NASA TECHNICAL MEMORANDUM

NASA TM-78228

STRAIN COMPATIBILITY ASSESSMENT FOR SRB SPRAYABLE ABLATOR MSA-1

By William J. Patterson

(NASA-TM-78228) STRAIN COMPATIBILITY ASSESSMENT FOR SRB SPRAYABLE ABLATOR MSA-1 (NASA) 45 p HC A03/MF A01 CSCL 11D
N79-25144
Unclas
G3/24 22172

April 1979

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

NOTICE

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
NASA TM-78228		

4. TITLE AND SUBTITLE
Strain Compatibility Assessment for SRB Sprayable Ablator MSA-1

5. REPORT DATE
April 1979

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
William J. Patterson

8. PERFORMING ORGANIZATION REPORT #

9. PERFORMING ORGANIZATION NAME AND ADDRESS
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO.

13. TYPE OF REPORT & PERIOD COVERED
Technical Memorandum

12. SPONSORING AGENCY NAME AND ADDRESS

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
Prepared by Materials and Processes Laboratory
Science and Engineering

16. ABSTRACT

Tensile and compressive strain compatibility testing was performed on as-sprayed samples of the Shuttle Solid Rocket Booster external ablator material, MSA-1. Strain gages on the aluminum substrate were used to monitor strain. Strain compatibility was determined as the percent strain in the substrate at first visual evidence of MSA-1 failure. The 1/8-in. MSA-1, baselined for large areas of the SRB external skin, was characterized by a strain compatibility of 1.5 to 1.8 percent, which far exceeded the yield range of the metal substrate. Thicker MSA-1 applications (1.4 to 3/8 in.) were characterized by a lower level of strain compatibility, which appeared to be a manifestation of application limitations.

17. KEY WORDS

18. DISTRIBUTION STATEMENT
Unclassified-Unlimited

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	48	NTIS

MSFC - Form 3292 (Rev Decembe[illegible])

For sale by National Technical Information Service, Springfield, Virginia 22151

ACKNOWLEDGEMENT

The author acknowledges the contributions of the Metallic Materials Division, Materials and Processes Laboratory, and particularly Mr. Paul Munafo for assistance in specimen design and test methodology.

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STRAIN COMPATIBILITY ASSESSMENT FOR SRB SPRAYABLE ABLATOR MSA-1

I. INTRODUCTION

The Marshall Space Flight Center (MSFC) developed sprayable ablator, MSA-1, has been specified in 1/8-in. and 1/4-in. thickness for thermal protection of the Solid Rocket Booster (SRB) nose cap, frustum, forward skirt, and systems tunnel cover. This material basically consists of glass fiber and microballoon fillers with an epoxy-modified urethane as a curable binder. The system is spray-applied to the SRB external skin surfaces and cures to a tough, high performance ablator. The ablator is nonstructural but must accommodate substrate strains and deformation under worst-case design conditions. This study was designed to determine the integrity of the ablator under tensile and compressive substrate loading conditions and to measure quantitatively the amount of substrate strain that the MSA-1 could accommodate without failure.

II. APPROACH

It was desirable to simulate tensile and compressive loading of the SRB skin and to assess the compatibility of the MSA-1 in both modes. Appropriate tensile and compressive specimens were machined from sprayed panels (MSA-1 sprayed onto 1/8-in. 2219-T87 aluminum).[1] Flatwise tensile specimens were prepared from these same panels to determine any correlation between flatwise tensile strength and strain compatibility. Panels representing a range of strength values were selected for evaluation. This approach was designed to demonstrate that the MSA-1 could accommodate significant substrate strains without failure, precluding the need for an unecessarily high strength requirement on the MSA-1.

1. The primary thrust of this study was 1/8 and 1/4-in. MSA-1 specimens. However, it was instructive to also include 3/8-in. material to determine any thickness-related trends in strain compatibility.

The coefficient of thermal expansion for the MSA-1 is approximately twice that of the metallic substrate; therefore, room temperature constitutes the worst case for the tensile mode, whereas elevated temperature should be worse for the compressive mode. The test methodology was designed to explore these conditions.

III. TEST PROCEDURES AND EXPERIMENTAL DATA

A. Tensile Testing

The tensile specimens are illustrated in Figures 1 and 2. These samples had a gage area of 2.0 × 6.0 in. and represented 1/8, 1/4, and 3/8 in. MSA-1. The gage length of the specimens was appropriately instrumented with strain rosettes spaced evenly along the center line, with one leg of each rosette oriented on the longitudinal axis of the specimen. As illustrated in Figure 3, tensile load was applied in approximately 20 increments until failure of the MSA-1 was observed. Strain gage readings were taken after each load increment was applied, and present substrate strain was calculated. This represented an average of all strain values from the longitudinally oriented rosette legs. The data collected for the 1/8, 1/4, and 3/8-in. MSA-1 are presented in Tables 1 through 4, where the strain compatibility is defined as substrate strain at the first indication of MSA-1 failure. The measured flatwise tensile strength of the material is also reported.

Figures 4 through 21 typify the range of failure modes which extended from a series of fine hairline cracks to complete transverse cracks accompanied by some debonding from the substrate.

B. Compressive Testing

The compressive test specimens, illustrated in Figure 22, were machined from 1/4-in. sprayed MSA-1 panels. The remaining MSA-1 area was 2.0 × 5.9 in. These specimens were tested primarily to assess compressive strain compatibility for 1/4-in. and thinner MSA-1. It was assumed that this type of test would be more severe with increasing sample thickness and that verification of strain compatibility for 1/4-in. MSA-1 would extend to thinner material samples. Thus, 1/8-in. MSA-1 was not tested separately.

TABLE 1. STRAIN COMPATIBILITY DATA FOR 1/8-INCH MSA-1

Sample No.	Flatwise Tensile Strength (psi)	Strain Compatibility (%)
83/N6B-1	75	1.73
82A/N3B-1	85	1.68
80A/N5A-1	105	1.73
97/6	106	1.75
79C/N3A-2	115	1.73
79A/N1A-2	125	1.73
84A/N7A-1	136	1.68
27/5	150	1.59
97/3	161	1.79
97/2	168	1.91
27/3	179	1.77
27/2	184	1.88
27/1	196	1.72
26/5	220	1.38
26/3	242	1.91
26/2	250	1.93
26/1	280	1.66

The compressive test specimen was typically loaded into a fixture (Fig. 23) which was compatible with a thermal/vacuum chamber (Fig. 24). The specimen substrate was first loaded in compression to approximately 50 ksi by means of the fixture and installed in the thermal/vacuum chamber. The test run in the chamber was 130 sec at a constant heating rate of 8 Btu/ft^2-sec with a simultaneous pressure decay in the chamber to a final value of approximately 0.4 psi. The specimens were further subjected to a post-test load check to

TABLE 2. STRAIN COMPATIBILITY DATA FOR 1/4-INCH MSA-1

Sample No.	Flatwise Tensile Strength (psi)	Strain Compatibility (%)
99/21	43	0.73
98/15	54	1.20
31/1	63	0.76
31/2	79	1.26
164/EAM-2	79	1.55
79/25	85	1.43
31/3	86	1.27
39/1	91	1.34
14/PL-2	99	1.82
38/5	104	1.36
163/SB-4	105	1.88
39/3	111	1.02
30/2	115	1.76
13/LOC-4	117	1.70
38/4	119	1.48
98/10	120	1.51
170/EAMR-2	120	2.01
30/3	122	1.86
170/EAMR-3	122	1.43
99/22	123	1.67
174/PDV-2	124	1.64
36/1	126	1.20
39/4	129	0.98
98/13	132	1.49
30/4	141	0.99
36/2	143	1.59
14/PL-7	145	1.79
36/4	156	1.21

TABLE 3. STRAIN COMPATIBILITY DATA FOR 3/8-INCH MSA-1

Sample No.	Flatwise Tensile Strength (psi)	Strain Compatibility (%)
40/3	47	0.92
40/2	47	1.09
48B/2	84	1.06
48B/3	96	1.36
43/1	107	1.35
48B/4	113	1.38
43/4	115	1.36
47/4	121	1.24
45/4	122	0.95
47/1	138	1.70
43/3	140	1.20
47/3	140	1.96
45/3	143	1.31
45/1	162	1.06

TABLE 4. SUMMARY OF STRAIN COMPATIBILITY DATA FOR MSA-1

Specimen Thickness (in.)	Average Flatwise Tensile Strength (psi)	Average Strain Compatibility (%)
1/8	163.3	1.74
1/4	109	1.40
3/8	112.5	1.27

verify that the preload had not decayed significantly. The qualitative observations on these tests are included in Table 5 and illustrated in Figures 25 through 30.

TABLE 5. COMPRESSIVE TESTING OF MSA-1

Sample No.	Flatwise Tensile Strength (psi)	Post-Test Condition
31/1	63	Typical Surface Char, No Cracks Extend Below Char Layer, No Debond
31/5[a]	66	Typical Surface Char, No Cracks Extend Below Char Layer, No Debond
31/3	86	Typical Surface Char, One Large Transverse Char Crack, No Cracks Extend Below Char Layer, No Debond
39/5	117	Typical Surface Char, No Cracks Extend Below Char Layer, No Debond
30/4[a]	141	Typical Surface Char, No Cracks Extend Below Char Layer, No Debond
36/1	156	Typical Surface Char, One Large Transverse Char Crack, No Cracks Extend Below Char Layer, No Debond

[a]Control, Not Compressive Loaded

IV. RESULTS AND DISCUSSION

The tensile strain compatibility testing resulted in an average of 1.74 percent substrate strain at failure of the 1/8-in. MSA-1 material. The strain compatibility appears to be independent of flatwise tensile strength over the range of 75 to 280 psi for 1/8-in. MSA-1. There was no well-defined correlation between flatwise tensile strength and mode of failure within this test series. The two types of failure typically observed were (1) multiple hairline cracks without debonding and (2) single large transverse cracks with some debond in the crack vicinity. Examples of each failure mode were observed throughout the MSA-1 strength spectrum.

The 1/4-in. tensile testing resulted in an average substrate strain of 1.4 percent at MSA-1 failure. Several relatively low individual values observed in this series indicate that the 1/4-in. MSA-1 does not accommodate the substrate strain as readily as the thinner material, which may be due to higher residual curing stresses in the thicker material. The lowest 1/4-in. strain compatibility values at the low end of the strength range (Table 2) would not be relevant to flight hardware applications, since the minimum acceptable flatwise tensile strength for 1/4-in. MSA-1 is 75 psi. The progressively lower strain compatibility for the 3/8-in. material tends to emphasize the effect of thickness-induced residual stresses.

The compressive load testing was considered perhaps more representative of the hardware flight environment since thermal stresses were superimposed on compressive load stresses. In this configuration, the shear loading at the MSA-1/substrate interface represented a worst-case condition, where the substrate was held in compression and the insulation was tending to elongate due to the temperature effect. All specimens tested in this configuration (1/4-in. MSA-1) showed similar char characteristics and surface cracking. No cracks extended below the char layer, and no ablator/substrate debond was observed. This observation is consistent with previous detailed studies on shear tensile strength of 1/8- and 1/4-in. MSA-1, which showed retention of 30 to 40 percent of room temperature shear tensile strength at 300°F. Another interesting observation was that the condition of tested samples was independent of substrate preload. There were no anomalous features of the charred samples that were unique to the preloaded substrate material.

V. CONCLUSIONS

The tensile strain testing on 1/8-in. MSA-1 indicates an average 1.74 percent substrate strain before any evidence of cracking or debonding of the MSA-1 occurs. This value is approximately 2.5 times the yield strain for the aluminum substrate. The compressive strain studies under thermal/vacuum conditions verified that no anomalous cracking or debonding occurs when the substrate is loaded in compression in an ablating environment. These findings basically qualified the use of the 1/8-inch MSA-1 ablator for SRB flight hardware with respect to strain compatibility. The thicker MSA-1 testing indicates the need to optimize material formulations and/or application techniques to minimize residual stress and enhance substrate/ablator interface integrity. These goals are currently being pursued as part of a second generation ablator development program.

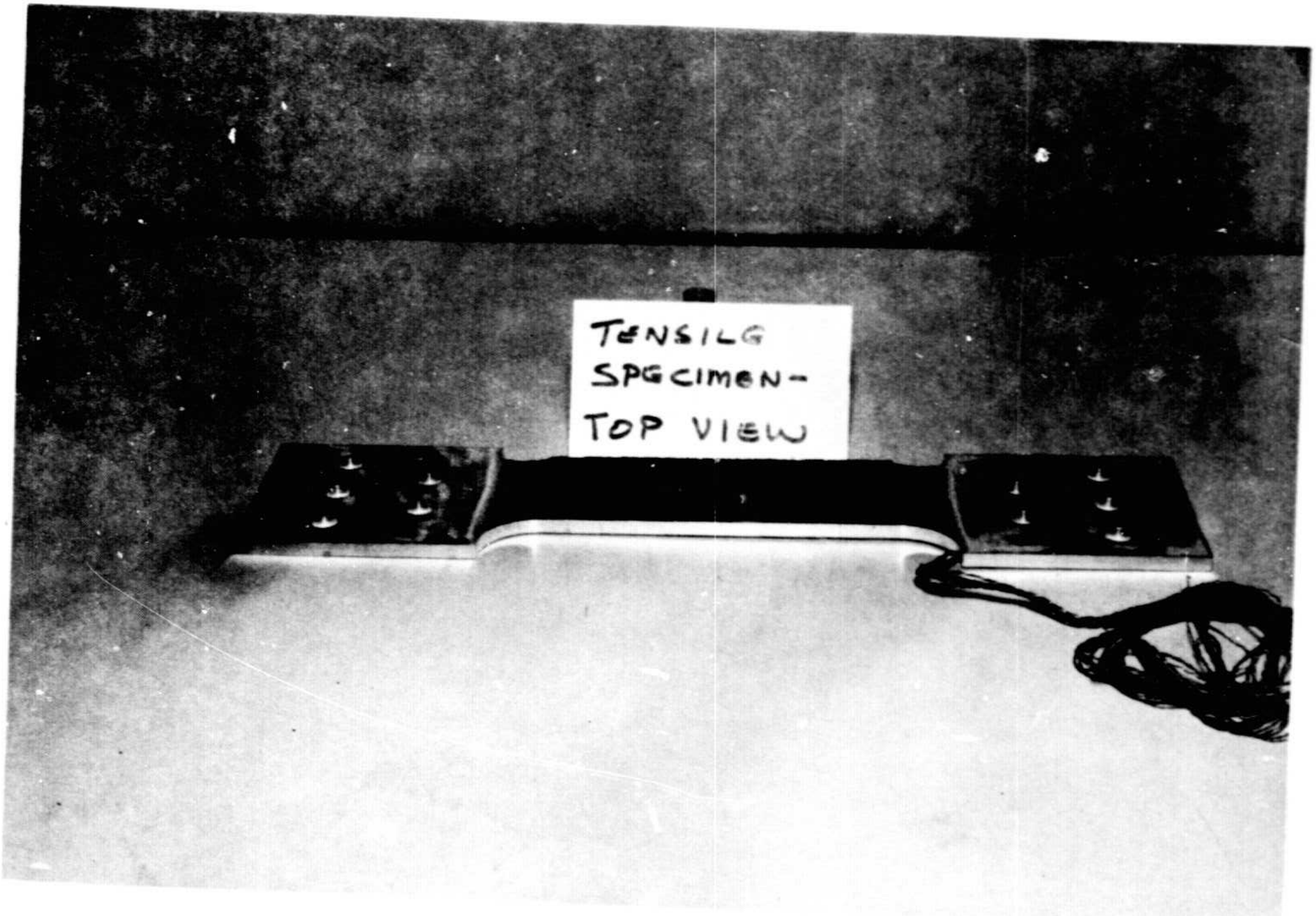

Figure 1. Tensile specimen, top view.

