(12)

AFWAL-TR-84-2048

DAMAGE CAUSED TO POLYURETHANE FOAMS BY AGING, SIMULATED SUNLIGHT EXPOSURE, HEAT AND FIRE

Leo Parts
MONSANTO RESEARCH CORPORATION
DAYTON LABORATORY
1515 NICHOLAS RD.
DAYTON, OHIO 45407

Thomas A. Hogan and Thomas J. Condron
AERO PROPULSION LABORATORY
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

JULY 1984

FINAL REPORT FOR PERIOD 15 JANUARY 1983 - 30 SEPTEMBER 1983

AERO PROPULSION LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICE

This report has been reviewed by the Office of Public Affairs (ASD/PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

J. R. Manheim

J. R. Manheim
T. Dues
Project Engineers

R. G. Clodfelter

R. G. Clodfelter
Chief, Fire Protection Branch

FOR THE COMMANDER:

R. D. Sherrill

R. D. Sherrill
Chief, Fuels and Lubrication Division

If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization, please notify AFWAL/POSH, Wright-Patterson Air Force Base, Ohio 45433 to help maintain a current mailing list.

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS
BEFORE COMPLETING FORM

1. REPORT NUMBER
AFWAL-TR-84-2048

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
DAMAGE CAUSED TO POLYURETHANE FOAMS BY AGING, SIMULATED SUNLIGHT EXPOSURE, HEAT, AND FIRE

5. TYPE OF REPORT & PERIOD COVERED
FINAL REPORT FOR PERIOD
15 Jan 1983 - 30 Sept 1983

6. PERFORMING ORG. REPORT NUMBER
MRC-DA-1150

7. AUTHOR(s)
Leo Parts, Monsanto Company
Thomas A. Hogan and Thomas J. Condron,
Aero Propulsion Laboratory

8. CONTRACT OR GRANT NUMBER(s)
F33615-78-C-2023
F33615-81-C-2035

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Monsanto Company
1515 Nicholas Road
Dayton, Ohio 45407

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
P.E. 62203F
Project 3048 05 15

11. CONTROLLING OFFICE NAME AND ADDRESS
Aero Propulsion Laboratory (AFWAL/POSH)
Air Force Wright Aeronautical Laboratories (AFSC)
Wright-Patterson AFB, Ohio 45433

12. REPORT DATE
July 1984

13. NUMBER OF PAGES
294

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Accident
Aging
Damage
Char
Burning
Degradation
Deposit
Fire
Flame
Foam
Fuel
Heat
Ignition
Incident
Photograph
Polyurethane
Reticulated
Simulation
Sunlight
Surface

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

Damage caused to reticulated polyurethane foams by aging (in air and liquid fuel), simulated sunlight exposure, hot wire cutting, hot air impingement, flame impingement, and sustained burning was investigated. The experiments simulated all conceivable types of environmental and unplanned exposure of these foams when used as explosion suppressant materials in aircraft fuel systems. Both polyether- and polyester-based polyurethanes were used.

(Block 20, continued)

It was demonstrated that the physical appearance of foams is often indicative of past exposure. A detailed photographic record of exposed specimens was obtained. The compilation of photographs, in conjunction with written description of damage, will serve as a reference for aircraft and fire accident investigators.

PREFACE

This is a summary Technical Report prepared by Monsanto Research Corporation, Dayton Laboratory. The effort was sponsored by the Air Force Wright Aeronautical Laboratories, Air Force Systems Command, Wright-Patterson AFB, Ohio; it was performed under Contracts F33615-78-C-2023 and F33615-81-C-2035 during the period 15 January 1983 - 30 September 1983. Dr Jon R. Manheim, AFWAL/POSH and Mr Tim Dues, AFWAL/POSF, served as Project Engineers.

Dr Leo Parts was technically responsible for the work at Monsanto Research Corporation. Messrs Thomas A. Hogan and Thomas J. Condron of the Fire Protection Branch, Aero Propulsion Laboratory, AFWAL, represented the Air Force part of the program team.

The following persons and organizations contributed significantly in the performance of this program. Mr Benjamin H. Wilt, University of Dayton Research Institute, supervised the accelerated aging testing of foam specimens. Mr J. Douglas Wolf, also of University of Dayton Research Institute, performed the instrumental surface analyses of foam specimens.. Blosser Color Laboratory, Inc., processed the color film and made the color prints.

Accession For
X

A-1

"Original contains color plates: All DTIC reproductions will be in black and white"

TABLE OF CONTENTS

Page

1. INTRODUCTION 1

2. EXPERIMENTAL 4

2.1 Foam Samples 4

2.2 Exposure of Polyurethane Foams to Aging, Simulated Sunlight, Heat, and Flames 5
- 2.2.1 Aging in Air 5
- 2.2.2 Aging in Jet Fuel 6
- 2.2.3 Simulated Sunlight Exposure 6
- 2.2.4 Hot Wire Cutting 6
- 2.2.5 Hot Air Impingement 6
- 2.2.6 Radiant Heat Exposure 7
- 2.2.7 Brief Flame Impingement 7
- 2.2.8 Sustained Burning 7
- 2.2.9 Flash Fire 7
- 2.2.10 Exposure Test Plan and Sample Code 13

2.3 Laboratory-Scale, Controlled Degradation Experiments With Blue Polyurethane Foam 18
- 2.3.1 Thermogravimetric Analysis 18
- 2.3.2 Pyrolysis and Thermo-oxidative Degradation of Blue Foam Under Controlled Conditions . . . 18
- 2.3.3 Infrared Spectroscopic Analysis of Degradation Products 19

2.4 Examination and Analysis of Polyurethane Samples Recovered From Aircraft Incident Sites 19
- 2.4.1 Visual Examination 19
- 2.4.2 Infrared Reflectance Spectroscopic Analysis . . 21
- 2.4.3 Emission Spectroscopic Analysis 22
- 2.4.4 Surface Analysis 22

3. RESULTS AND DISCUSSION 24

3.1 Exposure of Polyurethane Foams to Aging, Simulated Sunlight, Heat, and Flames 24
- 3.1.1 Aging in Air 24
- 3.1.2 Aging in Jet Fuel 26
- 3.1.3 Simulated Sunlight Exposure 26
- 3.1.4 Hot Wire Cutting 29
- 3.1.5 Hot Air Flow 29
- 3.1.6 Radiant Heat Flux 32
- 3.1.7 Brief Flame Impingement 34
- 3.1.8 Sustained Burning 34
- 3.1.9 Summary of Observed Effects of Aging and Simulated Sunlight, Heat, and Fire Exposure on Polyurethane Foams 38

TABLE OF CONTENTS (continued)

Page

3.2 Flash Fire Exposure 38
    3.2.1 Effect of Foam Geometry 43
    3.2.2 Effect of Foam Type 44
    3.2.3 Effect of Hydrocarbon Vapor Concentration; Dry vs. Fuel-Wetted Foam 47
    3.2.4 Effect of Foam Aging 48
    3.2.5 Effect of Pressure 49
3.3 Laboratory-Scale, Controlled Degradation Experiments With Blue Polyurethane Foam 50
    3.3.1 Thermogravimetric Analysis 50
    3.3.2 Pyrolysis and Thermo-Oxidative Degradation of Blue Foam Under Controlled Conditions . . . 50
    3.3.3 Infrared Spectroscopic Analysis of Degradation Products 51
3.4 Examination and Analysis of Polyurethane Foam Samples Recovered from Aircraft Incident Sites 57
    3.4.1 Foam from Fuel Vent Tanks 57
    3.4.2 Fuel Tank Foam 60
    3.4.3 Wipings from Vent Masts and from Right Side Vent, Tank Dome 66
    3.4.4 Emission Spectrographic Analysis of Specimens from Aircraft Incident Sites 69
    3.4.5 Surface Analysis of Foam Specimen from Aircraft No. 78-717 Fuel Vent Tank 70

4. CONCLUSIONS 73

REFERENCES 74

APPENDICES

1. Photographic Documentation of Test Specimens . . . 77
    A1.1 Introduction 78
    A1.2 Figures Depicting Foam Samples from Accelerated Aging Tests in Air 82
    A1.3 Figures Depicting Foam Samples from Accelerated Aging Tests in JP-5 92
    A1.4 Figures Depicting Samples from Simulated Sunlight Exposure Test 99
    A1.5 Figures Depicting Foam Samples from Hot Wire Cutting Experiments 110
    A1.6 Figures Depicting Samples from Hot Air Impingement Experiments 114
    A1.7 Figures Depicting Foam Samples from Radiant Heat Exposure Experiments 124
    A1.8 Figures Depicting Foam Samples from Brief Flame Impingement Experiments 134

TABLE OF CONTENTS (continued)

Page

APPENDICES (continued)

A1.9 Figures Depicting Foam Samples from Sustained Burning Experiments 150
A1.10 Figures Depicting Foam Samples from Flash Fire Experiments. 166
2. Brown-Stained Blue Foam in F-4 Aircraft. 224
3. Analysis of Soot-Stained Red Foam in A-10 Aircraft. 235
4. Tensile Strengths of Polyurethane Foams as Functions of Aging. 241
5. Report on Accelerated Aging of Foam Specimens in Simulated Sunlight Test Chamber, Humidity Cabinet, and Air Oven. 244
   Introduction. 247
   Procedure 247
6. Emission Spectrographic Analysis Report on Polyurethane Foam from an A-10 Aircraft. 257
7. Surface Analysis Report on Polyurethane Foam from an A-10 Aircraft 260

LIST OF FIGURES

Number		Page
1	Flash fire test system.	8
2	Cross-sectional view of flame tube in unvented configuration	10
3	Cross-sectional view of flame tube in vented configuration	11
4	Sample of the tan-colored solid formed upon pyrolysis of blue foam.	21
5	Cross-sectional views of foam specimens subjected to accelerated aging in air (8-5-1, five weeks; 8-2-5, two weeks; 8-2-7, two weeks)	25
6	Red foam specimen, after three weeks of accelerated aging in air.	27
7	Yellow foam specimen, after three weeks of accelerated aging in air.	27
8	Cross-sectional views of foam specimens subjected to accelerated aging in jet fuel (JP-5)	28
9	Cross-sectional views of foam specimens subjected to 200 hours of simulated sunlight exposure . . .	30
10	Magnified view of hot-wire-cut blue foam surface	30
11	Cross-sectional views of foam specimens subjected to hot air impingement.	31
12	Cross-sectional close-up view of red foam specimen subjected to hot air impingement	33
13	Cross-sectional views of foam specimens subjected to radiant heating.	33
14	Cross-sectional views of foam specimens subjected to brief flame impingement.	35
15	Cross-sectional views of specimens that had been involved in sustained top surface burning in horizontal position	35

LIST OF FIGURES (continued)

Number		Page
16	Cross-sectional view of red foam specimen from sustained horizontal top-burning experiments. . .	36
17	Cross-sectional view of fuel-soaked blue foam specimen that had been involved in sustained burning in horizontal position.	36
18	Cross-sectional view of fuel-soaked blue foam specimen that had been involved in sustained burning in vertical position.	37
19	Blue foam damage pattern, Test 22	45
20	Blue foam damage pattern, Test 5.	45
21	Red foam damage pattern, Test 16.	46
22	Yellow foam damage pattern, Test 25	46
23	Thermogram and differential thermogram for degradation of blue polyurethane foam in air. . .	52
24	Thermogram and differential thermogram for degradation of blue polyurethane foam in helium. . .	53
25	Infrared absorption spectrum of blue polyurethane foam	54
26	Infrared absorption spectrum of the solid, tan-colored pyrolysis product formed from blue polyurethane foam.	55
27	Infrared absorption spectrum of the liquid, brown-colored pyrolysis product formed from blue polyurethane foam.	56
28	Fuel vent tank foam, left half, A/C 78-717 (Specimen No. 1).	58
29	Fuel vent tank foam, right half, A/C 78-717 (Specimen No. 2).	58
30	Fuel vent tank foam, left half, A/C 78-704 (Specimen No. 3).	59
31	Close-up view of the damaged segment of fuel vent tank foam from A/C 78-704 (Specimen No. 3). . . .	59

LIST OF FIGURES (continued)

Number Page
32 Two halves of fuel vent tank foam from A/C 78-717 (Specimens Nos. 1 and 2) placed together. 61
33 Close-up view of white powder deposit on the surface of fuel tank foam (Specimen No. 1). . . . 62
34 Left halves of fuel tank foam from A/C-s 78-704 and 78-717 63
35 Wing tank foam, A/C 78-717 (Specimen No. 4) . . . 64
36 Fire-damaged surface of fuel tank foam (Specimen No. 4). 64
37 Close-up view of the fire-damaged surface of fuel tank foam (Specimen No. 4) 65
38 Foam pieces from the wing tank of A/C 78-717 (Specimens Nos. 5-8). 67
39 Inside view of foam specimen from the wing tank of A/C 78-717. 67
40 Infrared spectrum of wipings from vent mast of A/C 78-704 (Specimen No. 11; in KBr matrix) . . . 68
41 Light microscope photograph of deposit (white areas) on vent tank foam from A/C 78-717 (50X). . 71
42 Scanning electron photomicrograph of deposit on vent tank foam from A/C 78-717 (100X). 71
43 Scanning electron photomicrograph of deposit on vent tank foam from A/C 78-717 (100X). 72
44 Scanning electron photomicrograph of deposit on vent tank foam from A/C 78-717 (1000X) 72
A1-1 Magnified view of the Type IV 80
A1-2 Magnified view of the red foam structure. 80
A1-3 Magnified view of the yellow foam structure . . . 81

