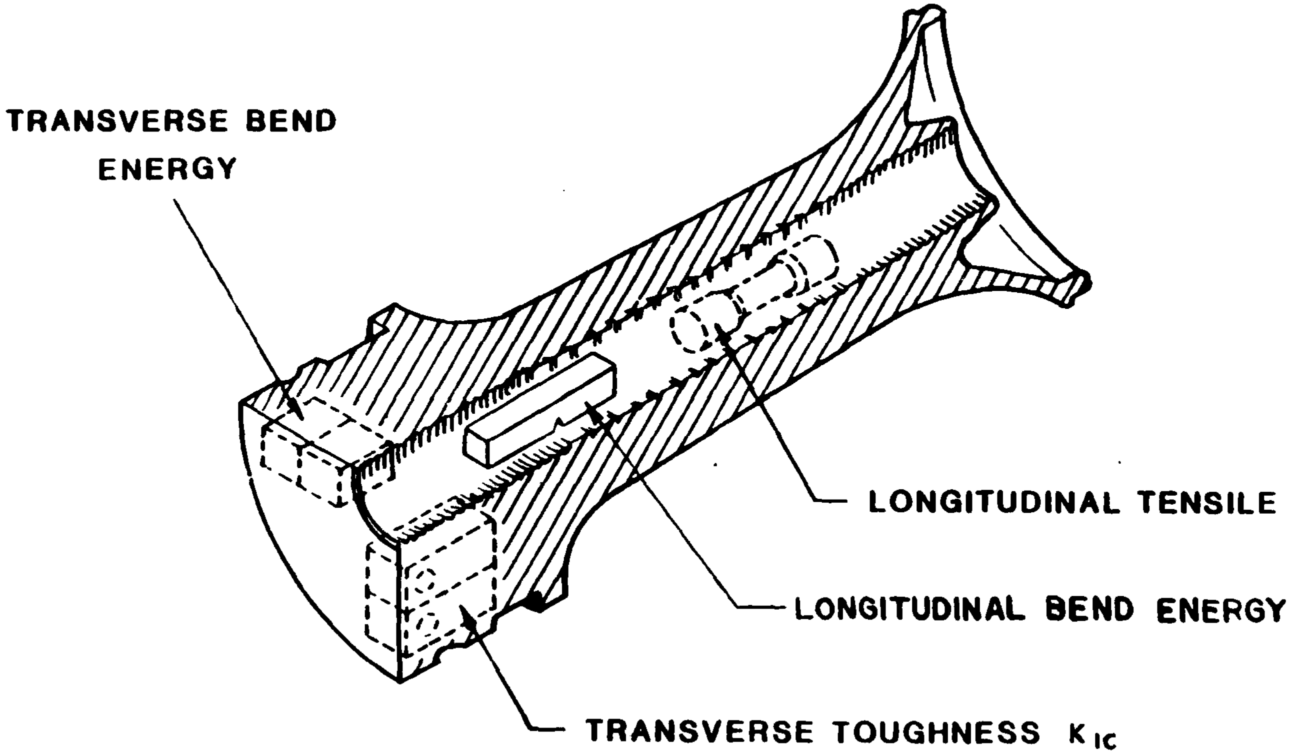
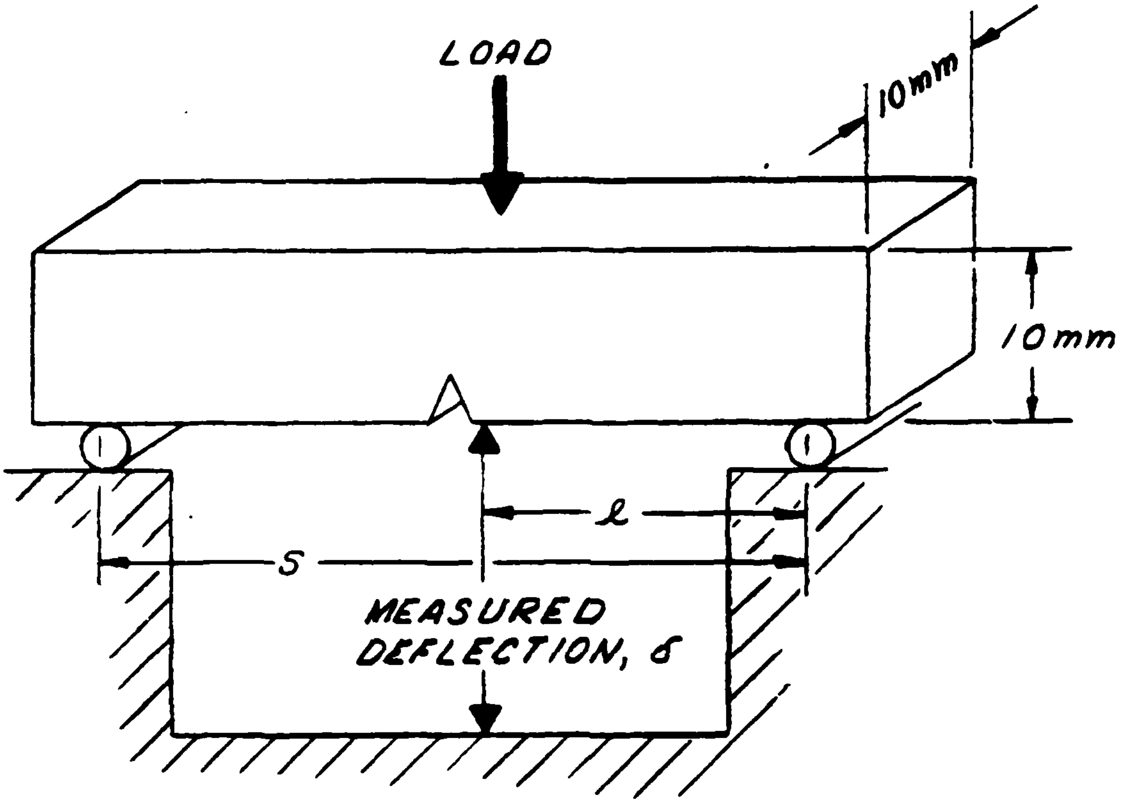