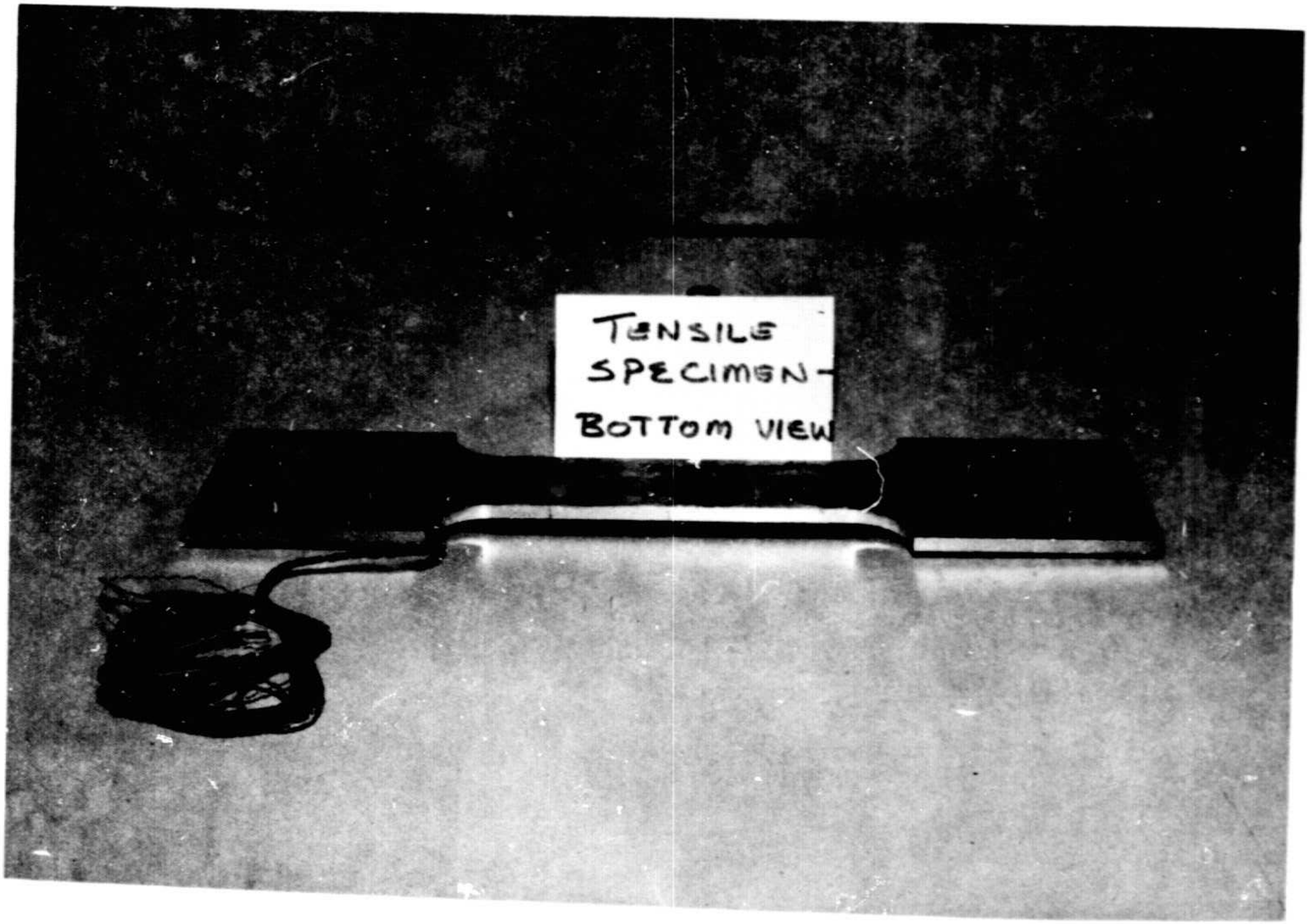

Figure 2. Tensile specimen, bottom view.

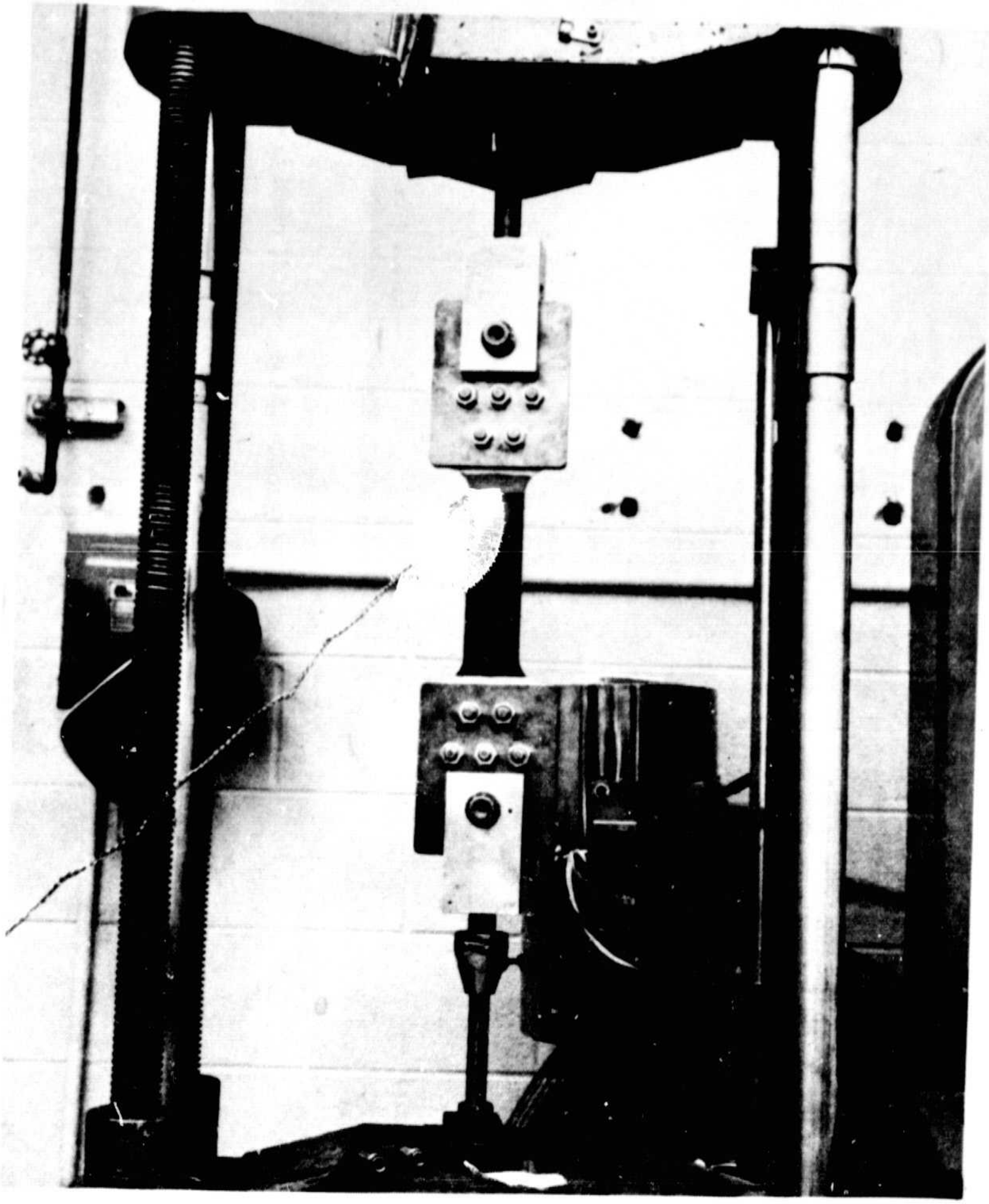

Figure 3. Tensile specimen in test.

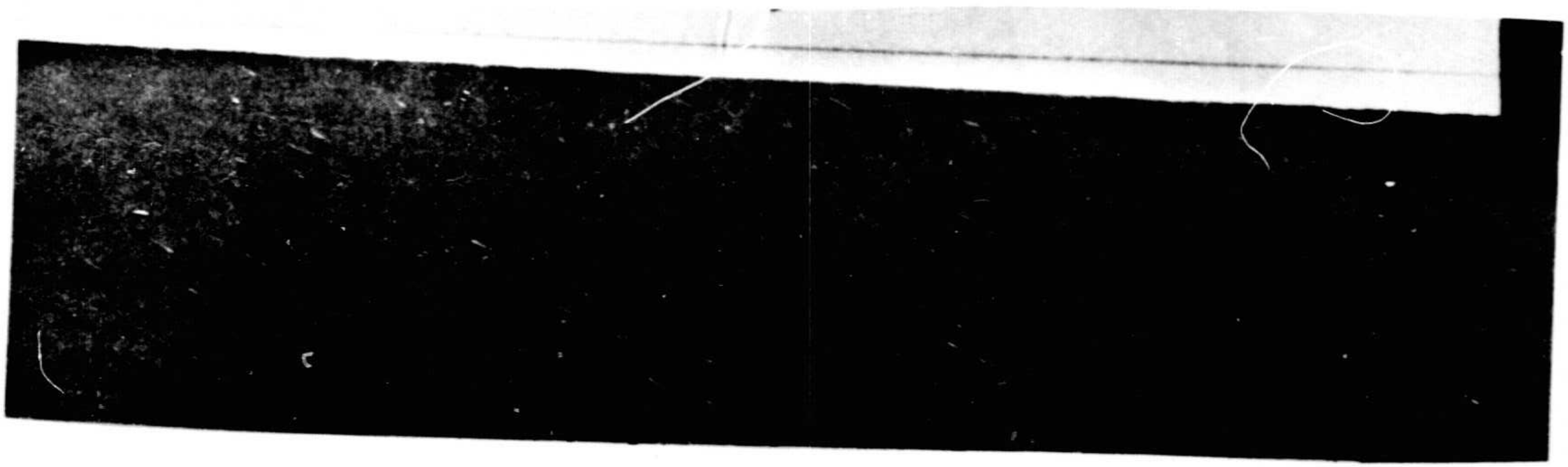

Figure 4. Post-test tensile specimen, 1/8-inch MSA-1, run 26, panel 1.

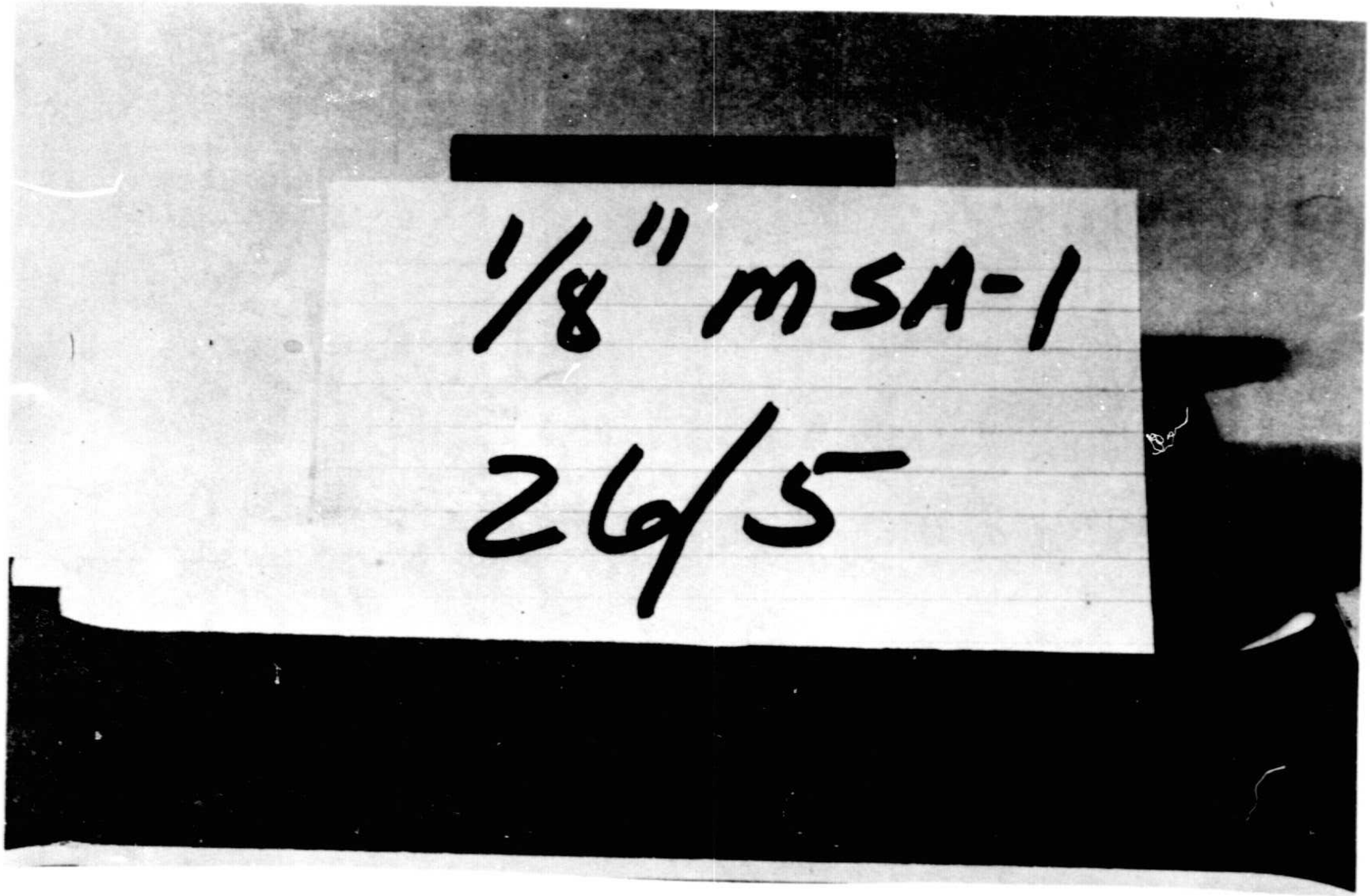

Figure 5. Post-test tensile specimen, 1/8-inch MSA-1, run 26, panel 5.