LIST OF FIGURES (continued)

Number Page

A1-4 Cross-sectional views of blue, red, and yellow foam specimens, subjected to accelerated aging in air (8-5-1, five weeks; 8-2-5, two weeks; 8-2-7, two weeks) 83

A1-5 Specimens of blue foam, subjected to accelerated aging in air at 200°F (93°C) for one to five weeks. (Reference sample of unexposed foam is also shown). 83

A1-6 Sample 8-1-1, perspective view. 84

A1-7 Sample 8-3-1, perspective view. 84

A1-8 Sample 8-5-1, perspective view. 85

A1-9 Sample 8-5-1, cross-sectional view. 85

A1-10 Specimens of red foam, subjected to accelerated aging in air at 200°F (93°C) for one to three weeks 86

A1-11 Sample 8-1-5, perspective view. 86

A1-12 Sample 8-2-5, perspective view. 87

A1-13 Sample 8-2-5, cross-sectional view. 87

A1-14 Red foam specimen 8-3-5, after three weeks of accelerated aging in air at 200°F (93°C). 88

A1-15 Specimens of yellow foam, subjected to accelerated aging in air at 200°F (93°C) for one to three weeks. 89

A1-16 Sample 8-1-7, perspective view. 89

A1-17 Sample 8-2-7, perspective view. 90

A1-18 Sample 8-2-7, cross-sectional view. 90

A1-19 Yellow foam specimen 8-3-7, after three weeks of accelerated aging in air at 200°F (93°C). 91

A1-20 Cross-sectional view of blue, red, and yellow foam specimens, subjected to accelerated aging in JP-5 for five weeks. 93

LIST OF TABLES (continued)

Number Page

A2-6 Fuel Additives for JP-4 and JP-8, and Fuel Leak Testing Dyes. 235

A5-1 Exposure Schedule for Blue Foams. 249

A5-2 Blue Foam Specimen Discoloration and Chamber Temperature During Operation of Sunlighter. . . . 250

A5-3 Exposure Schedule for Red and Yellow Foams. . . . 252

A5-4 Red and Yellow Foam Specimen Discoloration and Chamber Temperature During Operation of Sunlighter 253

A5-5 Exposure Schedule for Blue, Red, and Yellow Foams. Accelerated Aging at 200°F, 95% RH. . . . 255

A5-6 Exposure Schedule for Blue, Red, and Yellow Foams. Accelerated Aging at 200°F in JP-5. . . . 256

LIST OF TABLES

Number Page

1 Hot Wire Cutting. Test Plan and Sample Code. . . 14

2 Brief Flame Impingement. Exposure Test Plan and Sample Code 14

3 Sustained Burning. Exposure Test Plan and Sample Code 15

4 Hot Air Impingement. Exposure Test Plan and Sample Code 15

5 Radiant Heat Exposure. Test Plan and Sample Code 16

6 Accelerated Aging in Simulated Sunlight. Exposure Test Plan and Sample Code. 16

7 Accelerated Aging in Air. Exposure Test Plan and Sample Code 17

8 Accelerated Aging in Jet Fuel. Exposure Test Plan and Sample Code. 17

9 Pyrolysis and Thermo-Oxidative Degradation Experiments with Blue Polyurethane Foam Under Controlled Conditions 20

10 Elemental Analysis Results. 20

11 Summary of Observed Effects of Aging, and Simulated Sunlight, Heat, and Fire Exposure on Polyurethane Foams 39

12 Flash Fire Tests with Flame Tube. 40

13 Summary of TGA and DTG Data for Blue Polyurethane Foam in Air and Helium Atmospheres. 51

A2-1 Physical Properties of Foam Samples 229

A2-2 Soxhlet Extraction Results. 230

A2-3 Elemental Analysis Results for Extracts 230

A2-4 Summary of Extraction Test Results. 233

A2-5 Results for Metal Analyses. 234

LIST OF FIGURES (continued)

Number		Page
A2-1	F-4 brown-stained foam compared with new blue foam	226
A2-2	View of F-4 brown-stained foam in the fuel cell .	226
A2-3	Sample locations, F-4 (brown -stained) foam . . .	227
A2-4	Infrared spectrum of acetone extract from F-4 (brown-stained) foam.	231
A2-5	Infrared spectrum of acetone extract from fresh blue foam	231
A2-6	Ultraviolet spectra of acetone extracts from F-4 (brown-stained) foam and fresh blue foam.	232
A3-1	Red foam from A-10 aircraft (SN 75-00293) vent collector tank.	239
A3-2	End view of red foam vent collector tank kit. . .	239
A4-1	Tensile strengths of polyurethane foam in accelerated aging tests in air.	242
A4-2	Tensile strengths of polyurethane foam in accelerated fuel immersion aging tests.	243
A7-1	Deposit on filter (10X)	263
A7-2	Deposit on filter (100X).	263
A7-3	Deposit on filter (1000X)	264
A7-4	EDXA spectra of deposit on filter	264
A7-5	Control sample (100X)	265
A7-6	EDXA of control	265
A7-7	Light microscope photograph of deposit (white areas) 50X	266
A7-8	Low resolution XPS scan	267
A7-9	High resolution XPS scan.	268

LIST OF FIGURES (continued)

Number Page

A1-215 Sample 1-A-28, perspective front view 209
A1-216 Sample 1-3-28, direct front view. 209
A1-217 Sample 1-3-28, cross-sectional view 210
A1-218 Sample 1-3-31, perspective front view 211
A1-219 Sample 1-3-31, direct front view. 211
A1-220 Sample 1-3-31, cross-sectional view 212
A1-221 Sample 1-3-34, perspective front view 213
A1-222 Sample 1-3-34, direct front view. 213
A1-223 Sample 1-3-34, cross-sectional view 214
A1-224 Sample 1-3-37, perspective front view 215
A1-225 Sample 1-3-37, direct front view. 215
A1-226 Sample 1-3-37, cross-sectional view 216
A1-227 Sample 1-E-39, perspective front view 217
A1-228 Sample 1-E-39, direct front view. 217
A1-229 Sample 1-E-39, close-up view of front surface . . 218
A1-230 Sample 1-E-39, cross-sectional view 218
A1-231 Sample 1-E-39, close-up cross-sectional view. . . 219
A1-232 Sample 1-3-40, perspective front view 220
A1-233 Sample 1-3-40, direct front view. 220
A1-234 Sample 1-3-40, cross-sectional view 221
A1-235 Sample 1-3-43, perspective front view 222
A1-236 Sample 1-3-43, direct front view. 222
A1-237 Sample 1-3-43, cross-sectional view 223

LIST OF FIGURES (continued)

Number		Page
A1-195	Sample 1-1-17, close-up cross-sectional view, upper left quadrant	197
A1-196	Sample 1-1-20, perspective front view	198
A1-197	Sample 1-1-20, direct front view.	198
A1-198	Sample 1-1-20, close-up front view, upper left quadrant	199
A1-199	Sample 1-1-22, perspective front view	200
A1-200	Sample 1-1-22, direct front view.	200
A1-201	Sample 1-1-22, close-up front view, upper left quadrant	201
A1-202	Sample 1-1-22, cross-sectional view	201
A1-203	Sample 1-1-23, perspective front view	202
A1-204	Sample 1-1-23, direct front view.	202
A1-205	Sample 1-1-23, close-up front view, upper left quadrant	203
A1-206	Sample 1-1-23, cross-sectional view	203
A1-207	Sample 1-1-25, perspective front view	204
A1-208	Sample 1-1-25, direct front view.	204
A1-209	Sample 1-1-25, close-up front view, upper left quadrant	205
A1-210	Sample 1-1-25, cross-sectional view	205
A1-211	Sample 1-1-25, close-up cross-sectional view, upper left quadrant	206
A1-212	Sample 1-A-26, perspective front view	207
A1-213	Sample 1-A-26, direct front view.	207
A1-214	Sample 1-A-26, cross-sectional view	208

LIST OF FIGURES (continued)

Number Page

A1-175 Sample 1-1-11, close-up view of front surface, upper left corner 186

A1-176 Sample 1-1-11, cross-sectional view 186

A1-177 Close-up cross-sectional view, upper right corner. 187

A1-178 Sample 1-1-12, perspective front view 188

A1-179 Sample 1-1-12, direct front view. 188

A1-180 Sample 1-1-12, close-up view of front surface, upper left and central areas. 189

A1-181 Sample 1-1-12, cross-sectional view 189

A1-182 Sample 1-1-14, perspective front view 190

A1-183 Sample 1-1-14, direct front view. 190

A1-184 Sample 1-1-14, close-up front view, upper left quadrant 191

A1-185 Sample 1-1-14, cross-sectional view 191

A1-186 Sample 1-1-14, close-up cross-sectional view, upper left quadrant 192

A1-187 Sample 1-1-16, perspective front view 193

A1-188 Sample 1-1-16, direct front view. 193

A1-189 Sample 1-1-16, close-up front view, upper left quadrant 194

A1-190 Sample 1-1-16, cross-sectional view 194

A1-191 Sample 1-1-17, perspective front view 195

A1-192 Sample 1-1-17, direct front view. 195

A1-193 Sample 1-1-17, close-up front view, upper left quadrant 196

A1-194 Sample 1-1-17, cross-sectional view 196

LIST OF FIGURES (continued)

Number Page

A1-153 Sample 1-A-1, cross-sectional view, upper left corner 174

A1-154 Sample 1-1-5, perspective front view. 175

A1-155 Sample 1-1-5, direct front view 175

A1-156 Sample 1-1-5, close-up view of front surface. . . 176

A1-157 Sample 1-1-5, direct rear view. 176

A1-158 Sample 1-2-5, perspective front view. 177

A1-159 Sample 1-2-5, direct front view 177

A1-160 Sample 1-2-5, close-up view of front surface. . . 178

A1-161 Sample 1-2-5, direct rear view. 178

A1-162 Sample 1-2-5, cross-sectional view. 179

A1-163 Sample 1-2-5, close-up cross-sectional view, upper left quadrant 179

A1-164 Sample 1-D-7, perspective front view. 180

A1-165 Sample 1-D-7, direct front view 180

A1-166 Sample 1-D-7, close-up view of front surface, upper right corner. 181

A1-167 Sample 1-D-7, cross-sectional view. 181

A1-168 Sample 1-D-7, close-up cross-sectional view . . . 182

A1-169 Sample 1-D-10, perspective front view 183

A1-170 Sample 1-D-10, direct front view. 183

A1-171 Sample 1-D-10, close-up view of front surface, upper left and central areas. 184

A1-172 Sample 1-D-10, close-up view of the vent area . . 184

A1-173 Sample 1-1-11 perspective front view. 185

A1-174 Sample 1-1-11, direct front view. 185

LIST OF FIGURES (continued)

Number Page

A1-133 Sample 4-3-11, perspective view 161

A1-134 Sample 4-3-11, cross-sectional view 161

A1-135 Perspective view of yellow foam specimens, subjected to sustained burning. Samples ignited by flame from top while in horizontal position, and from bottom while in vertical and horizontal positions, respectively 162

A1-136 Sample 4-1-15, perspective view 163

A1-137 Sample 4-1-15, cross-sectional view 163

A1-138 Sample 4-2-15, perspective view 164

A1-139 Sample 4-2-15, cross-sectional view 164

A1-140 Sample 4-3-14, cross-sectional view 165

A1-141 Sample 4-3-14, perspective view 165

A1-142 Cross-sectional view of flame tube in unvented configuration 168

A1-143 Cross-sectional view of flame tube in vented configuration 169

A1-144 Sample 1-1-1, perspective front view. 170

A1-145 Sample 1-1-1, direct front view 170

A1-146 Sample 1-1-1, close-up front view 171

A1-147 Sample 1-1-1, direct rear view. 171

A1-148 Sample 1-1-1, cross-sectional view. 172

A1-149 Sample 1-A-1, perspective front view. 172

A1-150 Sample 1-A-1, direct front view 173

A1-151 Sample 1-A-1, close-up front view, upper left corner 173

A1-152 Sample 1-A-1, close-up front view, upper right corner. 174

LIST OF FIGURES (continued)

Number Page

A1-115 Perspective view of blue foam specimens subjected to sustained burning. Samples ignited by flame from top while in horizontal position, and from bottom while in vertical and horizontal positions, respectively 151