Figure 1. Schematic of a sabot petal showing the orientation of test specimens.



MIDPOINT DEFLECTION = $\delta S/2\ell$

S = 1.58 in FOR LONGITUDINAL

S = 1.20 in. FOR TRANSVERSE

Figure 2a. Schematic of SNBE test fixture.

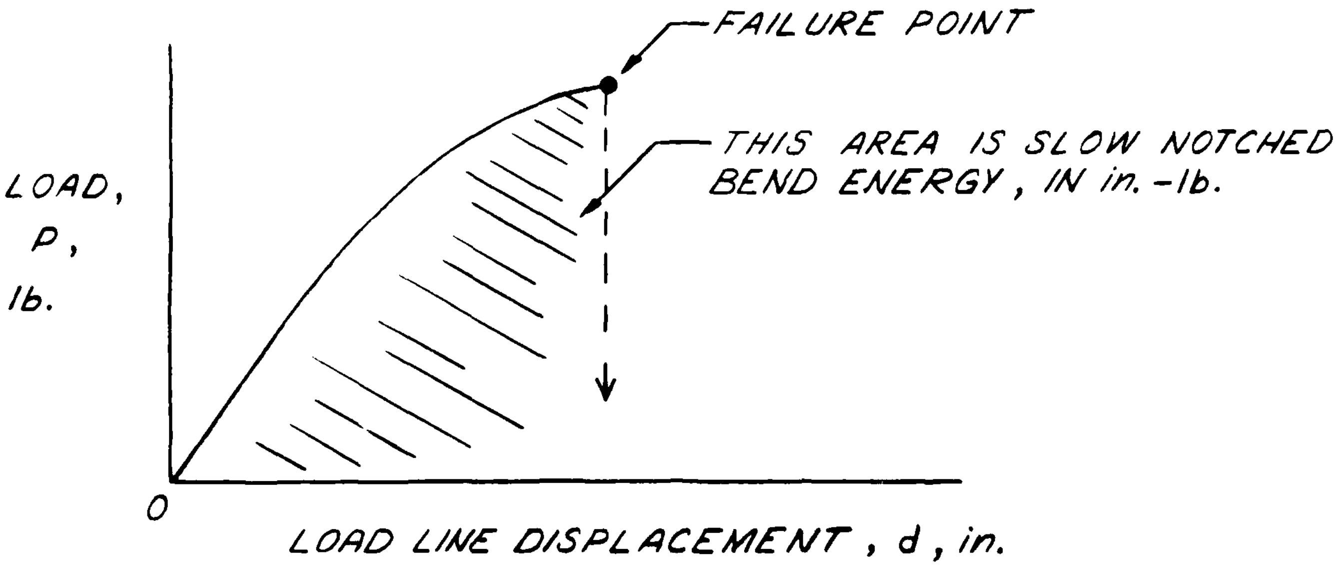


Figure 2b. Typical load deflection curve for an SNBE test.

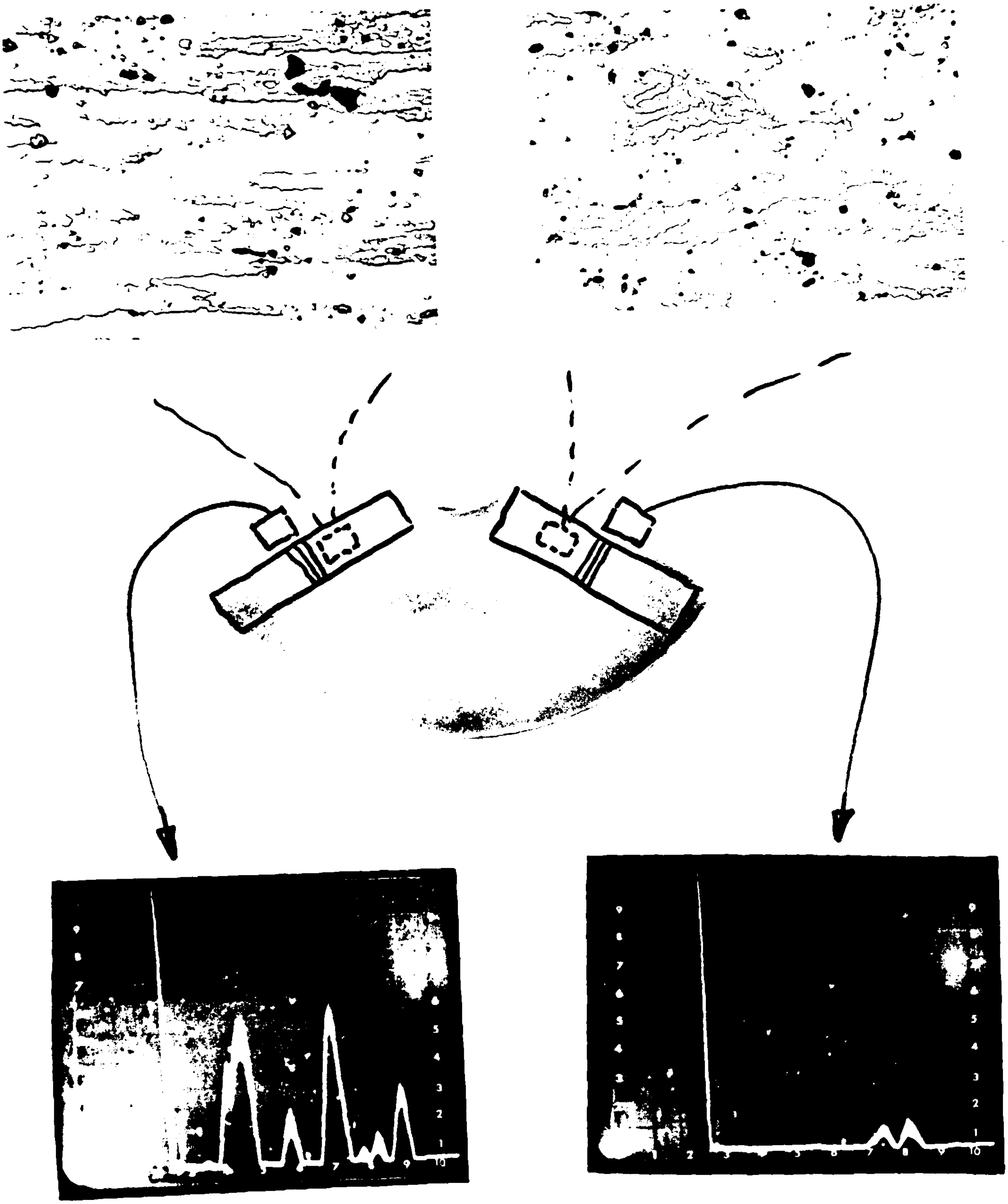
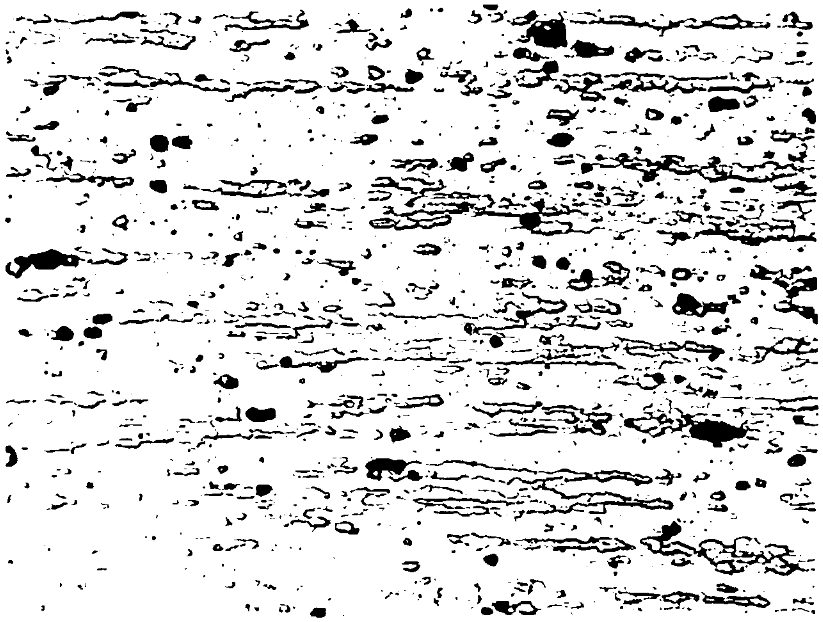