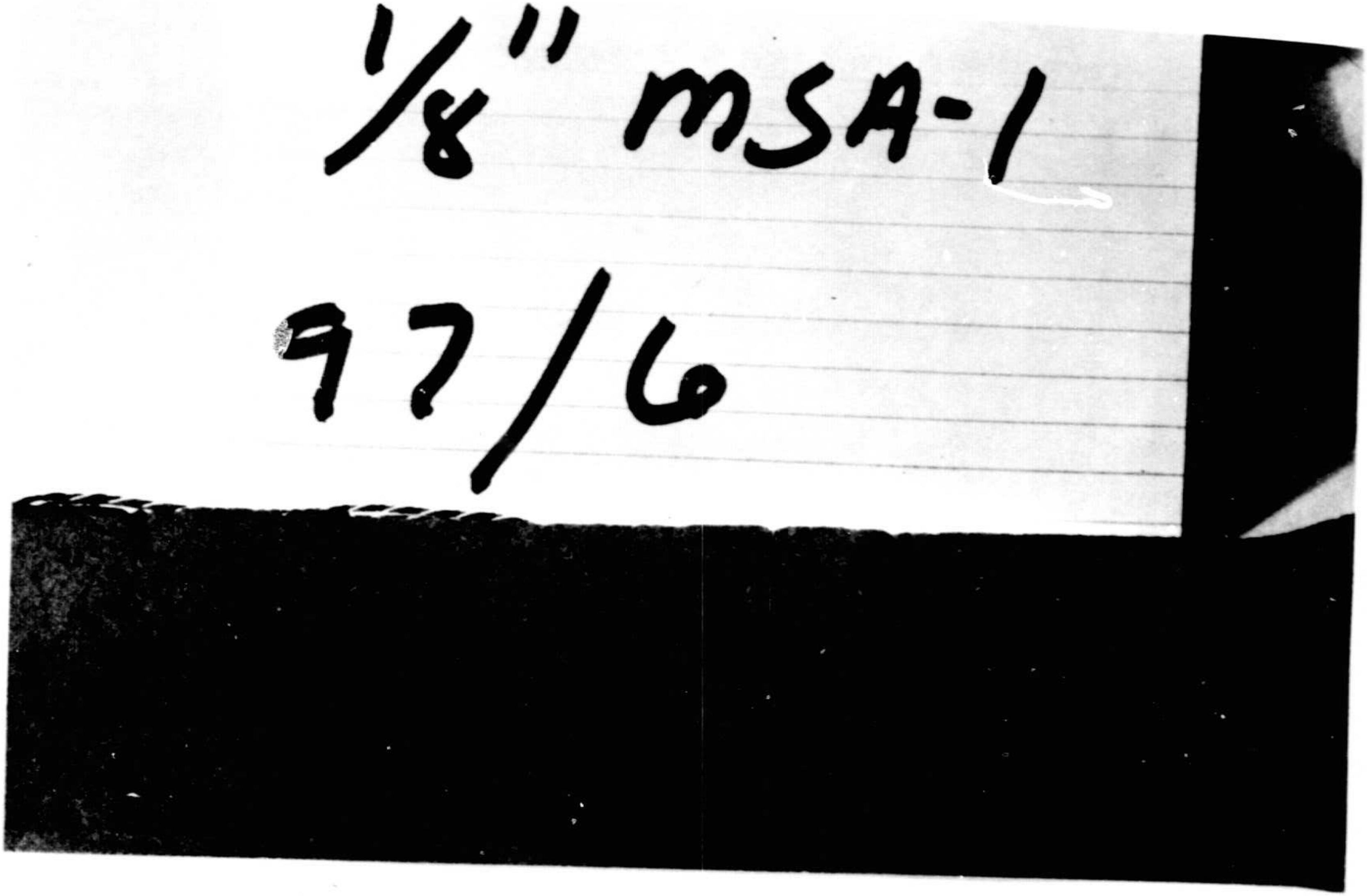

Figure 6. Post-test tensile specimen, 1/8-inch MSA-1, run 97, panel 6.

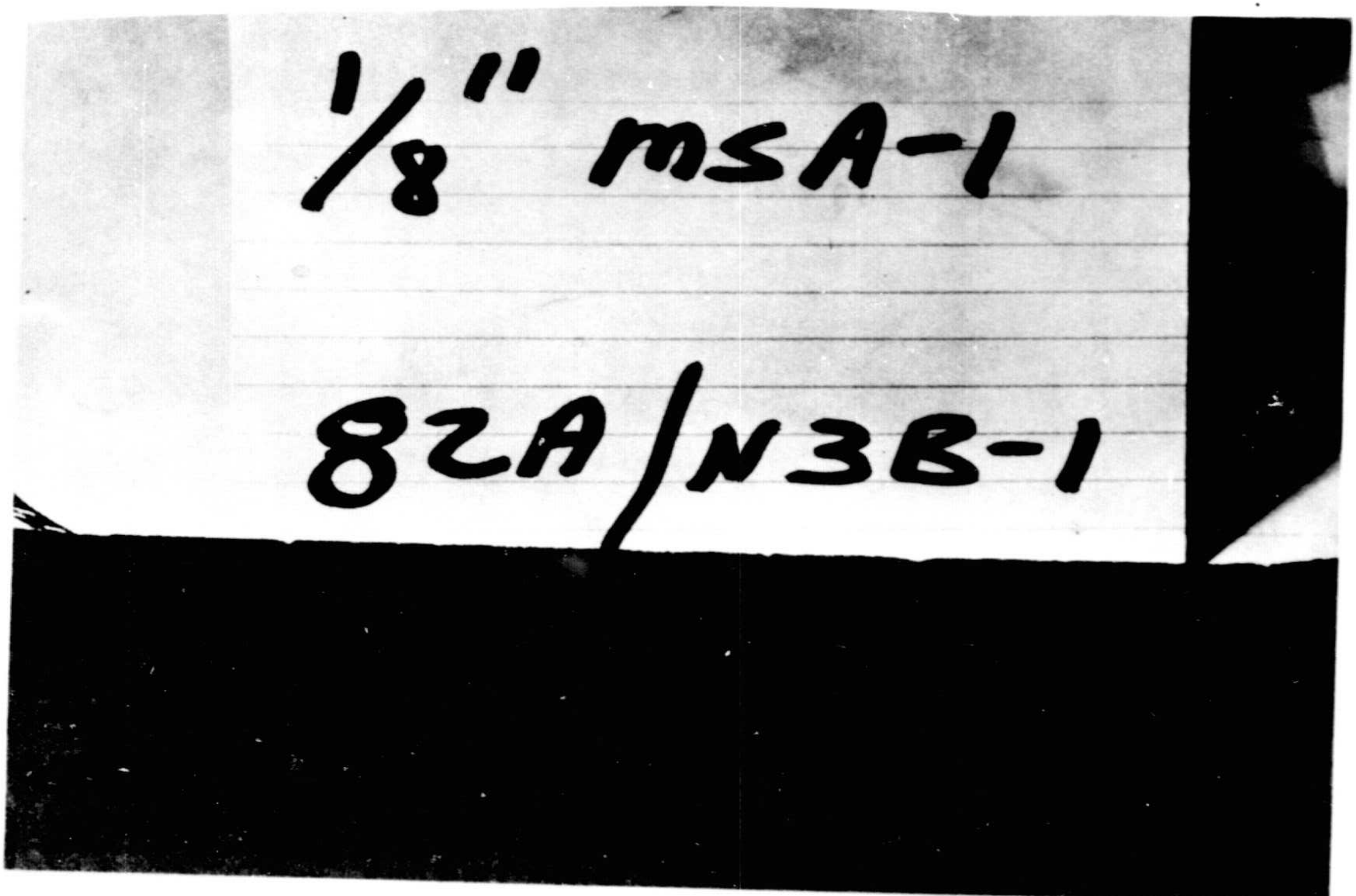

Figure 7. Post-test tensile specimen, 1/8-inch MSA-1, run 82A, panel N3B-1.

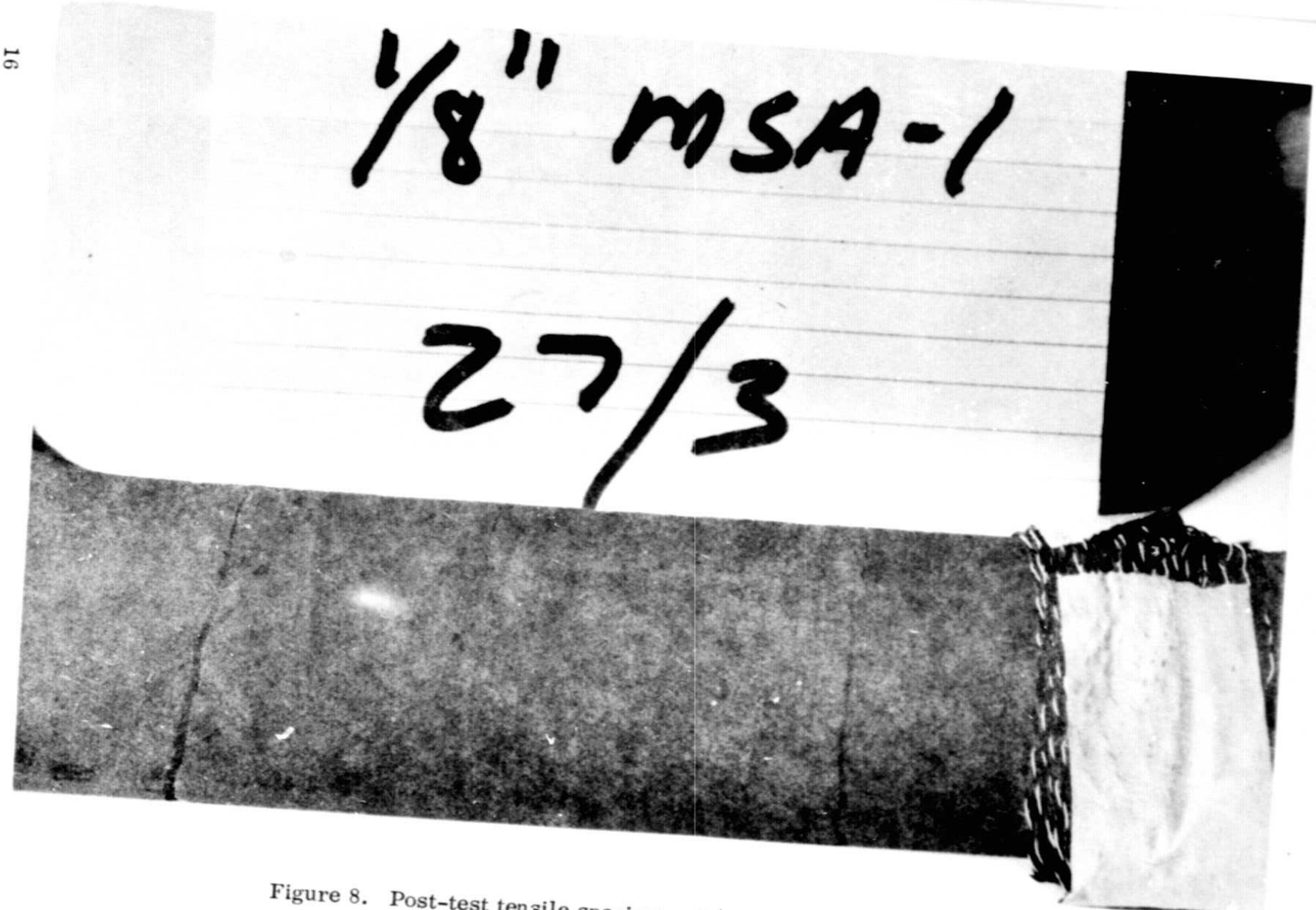

Figure 8. Post-test tensile specimen, 1/8-inch MSA-1, run 27, panel 3.