A1-116 Sample 4-1-3, perspective view. 152

A1-117 Sample 4-1-3, cross-sectional view. 152

A1-118 Sample 4-2-2, perspective view. 153

A1-119 Sample 4-2-2, cross-sectional view. 153

A1-120 Sample 4-3-3, perspective view. 154

A1-121 Sample 4-3-3, cross-sectional view. 154

A1-122 Sample 4-1-4 (wet, new foam), perspective view. . 155

A1-123 Sample 4-1-4 (wet, new foam), cross-sectional view. 155

A1-124 Sample 4-2-5 (wet, new foam), perspective view. . 156

A1-125 Sample 4-2-5 (wet, new form), cross-sectional view. 156

A1-126 Sample 4-1-9 (aged, dry foam), perspective view . 157

A1-127 Sample 4-1-9 (aged, dry foam), cross-sectional view. 157

A1-128 Perspective view of red foam specimens, subjected to sustained burning. Samples ignited by flame from top while in horizontal position, and from bottom while in vertical and horizontal positions, respectively 158

A1-129 Sample 4-1-12, perspective view 159

A1-130 Sample 4-1-12, cross-sectional view 159

A1-131 Sample 4-2-11, perspective view 160

A1-132 Sample 4-2-10, cross-sectional view 160

LIST OF FIGURES (continued)

Number Page

A1-97 Sample 3-2-5 (wet, new foam), cross-sectional view. 140

A1-98 Sample 3-1-9 (dry, aged foam), perspective view. 141

A1-99 Sample 3-1-9 (dry, aged foam), cross-sectional view. 141

A1-100 Perspective view of red foam specimens, subjected to brief flame impingement from top while in horizontal position, and from bottom while in vertical and horizontal positions, respectively . 142

A1-101 Sample 3-1-11, perspective view 143

A1-102 Sample 3-1-11, cross-sectional view 143

A1-103 Sample 3-2-10, perspective view 144

A1-104 Sample 3-2-10, cross-sectional view 144

A1-105 Sample 3-3-11, perspective view 145

A1-106 Sample 3-3-11, cross-sectional view 145

A1-107 Perspective view of yellow foam specimens, subjected to brief flame impingement from top while in horizontal position, and from bottom while in vertical and horizontal positions, respectively 146

A1-108 Sample 3-1-15, perspective view 147

A1-109 Sample 3-1-15, cross-sectional view 147

A1-110 Sample 3-2-15, perspective view 148

A1-111 Sample 3-2-15, cross-sectional view 148

A1-112 Sample 3-3-15, perspective view 149

A1-113 Sample 3-3-15, cross-sectional view 149

A1-114 Cross-sectional view of blue, red, and yellow foam specimens, subjected to sustained burning by bottom ignition while in horizontal position. 151

LIST OF FIGURES (continued)

Number		Page
A1-78	Sample 6-1-4 (aged foam), cross-sectional view. .	129
A1-79	Perspective view of red foam specimens, subjected to radiant heat exposure for 10, 20, and 30 seconds, respectively.	130
A1-80	Sample 6-1-8, perspective view.	131
A1-81	Sample 6-1-8, cross-sectional view.	131
A1-82	Sample 6-2-7, perspective view.	132
A1-83	Sample 6-2-7, cross-sectional view.	132
A1-84	Sample 6-3-7, perspective view.	133
A1-85	Sample 6-3-7, cross-sectional view.	133
A1-86	Cross-sectional view of blue, red, and yellow foam specimens, subjected to brief flame impingement at the bottom while in horizontal position .	135
A1-87	Perspective view of blue foam specimens, subjected to brief flame impingement from top while in horizontal position, and from bottom while in vertical and horizontal positions, respectively.	135
A1-88	Sample 3-1-1, perspective view.	136
A1-89	Sample 3-1-1, cross-sectional view.	136
A1-90	Sample 3-2-3, perspective view.	137
A1-91	Sample 3-2-3, cross-sectional view.	137
A1-92	Sample 3-3-1, perspective view.	138
A1-93	Sample 3-3-1, cross-sectional view.	138
A1-94	Sample 3-1-4 (wet, new foam), perspective view. .	139
A1-95	Sample 3-1-4 (wet, new foam), cross-sectional view.	139
A1-96	Sample 3-2-5 (wet, new foam), perspective view. .	140

LIST OF FIGURES (continued)

Number		Page
A1-57	Sample 5-2-1, cross-sectional view.	117
A1-58	Sample 5-3-2, perspective view.	118
A1-59	Sample 5-3-2, cross-sectional view.	118
A1-60	Sample 5-3-7 (aged foam), perspective view. . . .	119
A1-61	Sample 5-3-7 (aged foam), cross-sectional view. .	119
A1-62	Perspective view of red foam specimens, subjected to hot air impingement for ∿2, ∿3.5, and ∿5 seconds, respectively	120
A1-63	Sample 5-1-12, perspective view	121
A1-64	Sample 5-1-12, cross-sectional view	121
A1-65	Sample 5-2-10, perspective view	122
A1-66	Sample 5-2-11, cross-sectional view	122
A1-67	Sample 5-3-10, perspective view	123
A1-68	Sample 5-3-10, cross-sectional view	123
A1-69	Cross-sectional view of blue and red foam specimens, subjected to radiant heat exposure for 10, 20, and 30 seconds, respectively.	125
A1-70	Perspective view of blue foam specimens, subjected to radiant heat exposure for 10, 20, and 30 seconds, respectively.	125
A1-71	Sample 6-1-3, perspective view.	126
A1-72	Sample 6-1-3, cross-sectional view.	126
A1-73	Sample 6-2-3, perspective view.	127
A1-74	Sample 6-2-3, cross-sectional view.	127
A1-75	Sample 6-3-2, perspective view.	128
A1-76	Sample 6-3-2, cross-sectional view.	128
A1-77	Sample 6-1-4 (aged foam), perspective view. . . .	129

LIST OF FIGURES (continued)

Number Page

A1-38 Sample 7-1-5, cross-sectional view. 105

A1-39 Sample 7-3-5, cross-sectional view. 105

A1-40 Sample 7-5-5, cross-sectional view. 106

A1-41 Specimens of yellow foam, subjected to 40-200 hours of simulated sunlight exposure. 107

A1-42 Cross-sectional view of yellow foam specimens, subjected to 40, 120, and 200 hours of simulated sunlight exposure 107

A1-43 Sample 7-1-7, cross-sectional view. 108

A1-44 Sample 7-3-7, cross-sectional view. 109

A1-45 Sample 7-5-7, cross-sectional view. 109

A1-46 Specimens of blue foam, cut along the upper surface at 10, 5, and 2.5 ft/min, respectively . . . 111

A1-47 Sample 2-3-1, perspective view. 111

A1-48 Specimens of red foam, cut along the upper surface at 10, 5, and 2.5 ft/min, respectively . . . 112

A1-49 Sample 2-3-2, perspective view. 112

A1-50 Specimens of yellow foam, cut along the upper surface at 10, 5, 2.5 ft/min, respectively 113

A1-51 Sample 2-3-3, perspective view. 113

A1-52 Cross-sectional view of blue and red foam specimens, subjected to hot air impingement for five seconds 115

A1-53 Perspective view of blue foam specimens, subjected to hot air impingement for $\sim$2, $\sim$3.5, and $\sim$5 seconds, respectively. 115

A1-54 Sample 5-1-1, perspective view. 116

A1-55 Sample 5-1-1, cross-sectional view. 116

A1-56 Sample 5-2-1, perspective view. 117

LIST OF FIGURES (continued)

Number		Page
A1-21	Specimens of blue foam, subjected to accelerated aging in JP-5 at 200°F (93°C) for one to five weeks	93
A1-22	Sample 9-5-1, perspective view.	94
A1-23	Sample 9-5-1, cross-sectional view.	94
A1-24	Specimens of red foam, subjected to accelerated aging in JP-5 at 200°F (93°C) for one to five weeks	95
A1-25	Sample 9-5-5, perspective view.	96
A1-26	Sample 9-5-5, cross-sectional view.	96
A1-27	Specimen of yellow foam, subjected to accelerated aging in JP-5 at 200°F (93°C) for one to five weeks	97
A1-28	Sample 9-5-7, perspective view.	98
A1-29	Sample 9-5-7, cross-sectional view.	98
A1-30	Cross-sectional view of blue, red, and yellow foam specimens, subjected to 200 hours of simulated sunlight exposure	100
A1-31	Specimens of blue foam, subjected to 40-200 hours of simulated sunlight exposure.	101
A1-32	Cross-sectional view of blue foam specimens, subjected to 40, 120, and 200 hours of simulated sunlight exposure	101
A1-33	Sample 7-1-1, cross-sectional view.	102
A1-34	Sample 7-3-1, cross-sectional view.	102
A1-35	Sample 7-5-1, cross-sectional view.	103
A1-36	Specimens of red foam, subjected to 40-200 hours of simulated sunlight exposure.	104
A1-37	Cross-sectional view of red foam specimens, subjected to 40, 120, and 200 hours of simulated sunlight exposure	104

1. INTRODUCTION

Incidents have occurred with A-10 and other aircraft in which it appeared during subsequent investigations that heat or flame exposure of the polyurethane foam had taken place. The purpose for the use of that foam is to stop or reduce flame propagation in aircraft fuel tanks.

Specimens of the blue foam (Scott Safety Foam SF 0025, MIL-B-83054B, Type V), removed from A-10 aircraft at Glen Martin AFB, Baltimore, MD, were received for examination. Answers were sought to the following questions:

(1) What had been the heat or fire exposure history of the specimens?

(2) Had the fuel tank foam been immersed in fuel after the heat or fire exposure?

Wipings were also received from the vent mast area and from the right side vent tank dome of one aircraft. The compositions of these wipings were of interest. More specifically, these wipings were to be examined and analyzed for polyurethane degradation products and metal-containing substances.

To establish heat and fire exposure history of the recovered specimens, samples of unused blue foam were exposed to a hot air stream, radiant heat, and flame. The physical appearances of the incident specimens were examined with reference to controlled exposure samples. These examinations revealed that the physical appearance of foam specimens after exposure was very informative regarding past history. More extensive controlled exposure tests were subsequently performed. They encompassed all conceivable types of environmental and unwanted exposure. They included accelerated aging in air and in jet fuel (JP-5), and exposure to ultraviolet radiation. The red and the yellow polyester-based polyurethane foams (MIL-B-83054B, Types II and III) were also incorporated into the testing program.

The physical appearance of control test specimens was thoroughly documented photographically. That record, incorporated into the present report, will be of assistance to accident investigations in future aircraft incident cases.

Thermogravimetric analyses of the blue foam were performed in air and inert atmospheres, to establish its thermal and thermo-oxidative degradation characteristics under controlled conditions.

Preparative, controlled degradation experiments were subsequently performed with the blue foam in air and in inert atmosphere. The purpose of these experiments was to obtain degradation products formed under the selected conditions, characterize these, and compare them with specimens obtained from incident sites.

Infrared reflectance spectroscopic measurements were performed with the objective of determining if these could be utilized for distinguishing between heat and fire exposure.

Surface analyses were performed with a foam specimen from an A-10 fuel vent tank, that was coated with a white, powdered solid.

The results of the outlined simulation experiments, examinations, and analyses, and the conclusions are presented in this report.

Comprehensive photographic documentation of samples from accelerated aging and incident simulation experiments is presented in Appendix 1 of this report.

Appended to this volume of the report are two memoranda (Appendices 2 and 3) in which changes of appearance and physical properties of polyurethane foam are described. These foams had been in service in A-10 and F-4 aircraft fuel systems. Changes that had occurred during the service life were noticed during aircraft fuel system maintenance operations. The reasons for the observed changes in appearance were partially elucidated; they are summarized in the memoranda.

2. EXPERIMENTAL

2.1 FOAM SAMPLES

Samples of blue, red, and yellow, reticulated polyurethane foam were received from the Fire Protection Branch, AFWAL/POSH, in the form of 12 in. x 12 in. x 1-2/3 to 2 in. slabs. The densities of the received materials ranged from 1.25 to 1.28 lb/cu ft. The foam samples used in the present work had been produced by the SCOTFOAM Corporation.

Specimens of varying sizes were cut with a band saw from the slabs for different incident-simulative tests. The sizes of specimens used are indicated in tables in which also the exposure test plans and sample codes are presented.

In previous programs, hydrolytic stability tests had been performed with the coarse pore blue and yellow, and the fine pore red foams at the University of Dayton Research Institute. The results of these tests were used as qualification test data (Ref. 1 and 2). Graphs, depicting the results of hydrolytic stability tests, are included for reference as Appendix 4 in this report.

Laboratory-scale, controlled degradation experiments were performed with samples of the blue, reticulated foam, designated Scott Safety Foam SF 0025, Type V, fine pore. For use in aircraft fuel systems, it is required to meet Military Specification MIL-B-83054B. The chemical structure of this foam was made available (Ref. 3) by SCOTFOAM Corporation for the purpose of the present work. In chemical terms, the blue foam is polyether-based, whereas the yellow and red foams are polyester-based.

In addition to previously unused foam, sixteen aircraft incident-related specimens were received from Messrs. R. Clodfelter, G. Gandee, and T. Hogan, AFWAL/POSH. These specimens originated from several A-10 aircrafts at Glen Martin AFB, Baltimore, MD. They are listed below.