Figure 3. Photograph of an extruded section with the associated photomicrographs and ultrasonic responses.

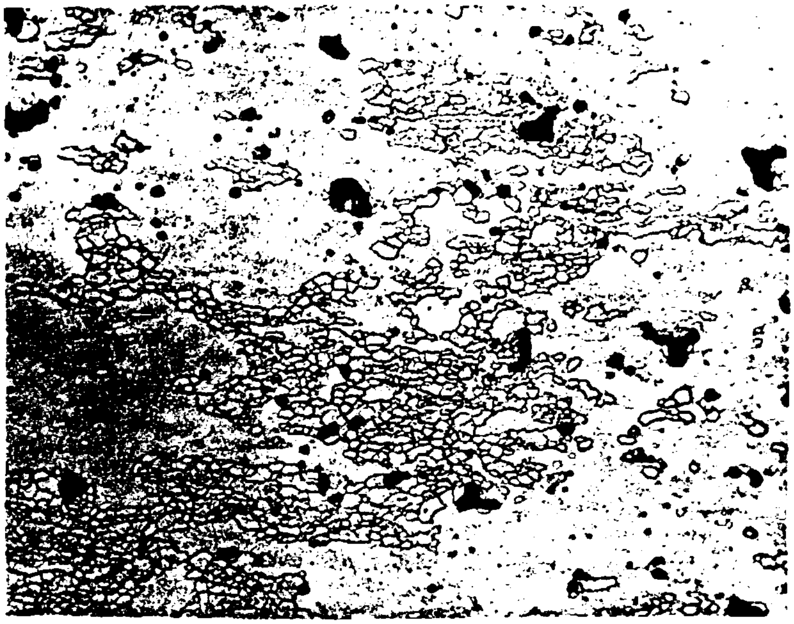
K3 25.1 in.-lb



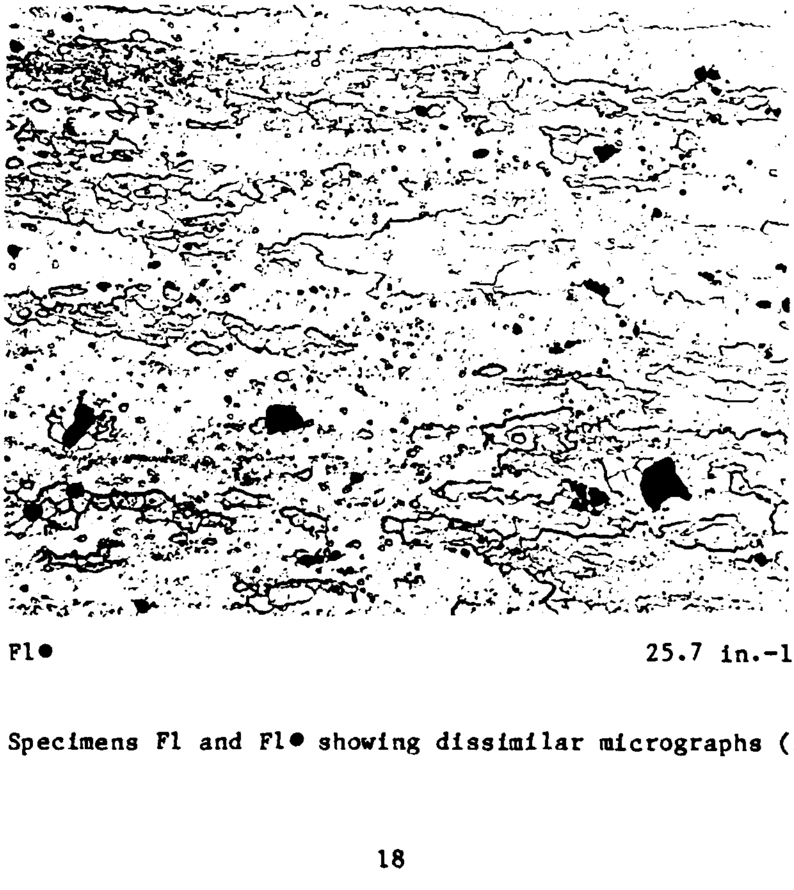
K3● 26.0 in.-lb

Figure 4. Micrographs of specimens taken from opposite sides of an extrusion, at a magnification of 500X perpendicular to the extrusion direction.