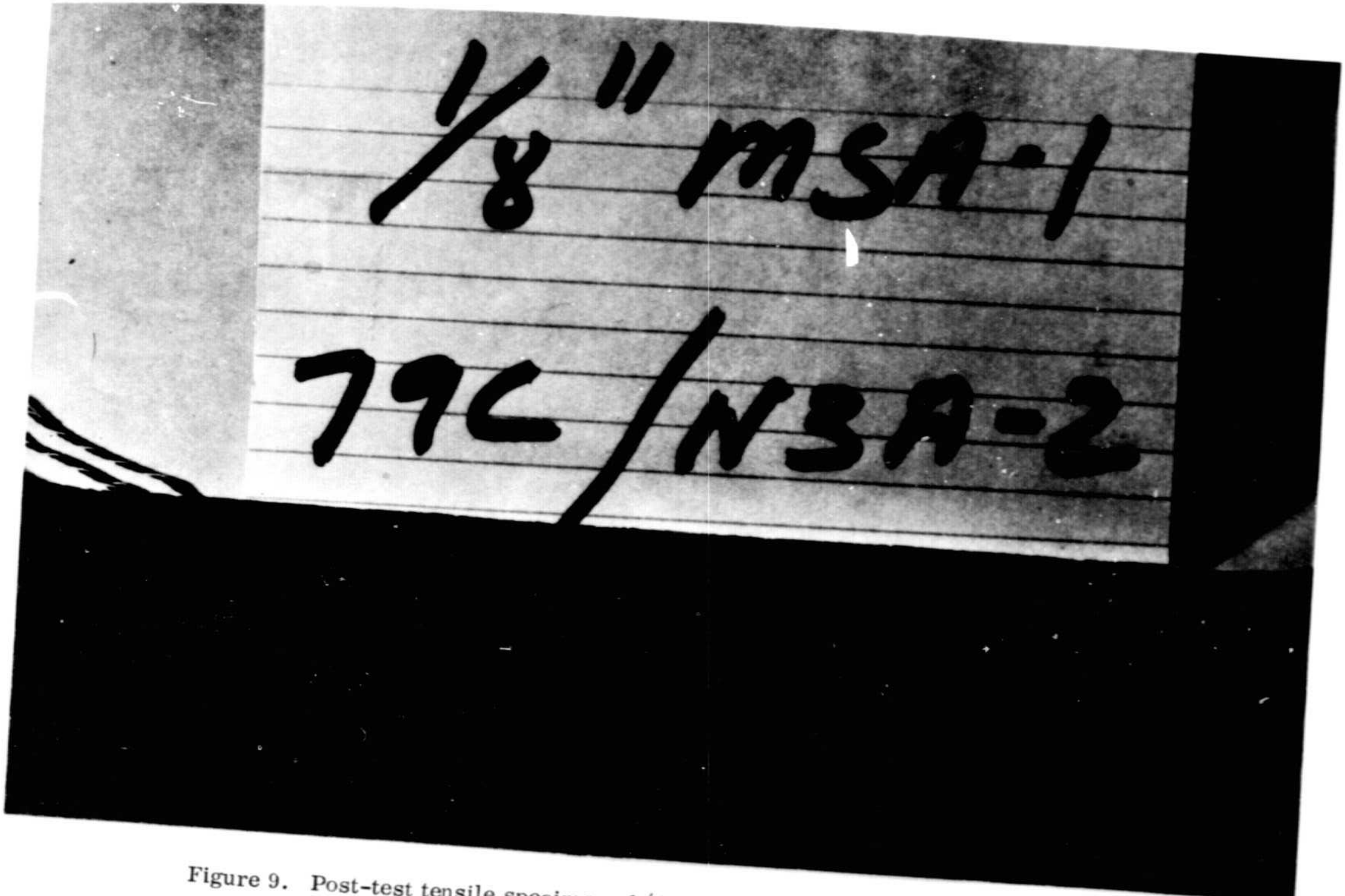

Figure 9. Post-test tensile specimen, 1/8-inch MSA-1, run 79C, panel N3A-2.

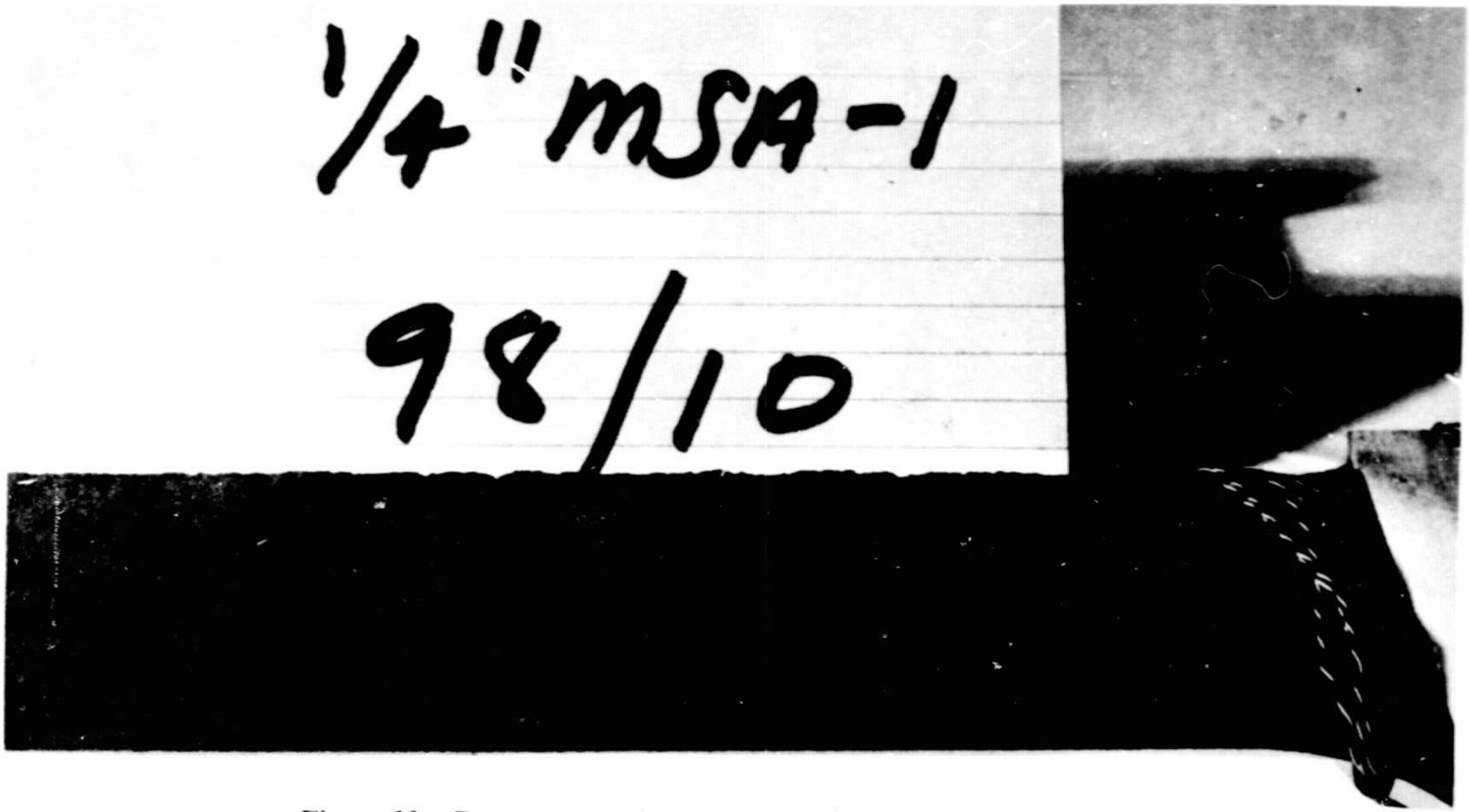

Figure 10. Post-test tensile specimen, 1/4-inch MSA-1, run 98, panel 10.

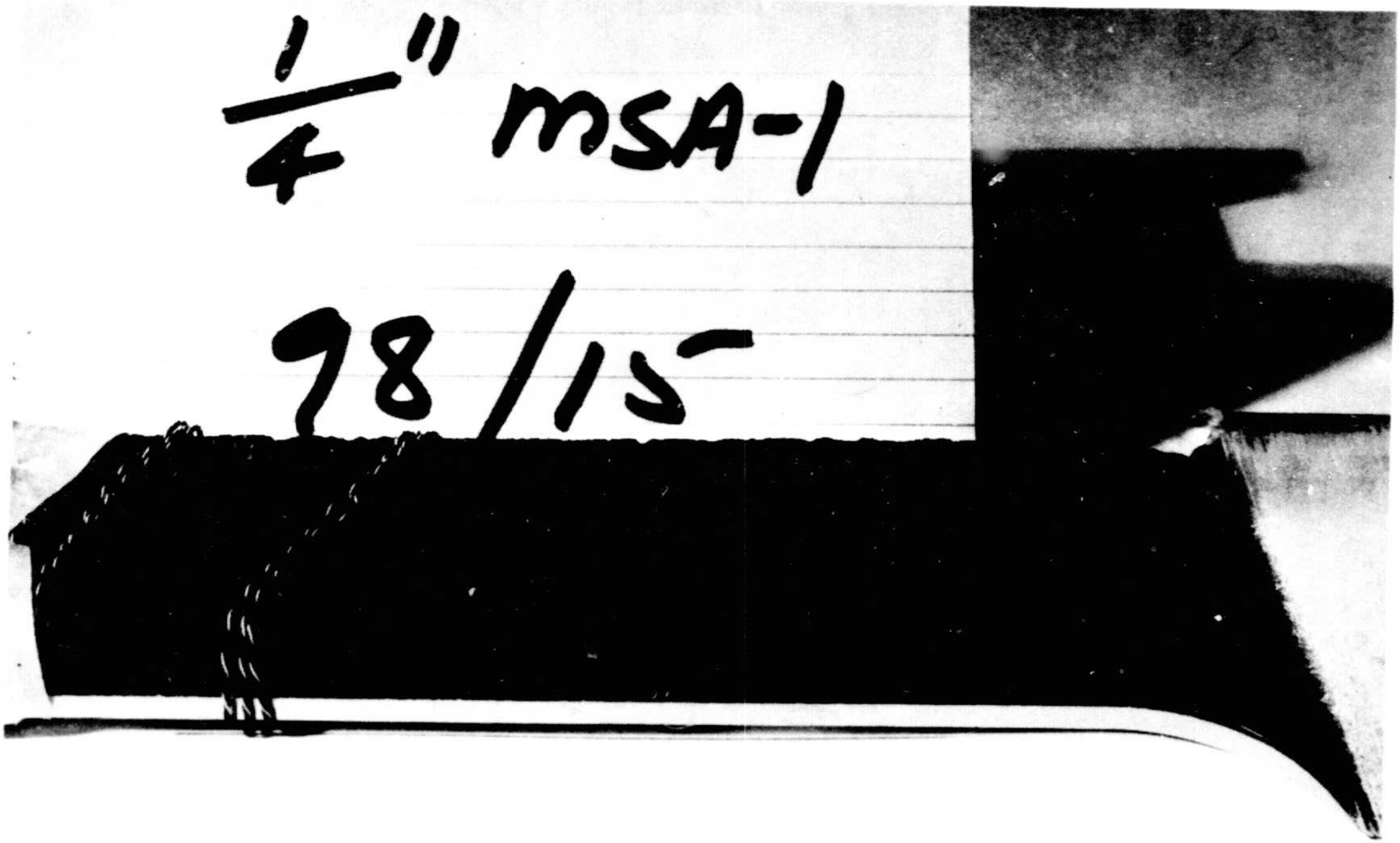

Figure 11. Post-test tensile specimen, 1.4-inch MSA-1, run 98, panel 15.

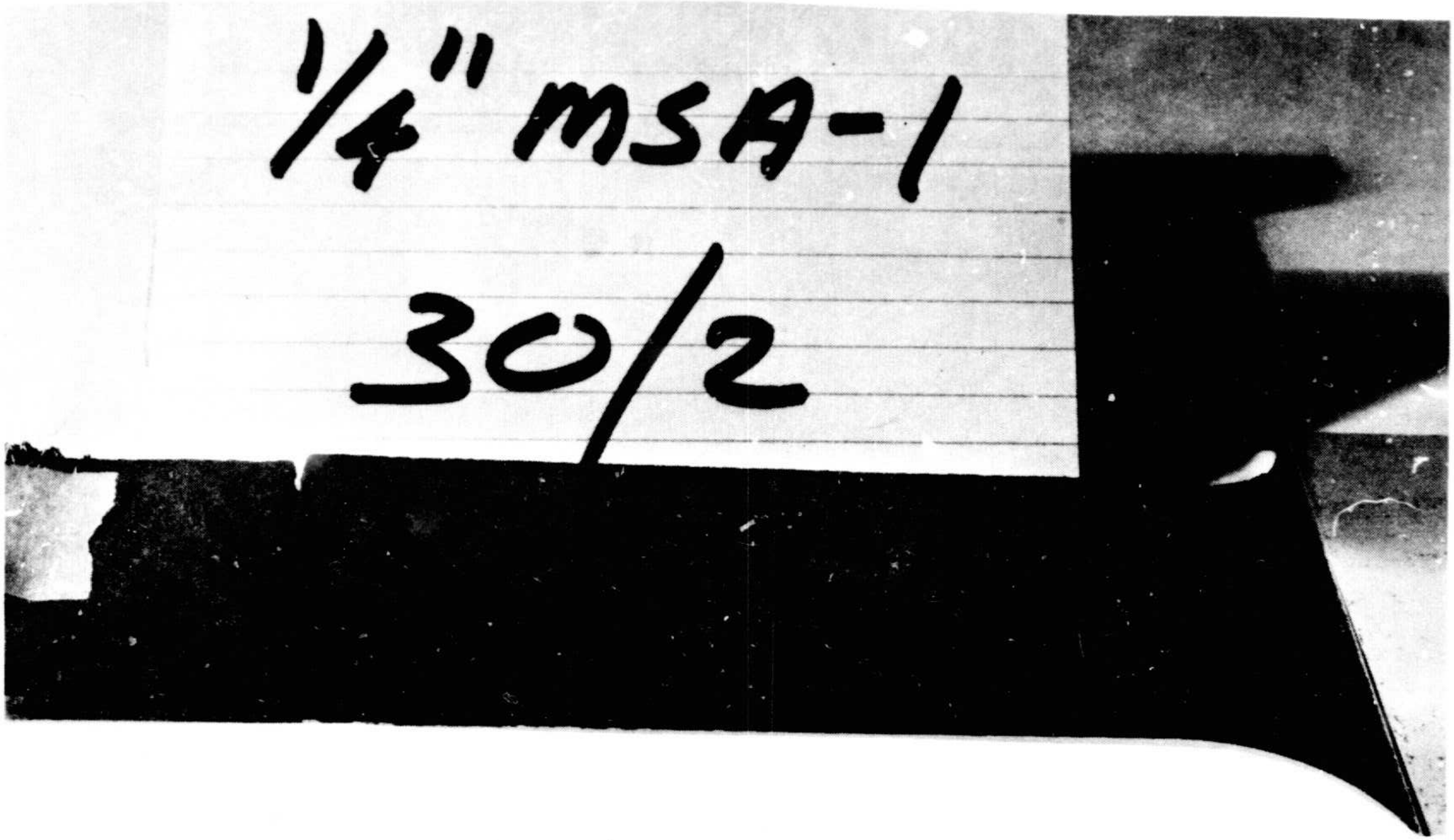

Figure 12. Post-test tensile specimen, 1.4-inch MSA-1, run 30, panel 2.