Number	Specimen
1	Fuel vent tank filler, left half, A/C 78-717 (see Figure 28, p. 58)
2	Fuel vent tank filler, right half, A/C 78-717 (see Figure 29, p. 58)
3	Fuel vent tank filler, left half, A/C 78-704 (see Figure 30, p. 59)
4	Wing tank filler, A/C 78-717 (see Figure 35, p. 64)
5-8	Foam pieces, from wing tank, A/C 78-717 (see Figure 38, p. 67)
9	Aft tank vent foam sample, A/C 78-717
10	Aft main filler cap foam sample, A/C 78-717
11	Wipings from vent mast on gauze, A/C 78-704
12	Wipings from vent mast on gauze, A/C 79-088
13	Wipings from vent mast on gauze, A/C 78-704
14	Wipings from vent mast on gauze, A/C 78-717
15	Wipings from vent mast on gauze, A/C 78-718
16	Wipings from right side vent, tank dome, A/C 78-717

2.2 EXPOSURE OF POLYURETHANE FOAMS TO AGING, SIMULATED SUNLIGHT, HEAT, AND FLAMES

2.2.1 Aging in Air

Accelerated aging experiments with foam samples in air, immersed in JP-5, and exposed to simulated sunlight radiation were performed in facilities at the University of Dayton Research Institute. A detailed report, describing the test apparatus and exposure conditions, is included in Appendix 5.

Aging tests with foam samples in air were performed at 200°F (93°C) in an atmosphere of 95% relative humidity. Test durations with groups of specimens ranged from one to five weeks, in one week intervals. Aging of the red and yellow foam specimens was discontinued at the end of the third week because of severe degradation.

2.2.2 Aging in Jet Fuel

For these tests, foam specimens were immersed in JP-5, contained in widemouth, sealed, one quart glass jars. The samples were heated in an air oven at 200°F (93°C) for periods ranging from one to five weeks, in one week intervals.

2.2.3 Simulated Sunlight Exposure

Simulated sunlight exposure tests were performed in Sunlighter IV test chamber (Ref. 4). Samples were supported by a rotating shelf. Exposure times with groups of samples ranged from 40 to 200 hours, in 40-hour increments.

2.2.4 Hot Wire Cutting

Hot wire cutting of foam was performed by the SCOTFOAM Corporation. Electrically resistance-heated wire was used for cutting. Foam slabs were passed past the wire at the following speeds: 10 ft/min, 5 ft/min, and 2.5 ft/min. The first of these speeds is the normally used cutting speed. Thermal degradation of foam occurs when hot wire cutting is performed. As the speed of cutting is decreased, the amount of damage inflicted on the foam surface is increased.

2.2.5 Hot Air Impingement

A stream of hot air, produced by a heat gun, was directed onto the top surface of foam specimens. Air temperature ranged up to 870°F (466°C). The air flow rate was approximately 10 cu ft/min. Exposure times ranged from 2 to 5 sec. These tests were performed in a well-ventilated hood.

2.2.6 Radiant Heat Exposure

Samples were held horizontally above the graphite bar of the 3000°F (1649°C) ignition test apparatus (Ref. 5) at the distance of 2 in. (5.1 cm). The resistance-heated graphite bar served as the heat source for irradiative and convective heating of foam specimens. The exposure times were 10, 15, and 20 seconds, respectively, for the three groups of test specimens.

2.2.7 Brief Flame Impingement

A glassblowing torch, operated with propane and oxygen input, was used as the flame source. The flame length was approximately ten inches (25.4 cm); the maximum flame temperature was 1560°F (849°C).

In brief flame impingement tests, the flame was traversed across the surface of foam specimens. The exposure times ranged up to two seconds. In these tests, the torch was traversed over the surface at a sufficiently rapid rate to prevent ignition of foam specimens.

2.2.8 Sustained Burning

Foam samples were ignited by means of the torch described in the preceding section. Samples in the three groups were allowed to burn for progressively longer periods of time, extending up to about five seconds.

2.2.9 Flash Fire

These tests were designed to simulate damage caused to foam during aircraft fuel tank fire. Flash fire exposure tests with foam were performed with the flame tube (Ref. 6) at the Aero Propulsion Laboratory (see Figure 1). The foam was packed into the flame tube with two void configurations of 10 percent by volume each,

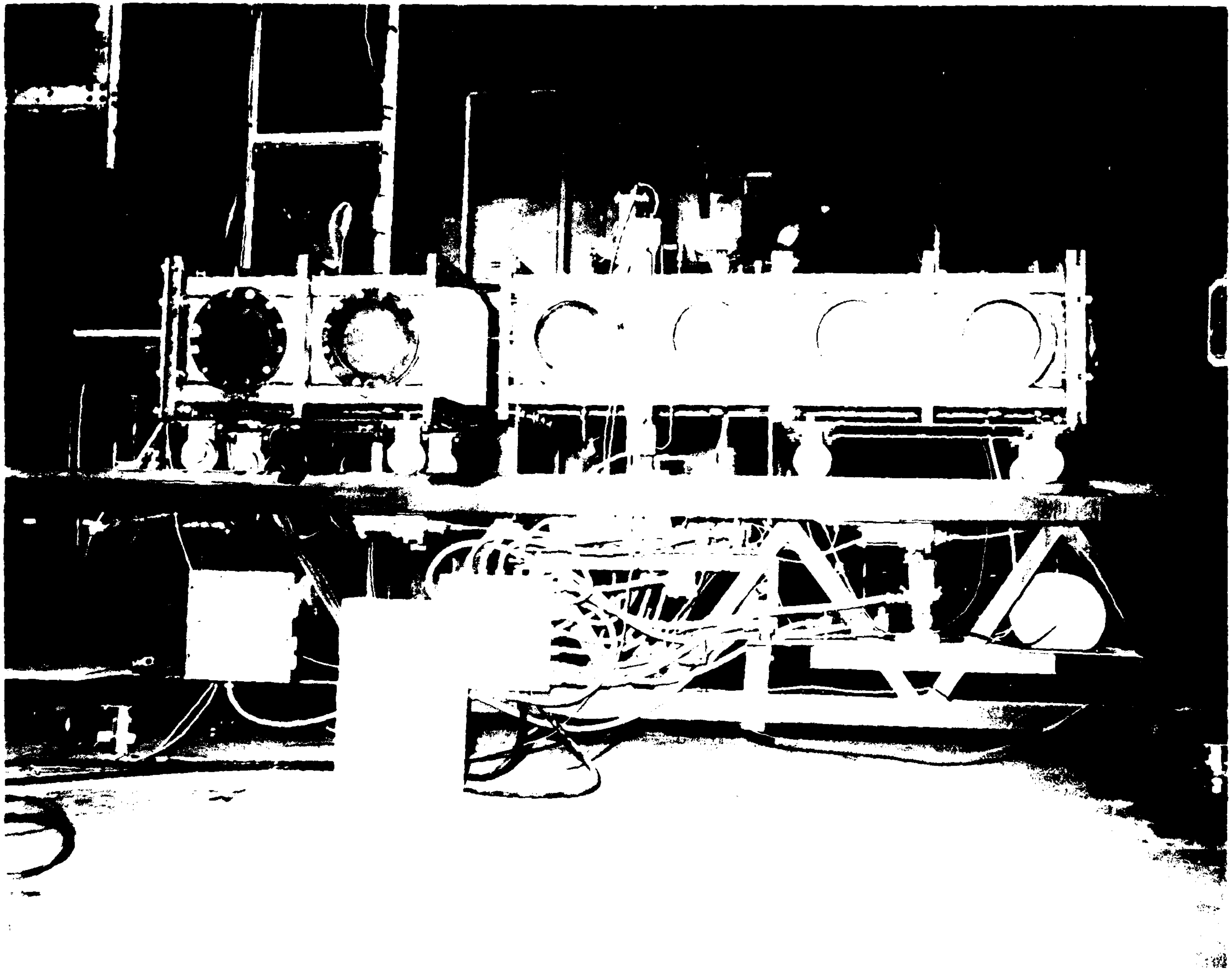


Figure 1. Flash fire test system.

as shown in Figure 2. Figure 3 depicts the corresponding configuration for the vented tests. The initial conditions were selected to simulate actual operating conditions, and conditions that could be encountered in a worst case situation. Experiments were conducted with combinations of the following parameters:

1. Foam type (blue, red, and yellow)
2. Propane concentration in air (3.5%, 5%, and 6.5% by volume)
3. Non-venting and venting of the chamber
4. Dry and JP-5 fuel-wetted foam
5. Initial pressures of 0 psig and 3 psig (17.7 psia)

The flame tube is of reinforced steel construction, with a square cross section [12 in. x 12 in x 90 in. (30.5 cm x 30.5 cm x 228.8 cm)]. Void spaces were enclosed along all walls by 2 inches (5.1 cm) thick slabs of reticulated foam, except for the wall where the igniter was located. The test assembly can be evacuated and subsequently filled with a gas mixture of desired, ignitable composition. Propane-air mixtures were used for these experiments. The gaseous mixtures were ignited by an electrical spark source.

The stoichiometric mixture of propane in air contains 4.02 volume-% of fuel. It was learned in experiments that the highest overpressure in the flame tube was developed at 5 volume-% propane concentration. Therefore, the latter fuel concentration was used in many experiments. To evaluate the effect of lean and rich fuel-air mixtures of foam damage, 3.5 and 6.5 volume-% propane in air mixtures were also used. Combinations of the above three fuel-air mixtures, with controlled variations of other parameters, were used.

The effect of foam wetting was investigated by performing tests with dry foam, and also with foam wetted by JP-5 fuel. After the test series with dry foam had been completed, JP-5 fuel-wetted

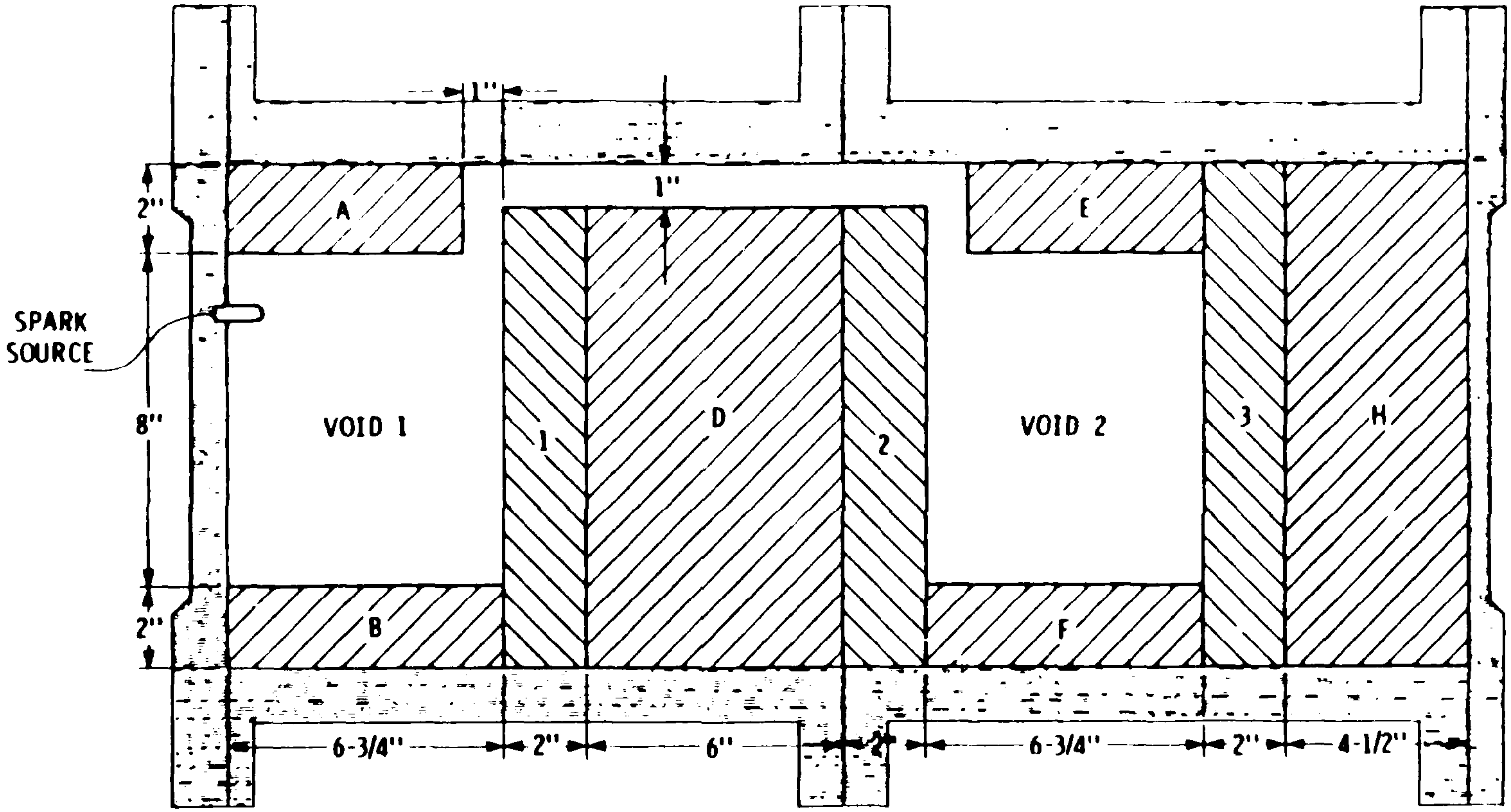


Figure 2. Cross-sectional view of flame tube in unvented configuration. (Dashed areas represent polyurethane foam. The opening between Voids 1 and 2 was 1 in. wide.)