a. Specimens K3 and K3● showing similar micrographs.

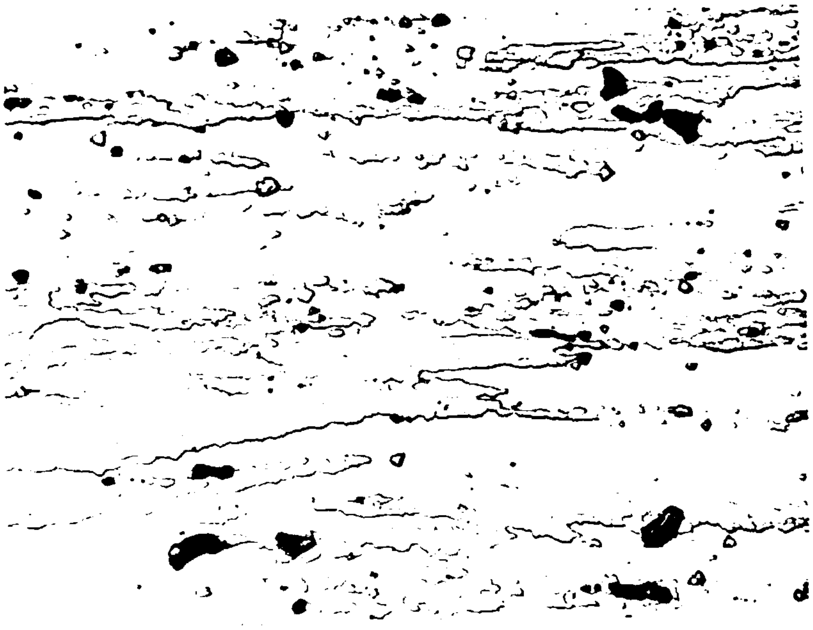


F1 17.5 in.-lb



F1● 25.7 in.-lb

4b. Specimens F1 and F1● showing dissimilar micrographs (500X).



L1 25.2 in.-lb

L1● 16.2 in.-lb

4c. Specimens L1 and L1● again showing dissimilar micrographs (500X).

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