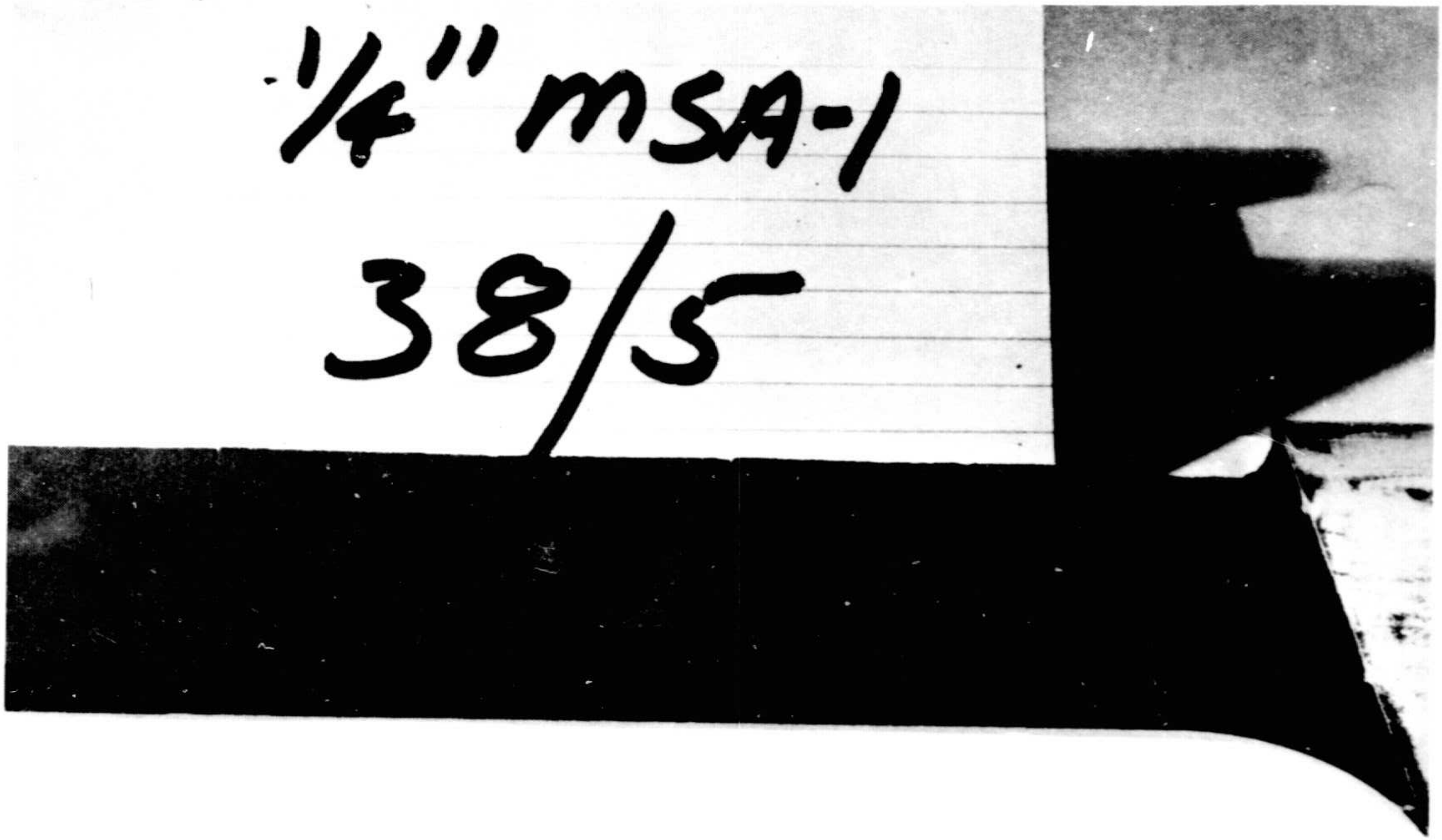

Figure 13. Post-test tensile specimen, 1/4-inch MSA-1, run 38, panel 5.

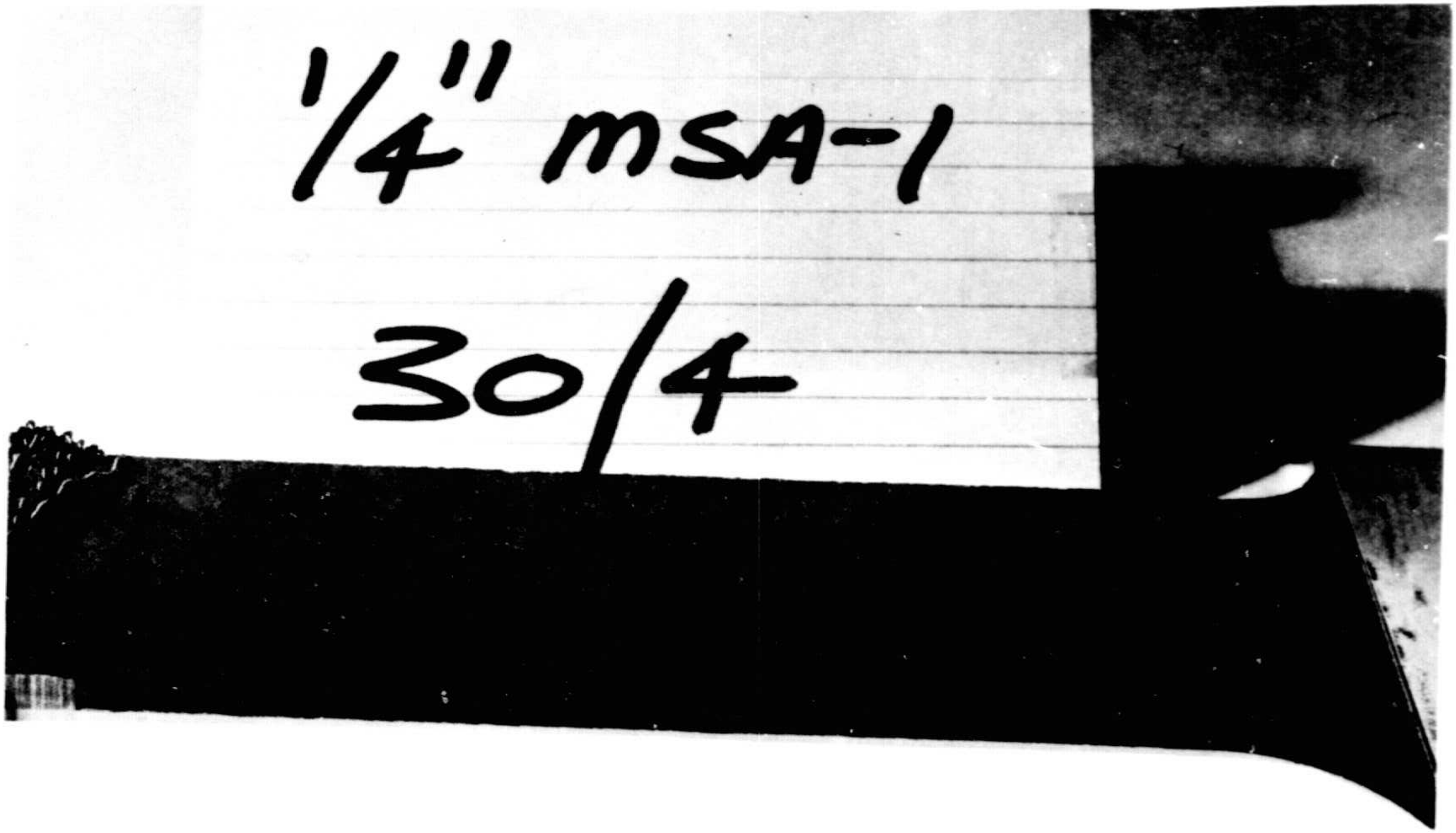

Figure 14. Post-test tensile specimen, 1/4-inch MSA-1, run 30, panel 4.

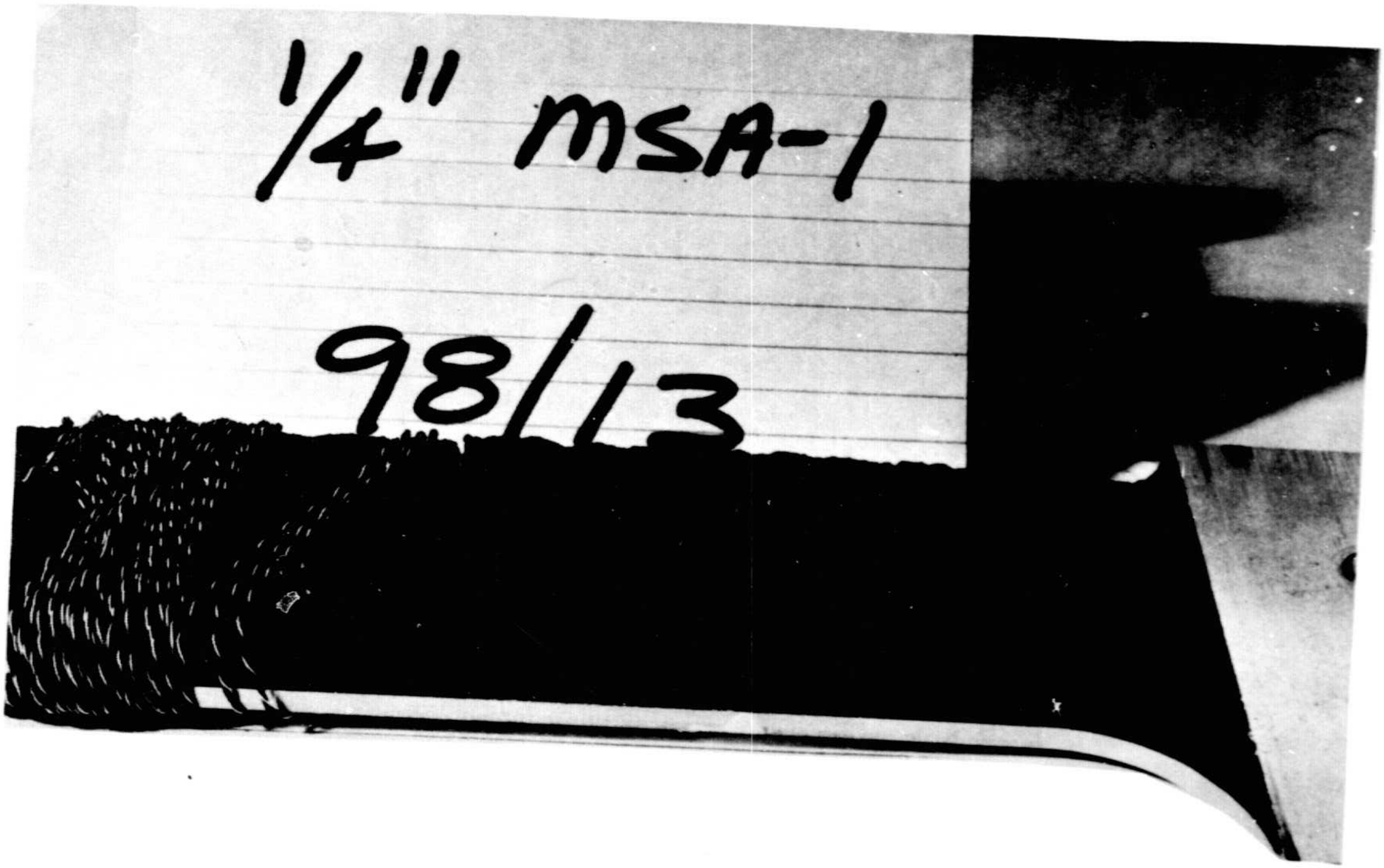

Figure 15. Post-test tensile specimen, 1/4-inch MSA-1, run 98, panel 13.

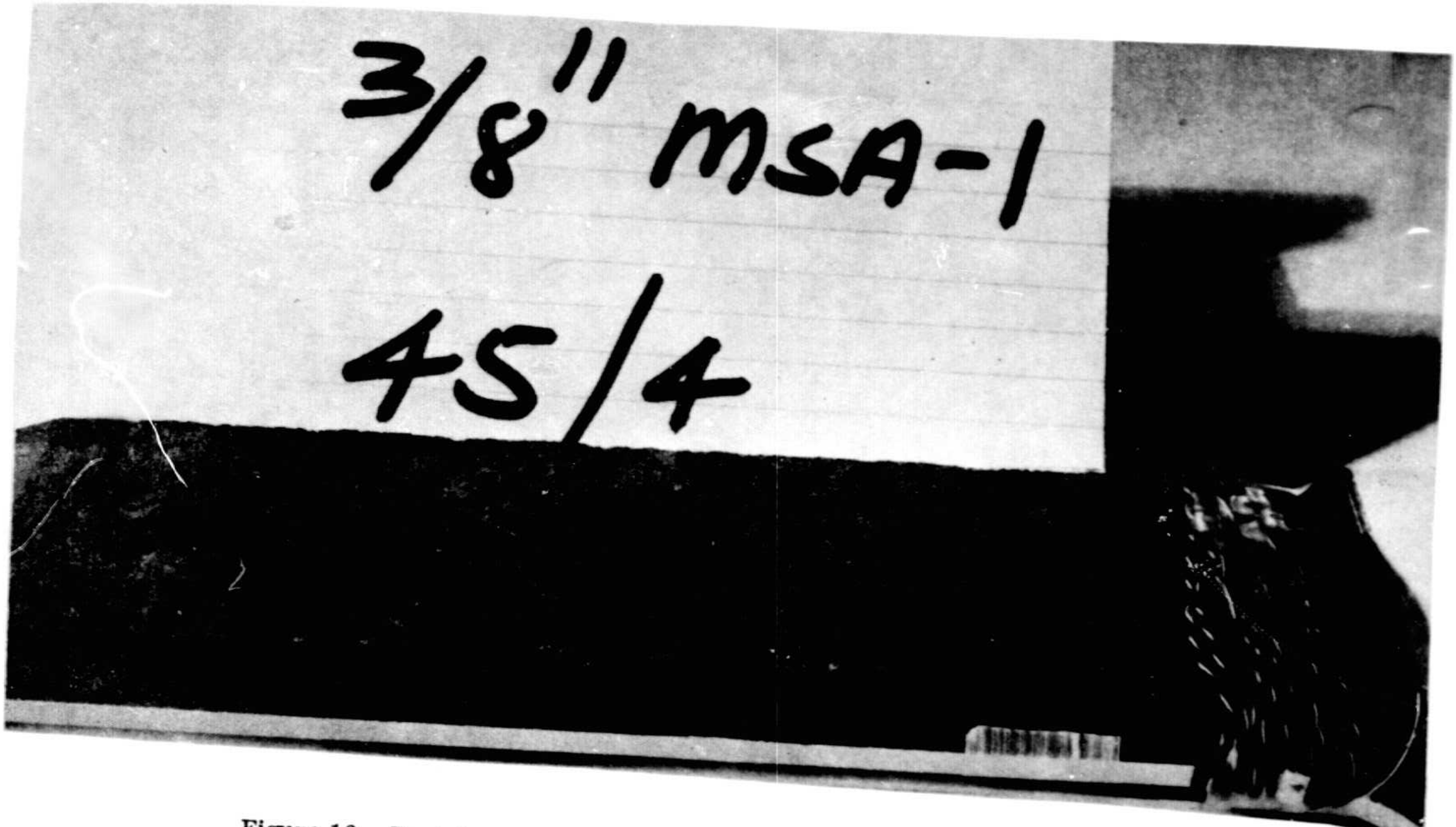

Figure 16. Post-test tensile specimen, 3/8-inch MSA-1, run 45, panel 4.