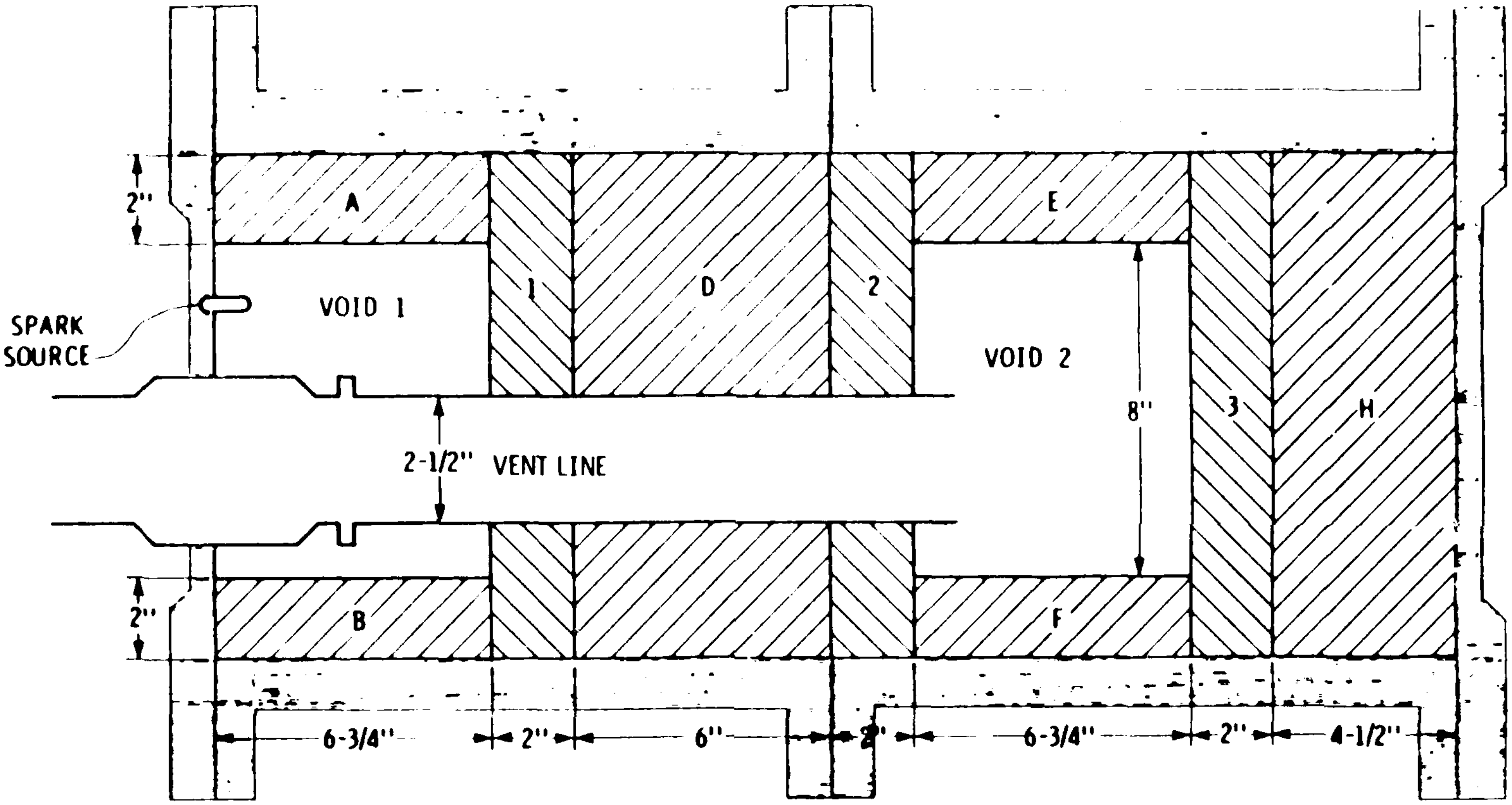


Figure 3. Cross-sectional view of flame tube in vented configuration. (Dashed areas represent polyurethane foam.)

foam was substituted. It was found that in experiments performed with the unvented system, the fuel raised the hydrocarbon vapor content to such an extent that ignition did not occur at the 6.5 volume-% propane concentration. Therefore, experiments with fuel-wetted foam in the unvented system were performed with 2.0, 3.5, and 5.0 volume-% propane mixtures in air.

The entire series of tests was first performed with closed flame tube assembly (see Figure 1) in an unvented manner. The tests were subsequently repeated in a vented manner with a 2-1/2 in. diameter A-10 vent line installed (see Figure 3) into the system. The vent line increased the void volume by two percent.

Internal system pressures were monitored continuously and maximum pressures were noted. Overpressures were calculated as the differences between the maximum and initial pressures.

To conduct the tests in the vented configuration, the vent line was capped with a flat aluminum plate and the flame tube was evacuated. A premixed propane and air mixture was then introduced into the tube. The plate fell off the vent line when the mixture inside the tube approached atmospheric pressure. The mixture was then immediately ignited to prevent circulation of the propane-air mixture with air outside the flame tube. With fuel-wetted foam in the open vent configuration, it was necessary to extinguish the flame by capping the vent. This was done in each test approximately 30 seconds after ignition. Sustained burning does not occur in aircraft, due to increased vent line length.

2.2.10 Exposure Test Plan and Sample Code

A test plan was developed for exposure of foam samples under the different, incident-simulating exposure conditions. This plan is summarized in Tables 1 to 8. A three-number code system, X-Y-Z, was designed for identification of samples.

The first number, X, designates the test type as follows:

(1) flash fire
(2) hot wire cutting
(3) brief flame impingement
(4) sustained burning
(5) hot air impingement
(6) radiant heat exposure
(7) accelerated aging in simulated sunlight
(8) accelerated aging in air
(9) accelerated aging in jet fuel

The second number, Y, in conjunction with the first, designates a group of tests performed under identical, specified conditions (e.g., exposure duration, temperature, cutting rate, site of ignition, etc.). It may involve several foams. However, test conditions remained identical for all samples carrying the same first two numbers.

The third number was used for sequential identification of samples. In some instances (e.g., experiments with aged foam samples), insufficient sample material was available for performing all initially planned tests. In those instances, all sequential numbers do not appear in Tables 1 to 8.

TABLE 1. HOT WIRE CUTTING. TEST PLAN AND SAMPLE CODE

Foam	Sample size, in.[a]	Cutting speed, ft/min		
		10	5	2.5
Blue, dry, new	12x12x2	2-1-1	2-2-1	2-3-1
Red, dry, new	12x12x2	2-1-2	2-2-2	2-3-2
Yellow, dry, new	12x12x2	2-1-3	2-2-3	2-3-3

---

[a] Size after hot wire cutting.

TABLE 2. BRIEF FLAME IMPINGEMENT. EXPOSURE TEST PLAN AND SAMPLE CODE

Foam	Sample size, in.	Horizontal, top ignition	Vertical, bottom ignition	Horizontal, bottom ignition
Blue, dry, new	6x6x2	3-1-1	3-2-1	3-3-1
	6x6x2	3-1-2	3-2-2	3-3-2
	6x6x2	3-1-3	3-2-3	3-3-3
Blue, wet, new	6x6x2	3-1-4	3-2-4	
	6x6x2	3-1-5	3-2-5	
Blue, dry, aged	3x3x2	3-1-9		
Red, dry, new	6x6x2	3-1-10	3-2-10	3-3-10
	6x6x2	3-1-11	3-2-11	3-3-11
	6x6x2	3-1-12	3-2-12	3-3-12
Yellow, dry, new	6x6x2	3-1-13	3-2-13	3-3-13
	6x6x2	3-1-14	3-2-14	3-3-14
	6x6x2	3-1-15	3-2-15	3-3-15

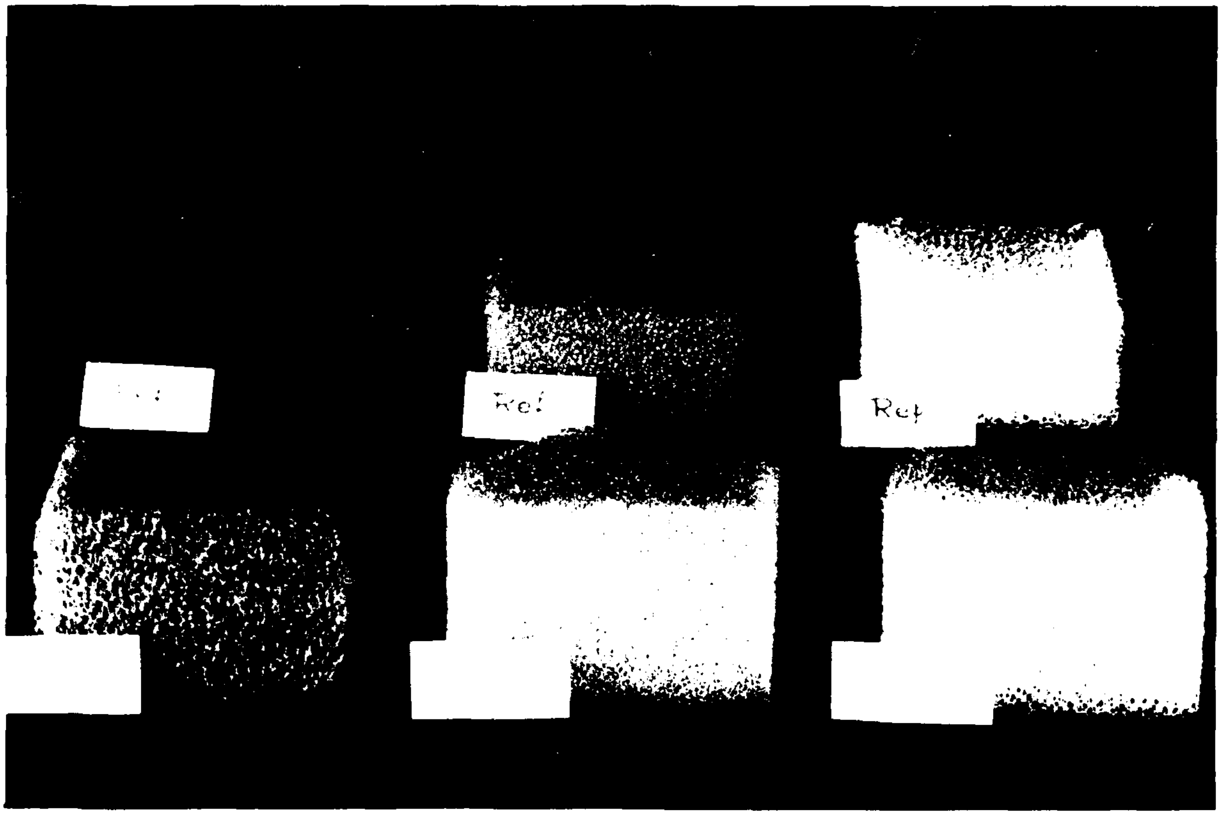


Figure 8. Cross-sectional views of foam specimens subjected to accelerated aging in jet fuel (JP-5).

Figure 6. Red foam specimen, after three weeks of accelerated aging in air.

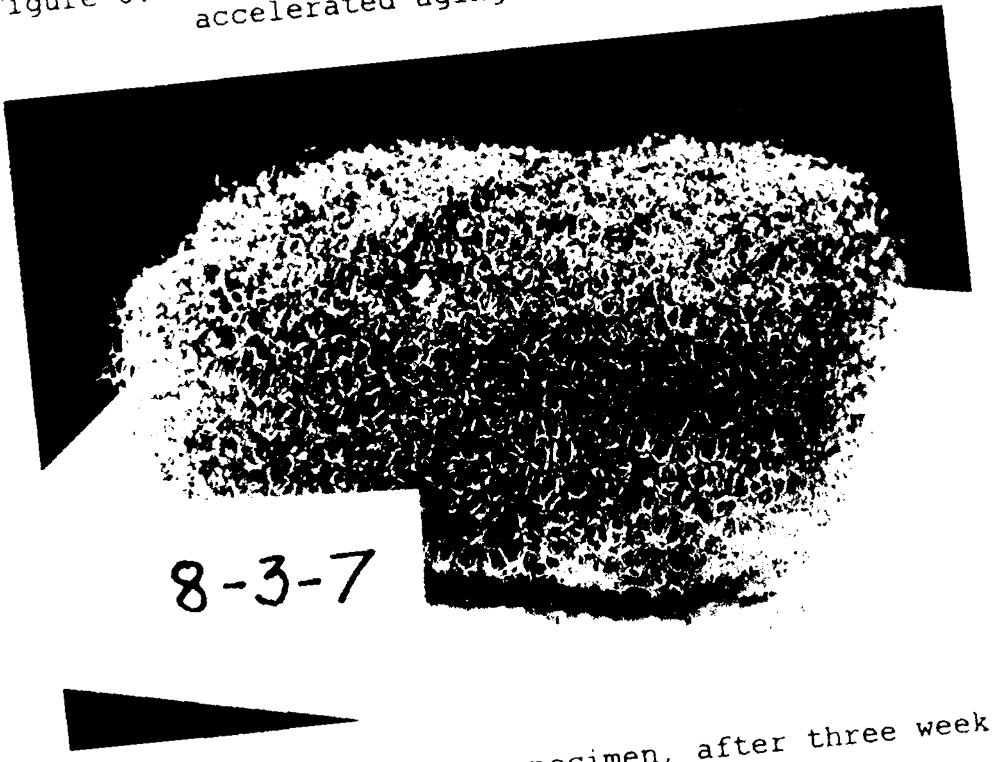


Figure 7. Yellow foam specimen, after three weeks of accelerated aging in air.