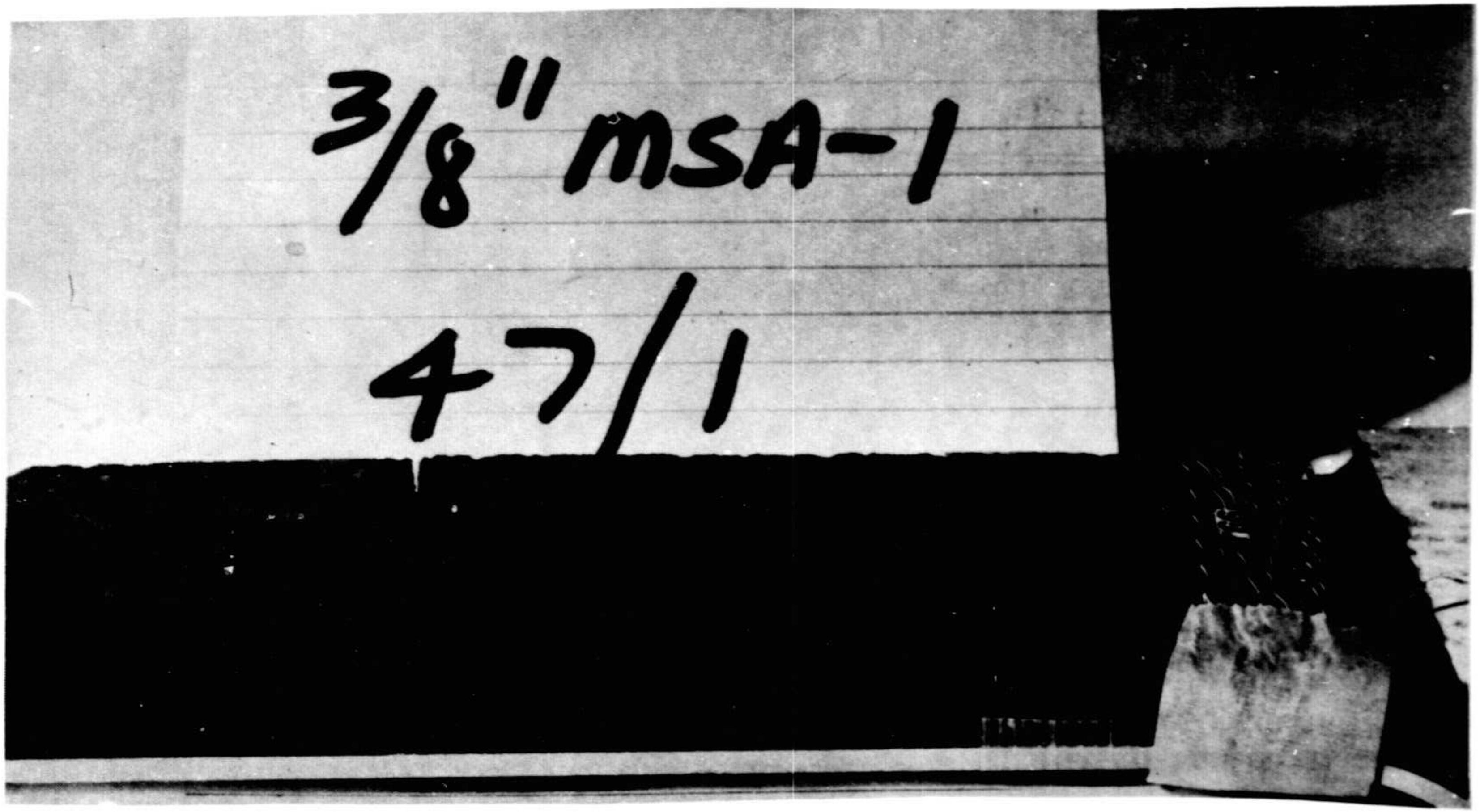

Figure 17. Post-test tensile specimen, 3/8-inch MSA-1, run 47, panel 1.

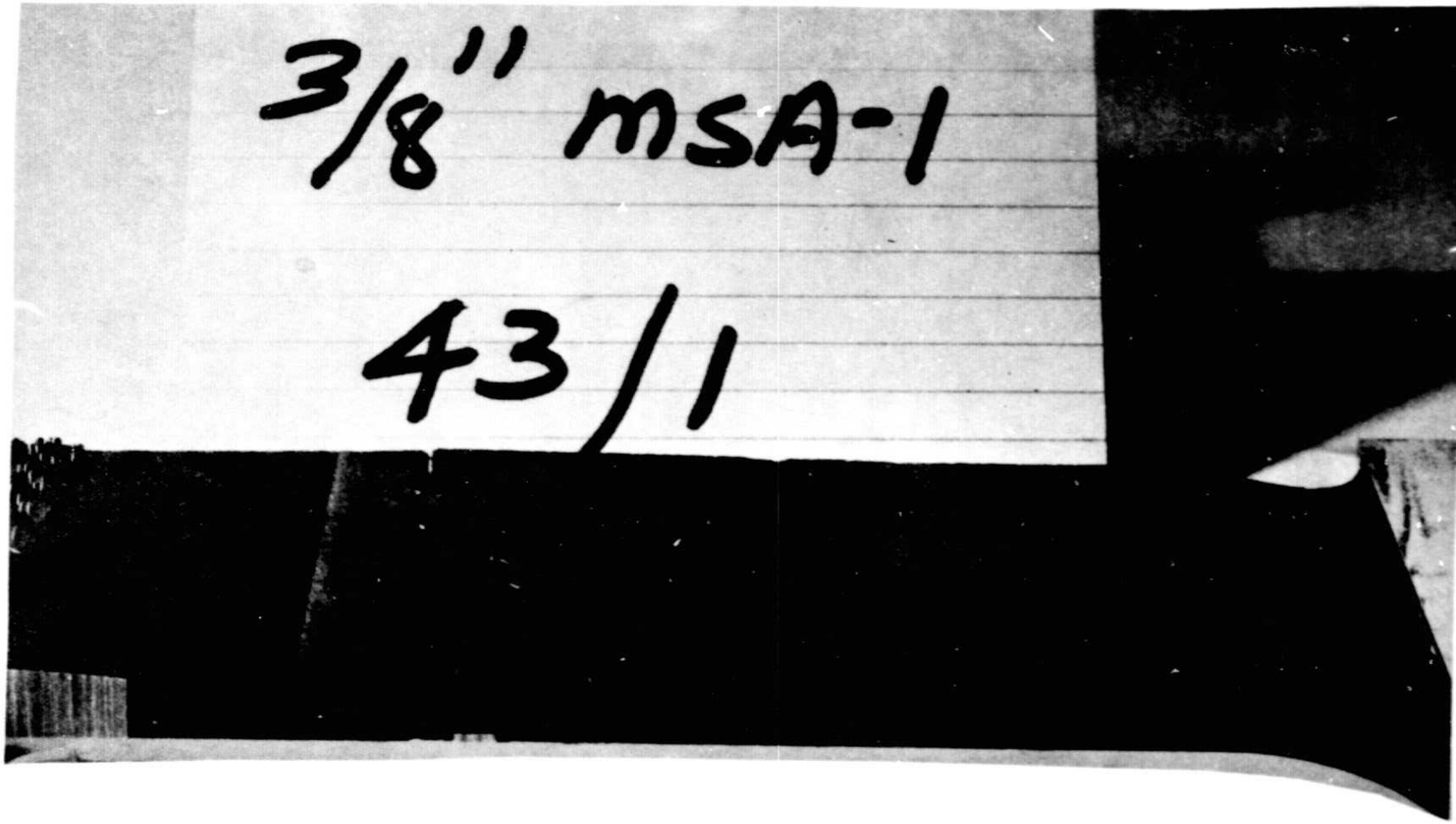

Figure 18. Post-test tensile specimen, 3/8-inch MSA-1, run 43, panel 1.

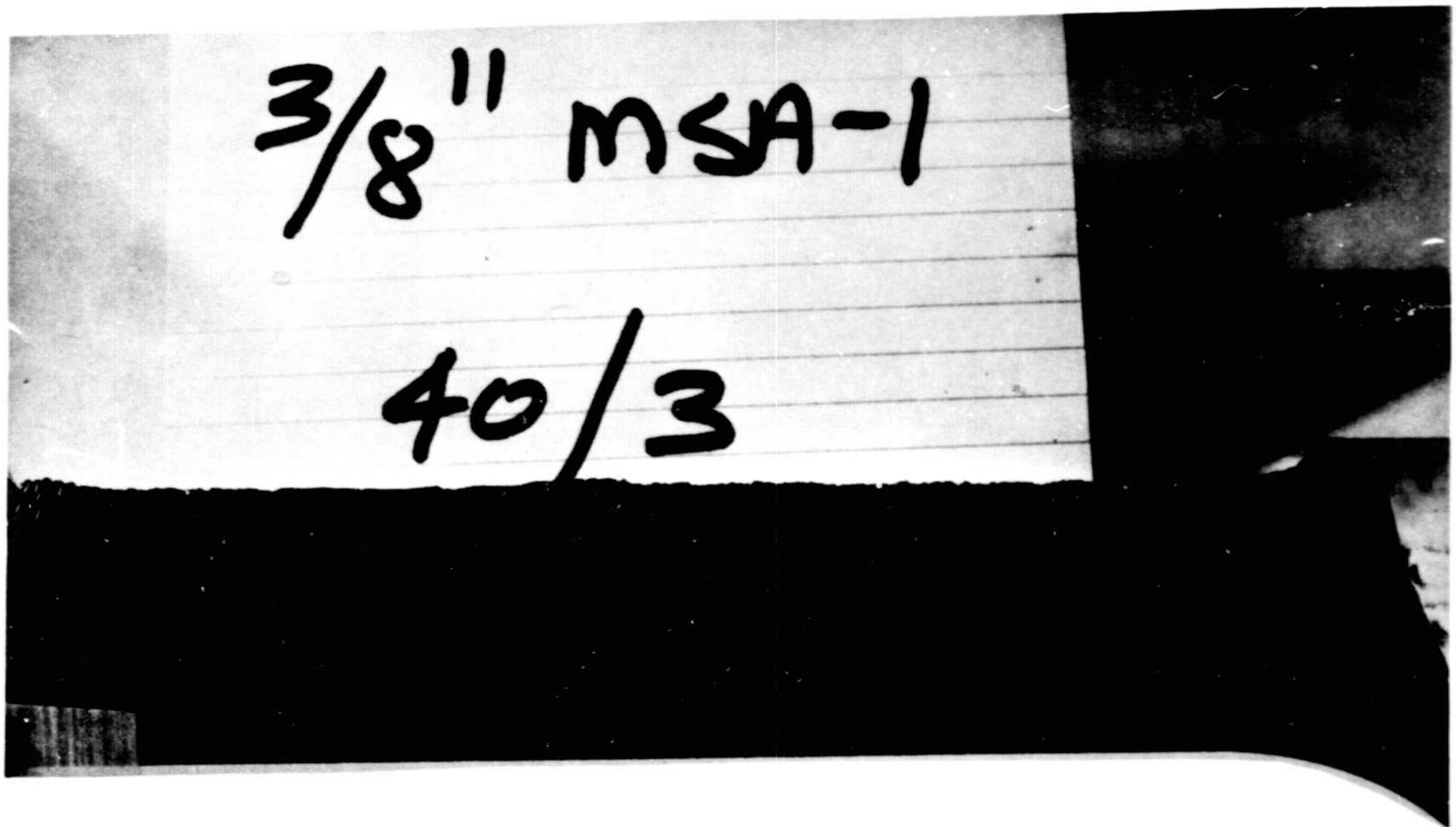

Figure 19. Post-test tensile specimen, 3/8-inch MSA-1, run 40, panel 3.