The blue foam acquires grayish appearance and discolors upon aging. The red foam becomes brownish-red, and the yellow foam becomes brown as the exposure progresses.

The appearances of the red and yellow specimens after three weeks of exposure in the 200°F (93°C) test chamber are depicted in Figures 6 and 7, respectively.

3.1.2 Aging in Jet Fuel

When the foam specimens were subjected to aging in liquid JP-5 environment, their appearance changed similarly to samples aged in air. Darkening occurred uniformly throughout the samples. However, the discoloration was less extensive (see Figure 8) than in tests performed in humid air. This was especially noticeable with red- and yellow-colored samples.

These tests were performed with samples immersed in JP-5, contained in sealed jars. The rounding of sample edges was caused by the confining containers. The discoloration of samples aged in fuel was partly caused by black pigment leached from sample labels that had been made with a DYMO tapewriter. Disintegration of specimens did not occur in tests performed in JP-5.

The results of tests described here parallel those made earlier at the University of Dayton Research Institute (Refs. 1, 2 and Appendix 4). Very limited foam degradation occurs in fuel aging tests due to the absence of moisture in the fuel. A plot of tensile strength as a function of time is shown in Appendix 4.

3.1.3 Simulated Sunlight Exposure

Ultraviolet light emitted by the light source used in present work is presumed to have caused most of the discoloration of all three reticulated foams. In contrast to heat-induced damage caused by

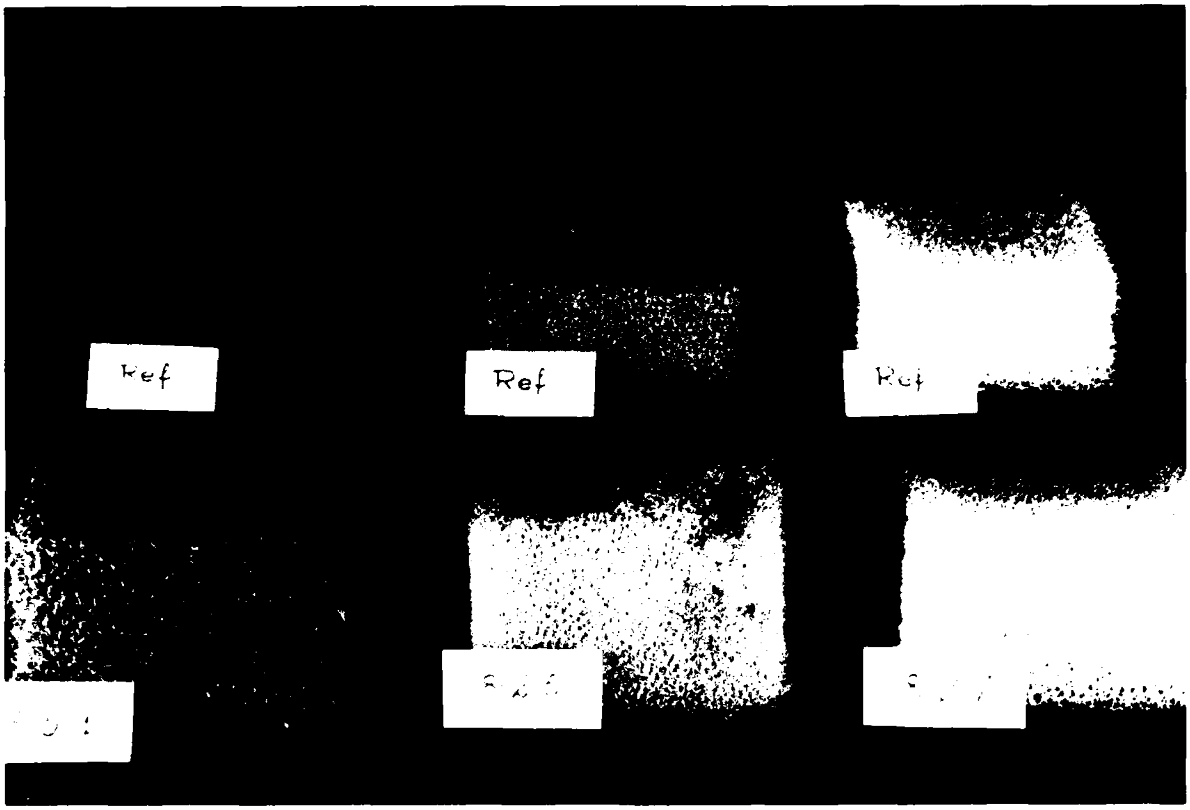


Figure 5. Cross-sectional views of foam specimens subjected to accelerated aging in air (8-5-1, five weeks; 8-2-5, two weeks; 8-2-7, two weeks).

3. RESULTS AND DISCUSSION

3.1 EXPOSURE OF POLYURETHANE FOAMS TO AGING, SIMULATED SUNLIGHT, HEAT, AND FLAMES

3.1.1 Aging in Air

Polyurethane foams are known to be subject to thermal, hydrolytic, and irradiative degradation (Refs. 1, 2, 7). Samples that would display the physical effects of chemical changes and breakdown were needed for photographic recording. For that purpose, accelerated heat and irradiation exposure tests were performed under conditions more severe than those to which the foams would become subjected in normal service.

Aging tests with foam samples in air and in jet fuel (JP-5) were performed at 200°F (93°C). The polyester-based (red and yellow) foams degraded rapidly in air of 95% relative humidity. During the third week of the five-week test period, these two foams disintegrated physically and the samples were withdrawn from tests. These observations are in accord with previous aging test results in which tensile strengths of samples were determined as functions of exposure time (Refs. 1, 2; see also Appendix 4 for graphs from these references). The degradation of polyester-based foams has been attributed to hydrolysis of the polymeric chains (Ref. 8). The polyol-based (blue) polyurethane foam samples retained their physical integrity during the 5-week test period.

A visually readily detectable feature of foam aging is uniform discoloration throughout the specimen. In Figure 5 are shown cross-sectional views of blue, red and yellow foam specimens that had been subjected to accelerated aging in air for five, two, and two weeks, respectively. Unaged reference samples are shown for comparison in the same figure.

The surface analyses were performed at the University of Dayton Research Institute. A copy of the report covering this work is included as Appendix 7. Results are presented in Section 3.4.5.

damaged and burned foam were found to differ from that of the undegraded foam mainly by very significant reduction of urethane functionality (NH bend ~1532 cm^{-1}), and increase of C-O-C functionality (C-O-C stretch ~1100 cm^{-1}) at the degraded surface. However, no significant differences were detected between the spectra of foams damaged by hot air and by burning.

2.4.3 Emission Spectroscopic Analysis

In search of metallic contaminants, that could be of assistance in tracing incident scenarios, emission spectrographic analyses were performed. The materials subjected to these analyses included foam from vent tank, with a white deposit on its surface, and wipings from vent masts and vent tank. The emission spectrographic analyses were performed by Bowser-Morner Testing Laboratories, Inc. The report covering this work is included as Appendix 6. Results are summarized in Section 3.4.4.

2.4.4 Surface Analysis

After detection of metallic contaminants in the foam sample from the incident site, using emission spectroscopic analysis, efforts were pursued to establish the distribution of metals in the specimen. Surface analysis techniques were used for this purpose.

Scanning electron microscopy was utilized to determine the physical appearance of particles that constituted the white coating on the foam surface. Energy-dispersive x-ray analysis (EDXA) revealed the presence of potassium as the major metallic constituent in the surface deposit. Carbonate ion was identified as the major anionic species in the surface deposit by x-ray photoelectron spectroscopy.

Figure 4. Sample of the tan-colored solid formed upon pyrolysis of blue foam.

2.4.2 Infrared Reflectance Spectrospcopic Analysis

The utility of infrared reflectance spectra of foam specimens for determining if an affected surface had been exposed to intense heat, or had been involved in fire, was explored. A Digilab Model 15B Fourier Transform Infrared Spectrometer, in conjunction with an attenuated total reflectance (ATR) measurement cell, was utilized for these measurements.

The ATR spectrum of the baseline, undegraded polyurethane foam sample was compared with the spectra of samples whose surfaces had been degraded by hot air and by burning. The spectra of hot air

TABLE 9. PYROLYSIS AND THERMO-OXIDATIVE DEGRADATION EXPERIMENTS WITH BLUE POLYURETHANE FOAM UNDER CONTROLLED CONDITIONS

	Experiment		
	1	2	3
Weight of foam sample, g	3.7	5.2	4.2
Atmosphere[a]	Nitrogen	Air	Air
Temperature at which initial discoloration observed, °C	260		200
Total heating time, min[b]	95	9[c]	105
Maximum temperature, °C	450	430	450
Weight of isolated solids, g	1.92	1.48	0.76
Appearance of isolated solids	Tan	Tan to black[d]	Black, charred
Weight of isolated liquids	0.36	1.60	1.94
Appearance of isolated liquids	Orange-brown	Red-brown	Dark brown, viscous, contains some water

---

[a] The rate of nitrogen or air flow rate through the reaction tube was 100 cm^3/min.

[b] All experiments were started with samples at room temperature.

[c] The reaction tube was introduced into tube furnace that had been preheated to 460°C.

[d] The solid that remained in the Pyrex tube (0.72 g) was black-colored. The volatilized and subsequently condensed solid was tan-colored. It contained some brown particles.

TABLE 10. ELEMENTAL ANALYSIS RESULTS

	Reference foam sample[a]	Foam degradation products		
		Exp. 1 Tan solid[a]	Exp. 2 Tan solid	Exp. 3 Black char
Elemental composition, wt-%[b]				
C	64.15	63.46	64.06	62.28
H	8.24	6.38	6.48	2.78
N	7.97	16.89	15.86	18.71
Elemental ratio				
C	18.8	8.8	9.4	7.8
H	28.7	10.5	11.4	4.1
N	2.0	2.0	2.0	2.0

---

[a] Shown in Figure 4.

[b] Elemental analysis data are based on duplicate determinations.

The main purpose of these experiments was to obtain degradation products of the polyurethane foam for characterization, and for comparison with wipings from aircraft that had been involved in the incidents. It was also of interest to acquire some understanding of the chemical degradation mechanism of this foam.

The experimental conditions and results are summarized in Table 9. The degradation products were recovered from the reaction tubes. Liquid products were separated from solids by extraction with methylene chloride. The solvent was removed by evaporation. The recovered, separated degradation products were analyzed spectrometrically. Also, elemental compositions of the solid materials were determined. The latter analyses were performed by Galbraith Laboratories, Inc., Knoxville, TN. These results are summarized in Table 10.

2.3.3 Infrared Spectroscopic Analysis Of Degradation Products

The infrared absorption spectra of the reference sample of unused, blue polyurethane foam, and of the degradation products, were recorded with Perkin-Elmer Model 137 Spectrometer. To obtain the spectrum of the blue foam, the sample was ground at liquid nitrogen temperature. The powdered foam was mixed with dry potassium bromide in order to pelletize the mixture.

2.4 EXAMINATION AND ANALYSIS OF POLYURETHANE SAMPLES RECOVERED FROM AIRCRAFT INCIDENT SITES

2.4.1 Visual Examination

The samples were initially examined visually with an unaided eye and also with the assistance of a magnifier. Subsequently, specific surface analysis techniques were utilized for characterization and identification purposes.

For flash fire experiments, the second number identifies the sample location in the flame tube (see Figures 2 and 3). The third code number (Z) identifies the sequential test number.

The numbers designating tests, X, were issued in sequence. They corresponded to the planned schedule in which samples from different exposure tests were expected to become available. The discussion of test methods and results in this and the next section of the report follow a different sequence. Accelerated foam aging in air, in jet fuel, and upon exposure to sunlight are discussed first. Hot wire cutting of foam is discussed next. Subsequently, simulated unwanted exposures to environments of progressively increasing severity (i.e., hot air impingement, radiant heat exposure, brief flame impingement, and sustained burning) are discussed. The results of flash fire experiments are presented last. Evidence of exposures discussed in all preceding sections could be encountered with foams that have been in flash fire environments.

2.3 LABORATORY-SCALE, CONTROLLED DEGRADATION EXPERIMENTS WITH BLUE POLYURETHANE FOAM

2.3.1 Thermogravimetric Analysis

Thermogravimetric analyses (TGA) [weight loss (%)] were performed in air and helium atmospheres at the heating rate of 10°C/min. The acquired data were also utilized to simultaneously produce the differential thermogravimetric (DTG) curves [rate of weight loss (mg/min)].

2.3.2 Pyrolysis and Thermo-oxidative Degradation of Blue Foam Under Controlled Conditions

Three preparative experiments were performed in which known masses of polyurethane foam were heated in Pyrex tubes, either in a stream of air or inert (nitrogen) gas. The products were collected on air-cooled sections of the tube and in a trap immersed in dry ice.

TABLE 7. ACCELERATED AGING IN AIR. EXPOSURE TEST PLAN AND SAMPLE CODE

Foam	Sample size, in.	Exposure time, weeks				
		1	2	3	4	5
Blue, dry, new	3x3x2	8-1-1	8-2-1	8-3-1	8-4-1	8-5-1
	3x3x2	8-1-2	8-2-2	8-3-2	8-4-2	8-5-2
	3x3x2	8-1-3	8-2-3	8-3-3	8-4-3	8-5-3
	3x3x2	8-1-4	8-2-4	8-3-4	8-4-4	8-5-4
Red, dry, new	3x3x2	8-1-5	8-2-5	8-3-5	8-4-5	8-5-5
	3x3x2	8-1-6	8-2-6	8-3-6	8-4-6	8-5-6
Yellow, dry, new	3x3x2	8-1-7	8-2-7	8-3-7	8-4-7	8-5-7
	3x3x2	8-1-8	8-2-8	8-3-8	8-4-8	8-5-8

TABLE 8. ACCELERATED AGING IN JET FUEL. EXPOSURE TEST PLAN AND SAMPLE CODE

Foam	Sample size, in.	Exposure time, weeks				
		1	2	3	4	5
Blue, dry, new	3x3x2	9-1-1	9-2-1	9-3-1	9-4-1	9-5-1
	3x3x2	9-1-2	9-2-2	9-3-2	9-4-2	9-5-2
	3x3x2	9-1-3	9-2-3	9-3-3	9-4-3	9-5-3
	3x3x2	9-1-4	9-2-4	9-3-4	9-4-4	9-5-4
Red, dry, new	3x3x2	9-1-5	9-2-5	9-3-5	9-4-5	9-5-5
	3x3x2	9-1-6	9-2-6	9-3-6	9-4-6	9-5-6
Yellow, dry, new	3x3x2	9-1-7	9-2-7	9-3-7	9-4-7	9-5-7
	3x3x2	9-1-8	9-2-8	9-3-8	9-4-8	9-5-8

TABLE 5. RADIANT HEAT EXPOSURE. TEST PLAN AND SAMPLE CODE

Foam	Sample size, in.	Exposure time, sec 10	15	20
Blue, dry, new	6x6x2	6-1-1	6-2-1	6-3-1
	6x6x2	6-1-2	6-2-2	6-3-2
	6x6x2	6-1-3	6-2-3	6-3-3
Blue, dry, aged	3x3x2	6-1-4[a]		
Red, dry, new	6x6x2	6-1-7	6-2-7	6-3-7
	6x6x2	6-1-8	6-2-8	6-3-8
	6x6x2	6-1-9	6-2-9	6-3-9

---

[a] This sample had been subjected to accelerated aging in air at 200°F (93°C) for five weeks.

TABLE 6. ACCELERATED AGING IN SIMULATED SUNLIGHT. EXPOSURE TEST PLAN AND SAMPLE CODE

Foam	Sample size, in.	Exposure time, hours 40	80	120	160	200
Blue, dry, new	3x3x2	7-1-1	7-2-1	7-3-1	7-4-1	7-5-1
	3x3x2	7-1-2	7-2-2	7-3-2	7-4-2	7-5-2
	3x3x2	7-1-3	7-2-3	7-3-3	7-4-3	7-5-3
	3x3x2	7-1-4	7-2-4	7-3-4	7-4-4	7-5-4
Red, dry, new	3x3x2	7-1-5	7-2-5	7-3-5	7-4-5	7-5-5
	3x3x2	7-1-6	7-2-6	7-3-6	7-4-6	7-5-6
Yellow, dry, new	3x3x2	7-1-7	7-2-7	7-3-7	7-4-7	7-5-7
	3x3x2	7-1-8	7-2-8	7-3-8	7-4-8	7-5-8

TABLE 3. SUSTAINED BURNING. EXPOSURE TEST PLAN AND SAMPLE CODE

Foam	Sample size, in.	Horizontal, top ignition	Vertical, bottom ignition	Horizontal, bottom ignition
Blue, dry, new	6x6x2	4-1-1	4-2-1	4-3-1
	6x6x2	4-1-2	4-2-2	4-3-2
	6x6x2	4-1-3	4-2-3	4-3-3
Blue, wet, new	6x6x2	4-1-4	4-2-4	
	6x6x2	4-1-5	4-2-5	
Blue, dry, aged	3x3x2	4-1-9		
Red, dry, new	6x6x2	4-1-10	4-2-10	4-3-10
	6x6x2	4-1-11	4-2-11	4-3-11
	6x6x2	4-1-12	4-2-12	4-3-12
Yellow, dry, new	6x6x2	4-1-13	4-2-13	4-3-13
	6x6x2	4-1-14	4-2-14	4-3-14
	6x6x2	4-1-15	4-2-15	4-3-15

TABLE 4. HOT AIR IMPINGEMENT. EXPOSURE TEST PLAN AND SAMPLE CODE

Foam	Sample size, in.	Exposure duration, sec		
		∿2	∿3.5	∿5
Blue, dry, new	4x4x2	5-1-1	5-2-1	5-3-1
	4x4x2	5-1-2	5-2-2	5-3-2
	4x4x2	5-1-3	5-2-3	5-3-3
Blue, dry, aged	3x3x2			5-3-7[a]
Red, dry, new	4x4x2	5-1-10	5-2-10	5-3-10
	4x4x2	5-1-11	5-2-11	5-3-11
	4x4x2	5-1-12	5-2-12	5-3-12

---

[a] This sample had been subjected to accelerated aging in air at 200°F (93°C) for five weeks.

aging in a uniformly heated space, light-induced effects are most severe at the outer surface that faces the source. The extent of damage diminishes with distance from the surface toward the interior because of absorption and scattering of radiation by the foam (see Figure 9). Damage increases with exposure time.

Reduction of foam elasticity occurs simultaneously with darkening. However, at the end of the 200-hour exposure times, all foam specimens retained some surface resilience.

The lamps used for present work simulate spectral distribution of sunlight (Ref. 4). The energy flux at the upper sample surface is approximately two hundred and forty-five times more intense than in normal daylight exposure. Two hundred hours of exposure in the test apparatus correspond approximately to 5.6 years of exposure under environmental conditions (Ref. 4).

3.1.4 Hot Wire Cutting

Cutting of foams into required shapes is sometimes done with a hot wire. No visibly detectable degradation occurs when cutting is performed at established speeds (10 ft/min). A magnified surface view of blue foam is presented in Figure 10. At reduced cutting speeds (e.g., in sharp corner cuts), some localized foam degradation occurs only at the cutting surface. With blue foam, this effect is physically evidenced by change of color to a shade of green or brown, depending upon the extent of degradation.

The appearances of foam surfaces formed by cutting at normal and subnormal speeds are depicted in photographs included in Appendix 1 of this report.

3.1.5 Hot Air Flow

The effects of hot air impingement onto blue and red foam samples are shown in cross-sectional views in Figure 11. Melting,

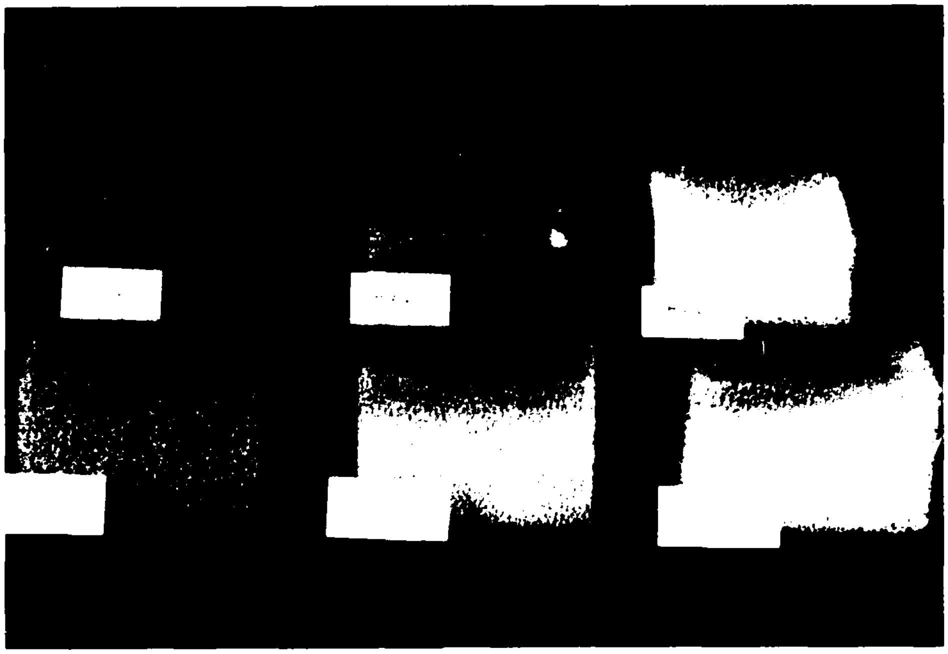


Figure 9. Cross-sectional views of foam specimens subjected to 200 hours of simulated sunlight exposure.

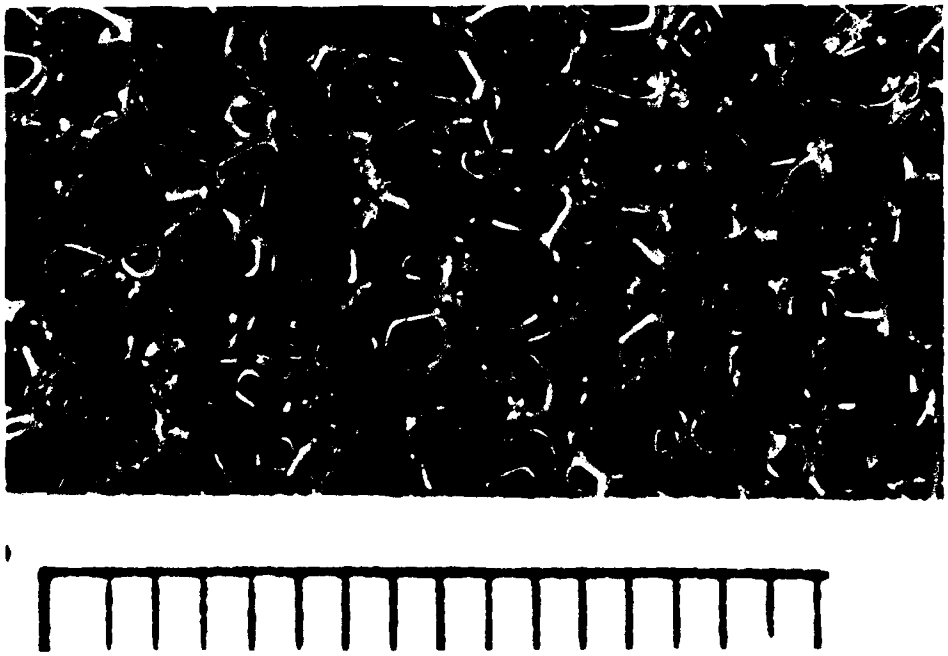


Figure 10. Magnified view of hot-wire-cut blue foam surface. (Each scale division corresponds to 1/16 in.).