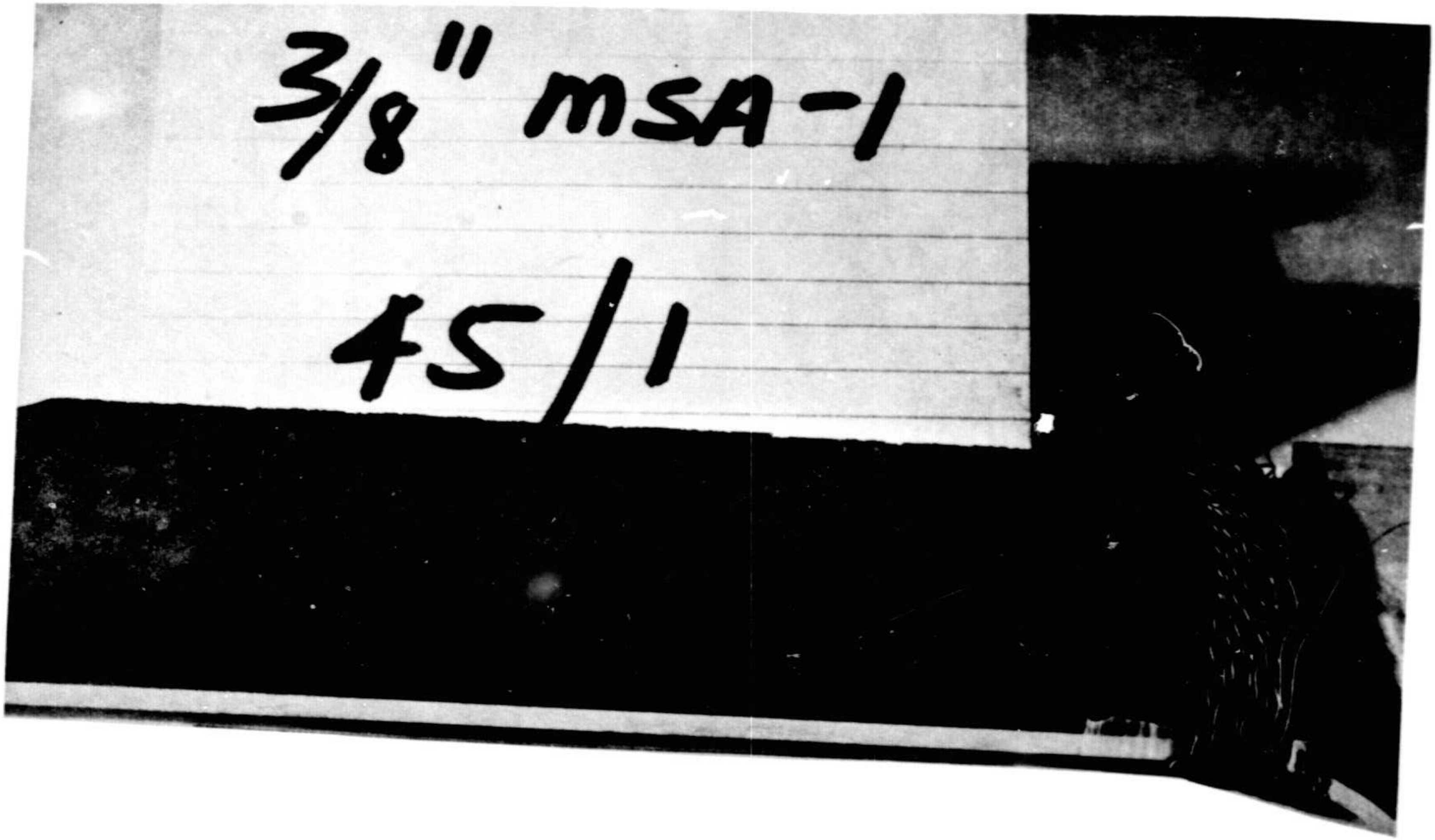

Figure 20. Post-test tensile specimen, 3/8-inch MSA-1, run 45, panel 1.

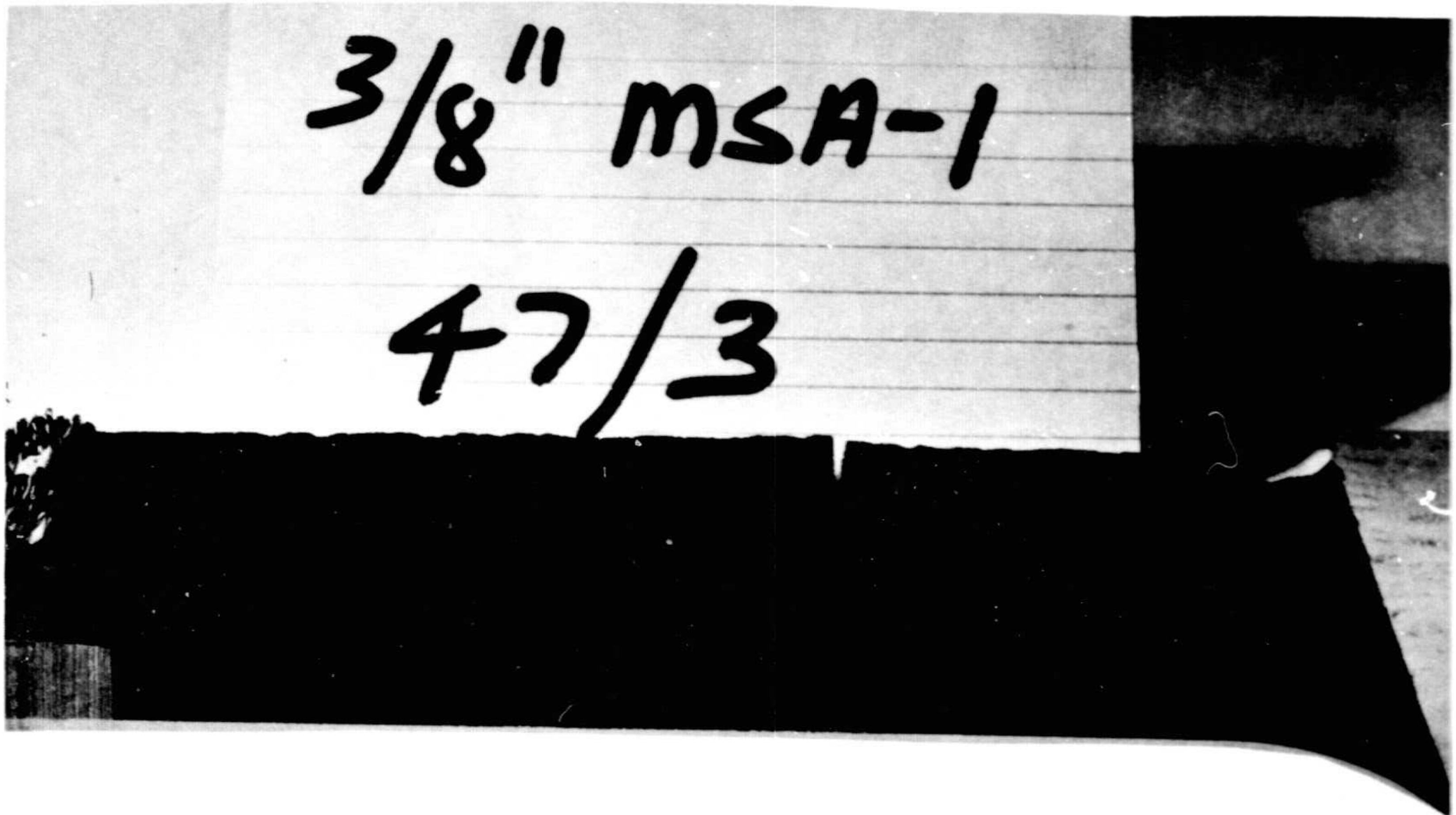

Figure 21. Post-test tensile specimen, 3/8-inch MSA-1, run 47, panel 3.

Figure 22. MSA-1 compressive strain specimen.

Figure 23. Compressive specimen mounted in test fixture.

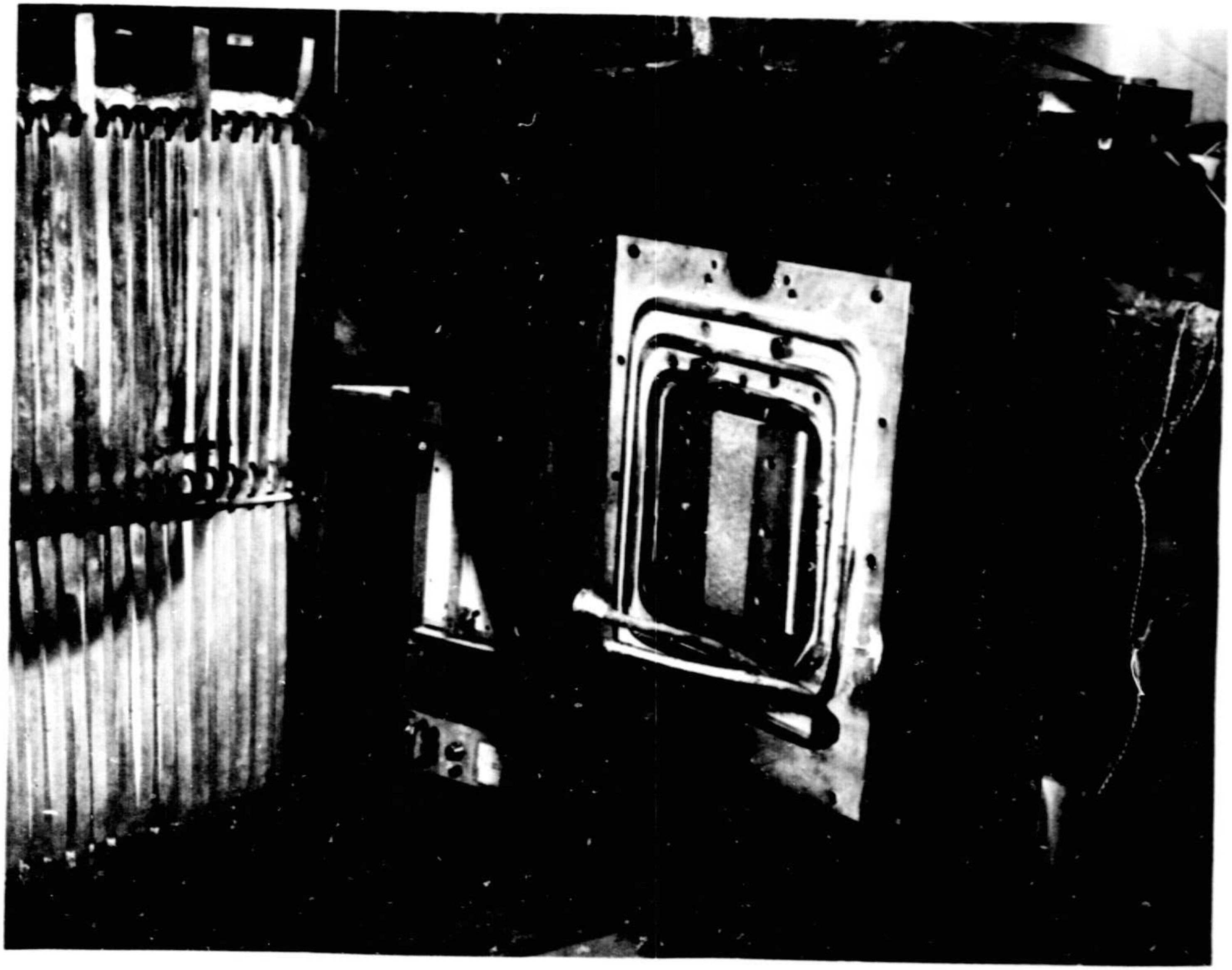

Figure 24. Compressive specimen in thermal/ vacuum chamber.

Figure 25. Post-test compressive specimen, 1/4-inch MSA-1, run 31, panel 1.

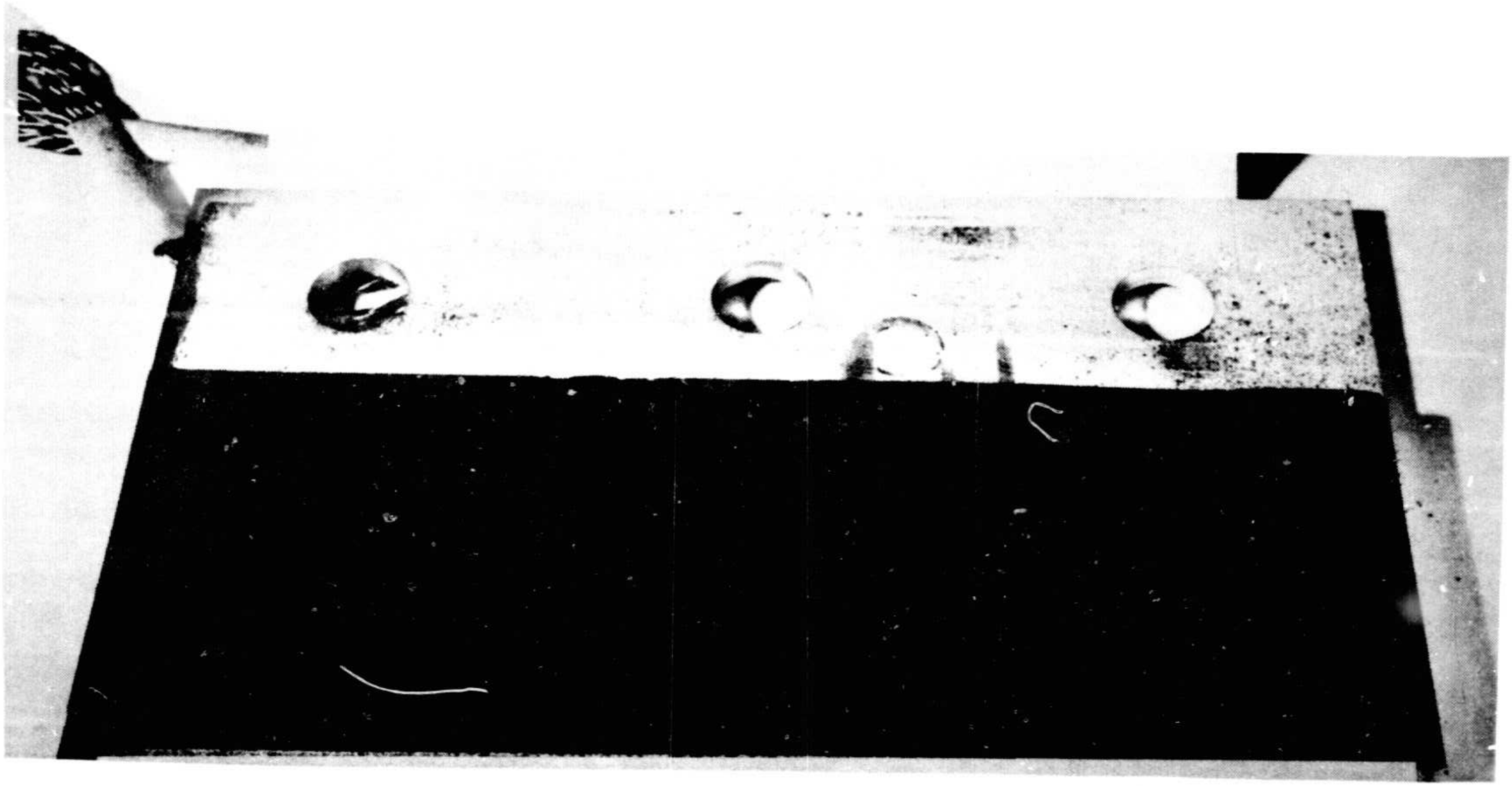

Figure 26. Post-test compressive specimen, 1/4-inch MSA-1, run 31, panel 5.

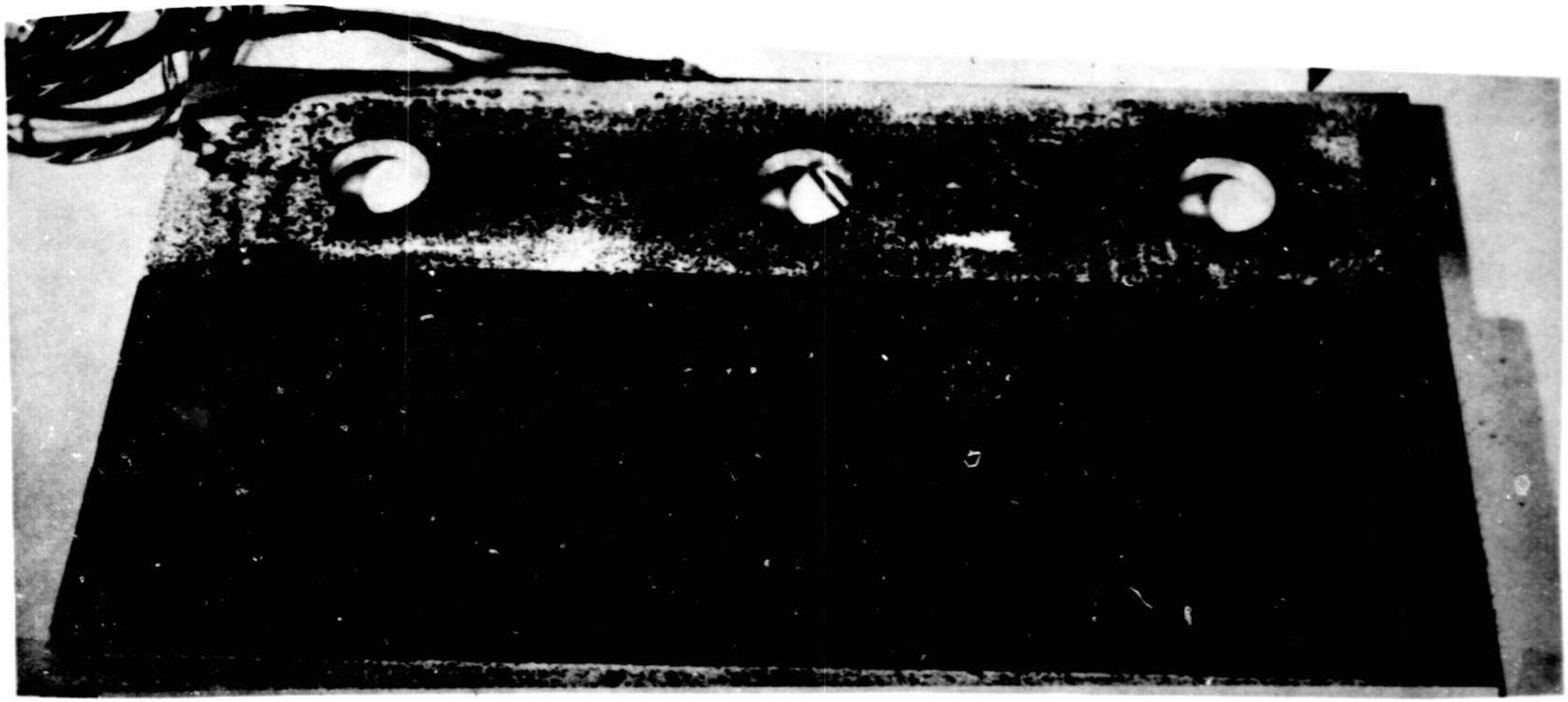

Figure 27. Post-test compressive specimen, 1/4-inch MSA-1, run 31, panel 3.

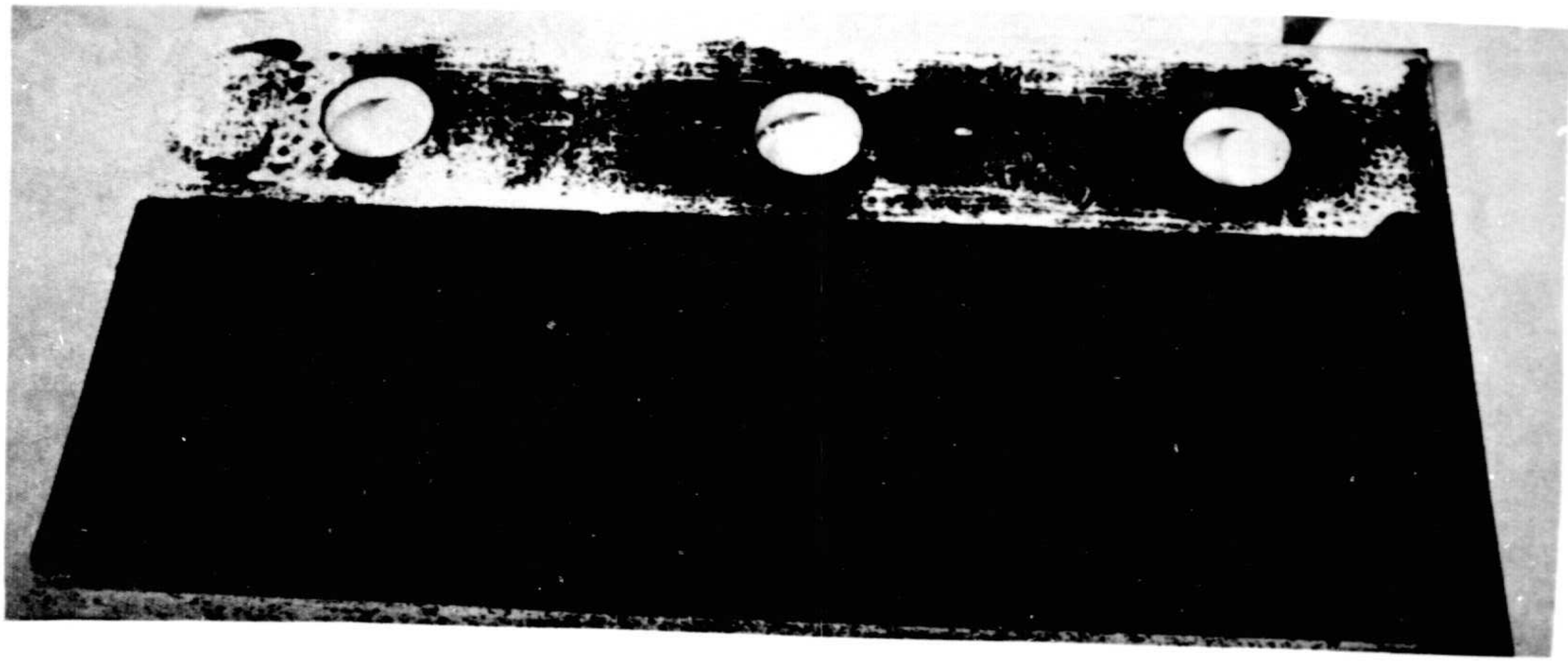

Figure 28. Post-test compressive specimen, 1/4-inch MSA-1, run 36, panel 1.

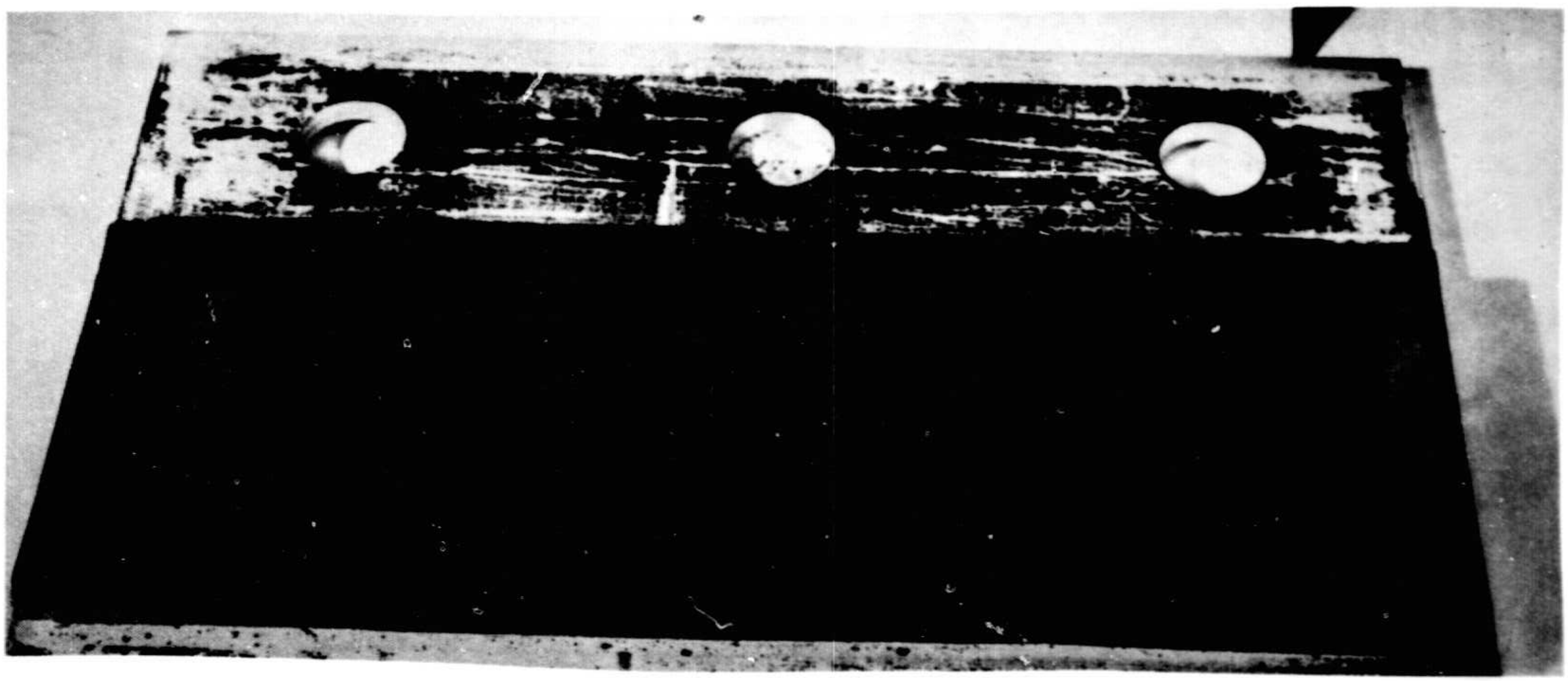

Figure 29. Post-test compressive specimen, 1/4-inch MSA-1, run 39, panel 5.

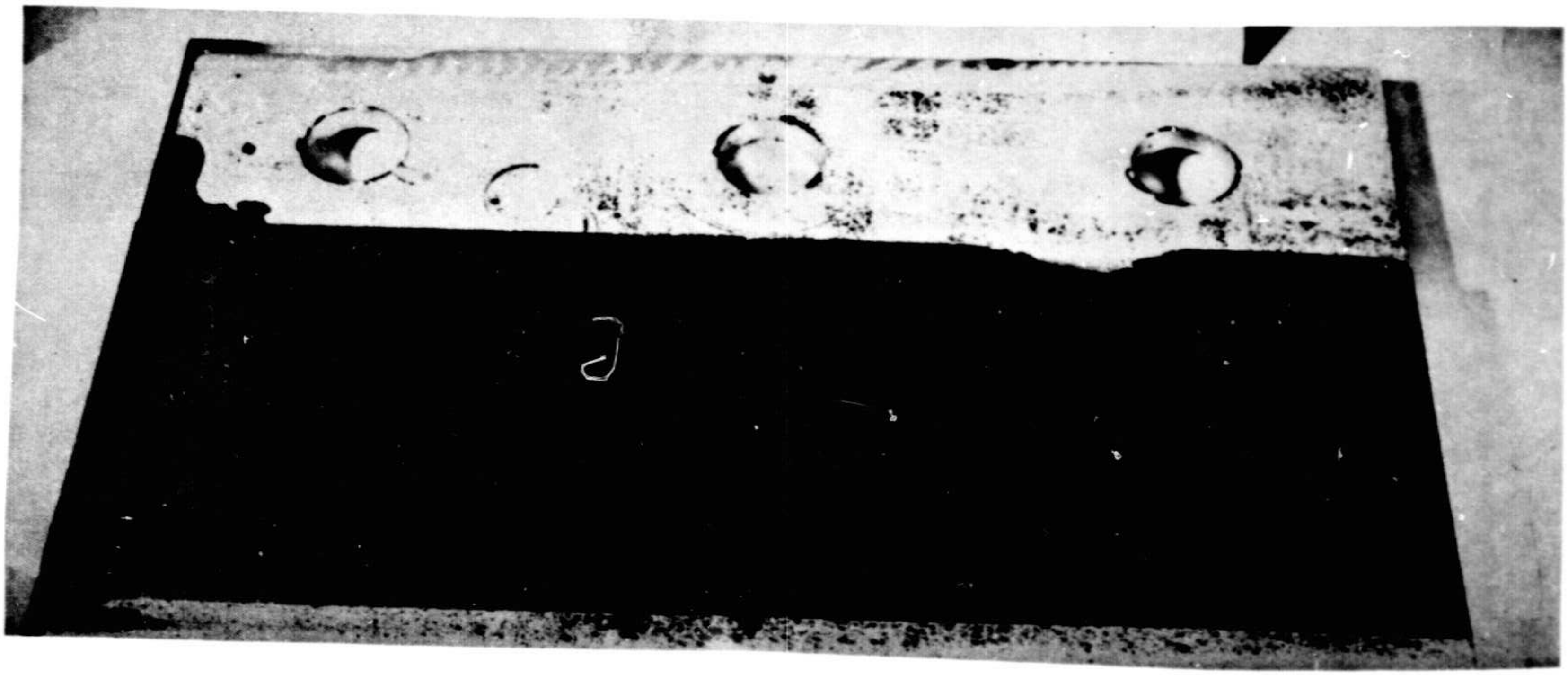

Figure 30. Post-test compressive specimen, 1/4-inch MSA-1, run 30, panel 4.

APPROVAL

STRAIN COMPATIBILITY ASSESSMENT FOR SRB SPRAYABLE ABLATOR MSA-1

By William J. Patterson

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or nuclear energy programs or activities has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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