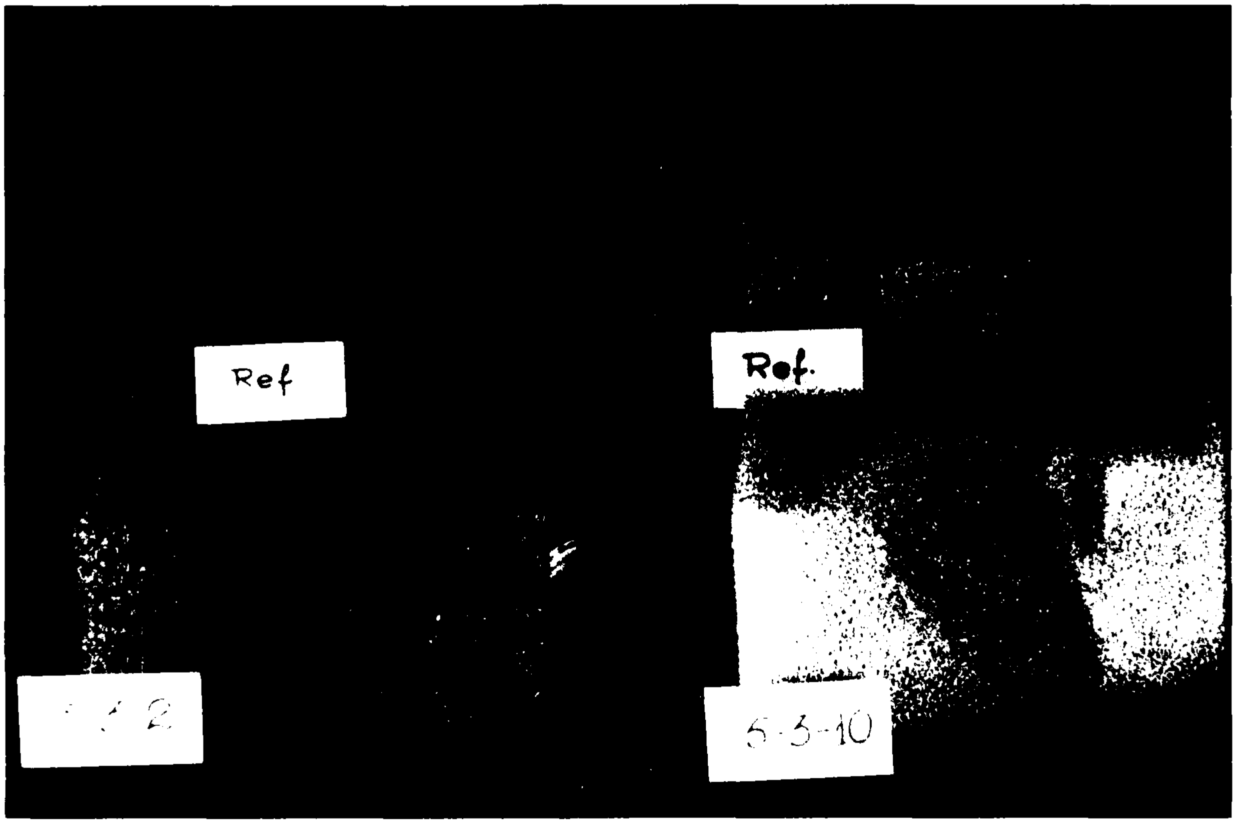


Figure 11. Cross-sectional views of foam specimens subjected to hot air impingement.

degradation, discoloration, and sample surface recession occurred at the site of hot air stream impingement. Since the foams are of open pore type, hot air flowed into the foam structure. This resulted in partial degradation and discoloration of the foam, without significant change of physical structure, below the shrunken and degraded mass at the surface. The depth of the discolored zone increased with progressive exposure to the hot air stream, extending to more than 1 in. (2.5 cm).

Upon closer inspection, molten and subsequentially solidified droplets of polymer mass can be observed on the walls of the recession (see Figure 12).

Samples of blue foam that had been subjected to accelerated aging at 200°F (93°C) for five weeks were also used for hot air impingement tests. These samples responded qualitatively very similarly to unaged foam.

It should be noted that the most characteristic feature of foams exposed to hot air flow is a deep, discolored, but otherwise physically unaltered zone of material.

3.1.6 Radiant Heat Flux

Foam samples subjected to irradiative and convective heating, by a resistance-heated graphite element, exhibited surface-degradation. Additionally, some discoloration was observed below the surface at which the degradation products formed droplets of liquid matter that subsequently solidified (see Figure 13). The depth of the discolored zone, with reference to the degraded zone depth, was much shallower than in experiments in which a hot air stream impinged onto foam specimens.

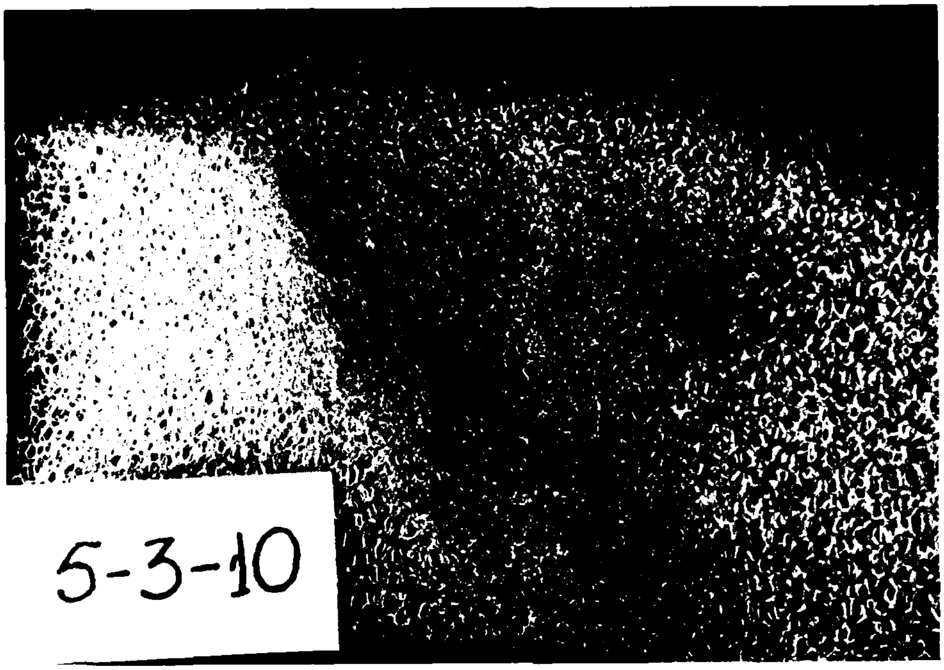


Figure 12. Cross-sectional close-up view of red foam specimen subjected to hot air impingement.

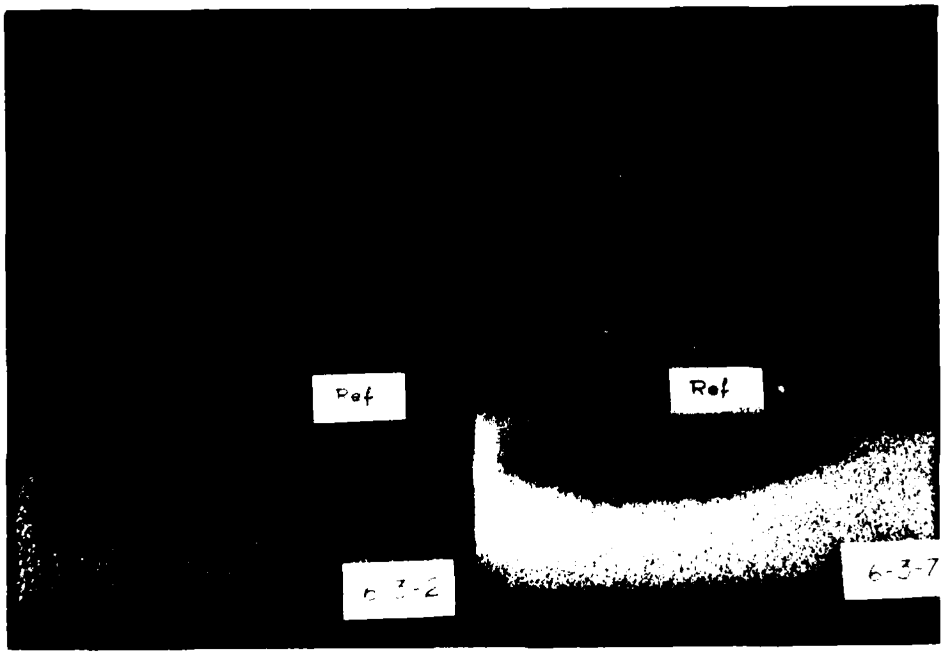


Figure 13. Cross-sectional views of foam specimens subjected to radiant heating.

3.1.7 Brief Flame Impingement

For this sequence of simulative experiments, flame impingement was of such short duration that foam ignition did not occur. Degradation and darkening were limited to sample surface; no damage was affected below the surface (see Figure 14). The strands of reticulated foam were darkened in the impingement area; in some instances, dark beads, composed of partially degraded polymeric material, were formed at the surface.

3.1.8 Sustained Burning

In this sequence of experiments, samples were subjected to flame impingement from a propane torch until ignition occurred. Subsequently, they were allowed to burn without support from the external flame. Experiments were performed with dry foam specimens, and also with those that had been soaked in JP-4.

With dry foam specimens, flames propagated rapidly along the surface. Flame propagation was particularly rapid when vertically held samples were ignited close to the bottom edge. The very limited foam damage below the burn zone (see Figures 15 and 16) was quite unexpected. Apparently, the expanding air below the burn zone hinders diffusion of hot gases into the samples and thereby limits degradative damage.

Intense flames spread very rapidly across entire blue foam specimens that had been soaked in JP-5. During the initial burning phase, the fuel was the major combustible component. Severe darkening of foam surface was observed already during the initial burning (see Figure 17). The discoloration of foam below the combustion zone was slightly more noticeable with fuel-soaked samples, than with dry specimens (compare Figures 15 and 17). More discoloration below the flame zone occurred with fuel-soaked samples during vertical burning than in the course of horizontal top surface burning (compare Figures 17 and 18).

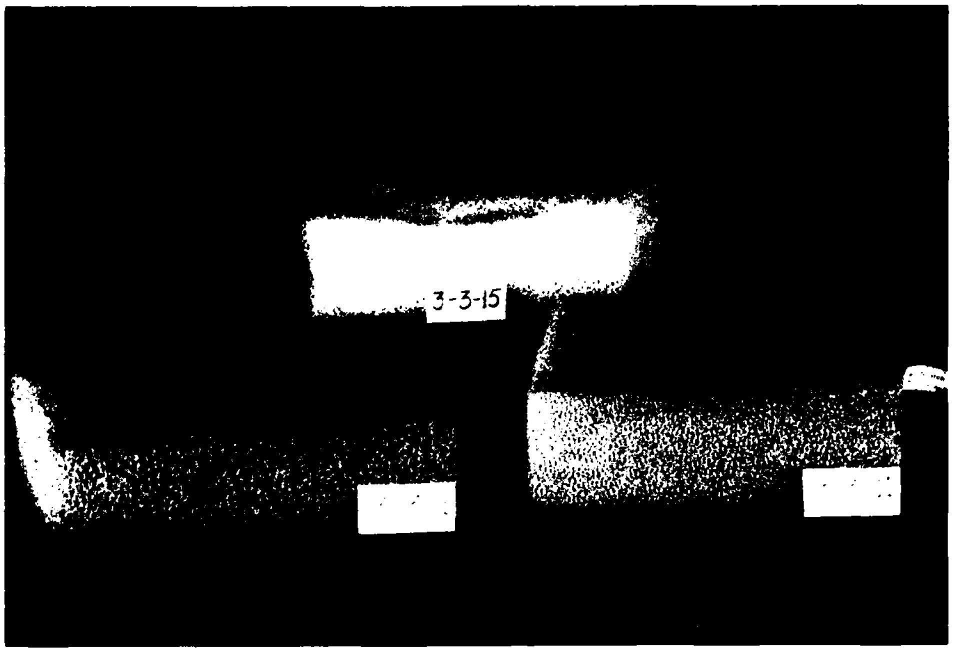


Figure 14. Cross-sectional views of foam specimens subjected to brief flame impingement.

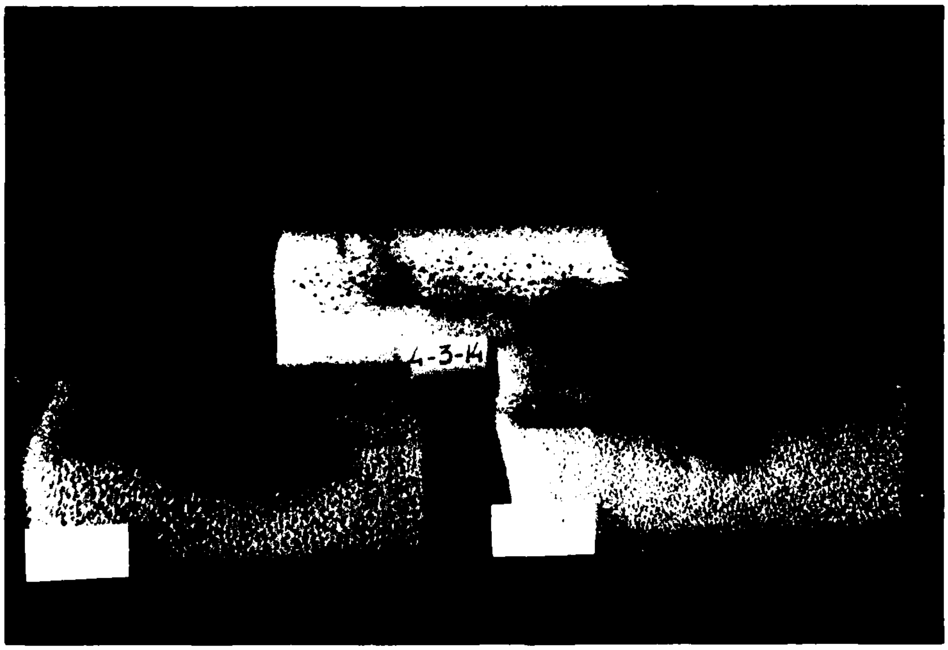


Figure 15. Cross-sectional views of specimens that had been involved in sustained top surface burning in horizontal position.

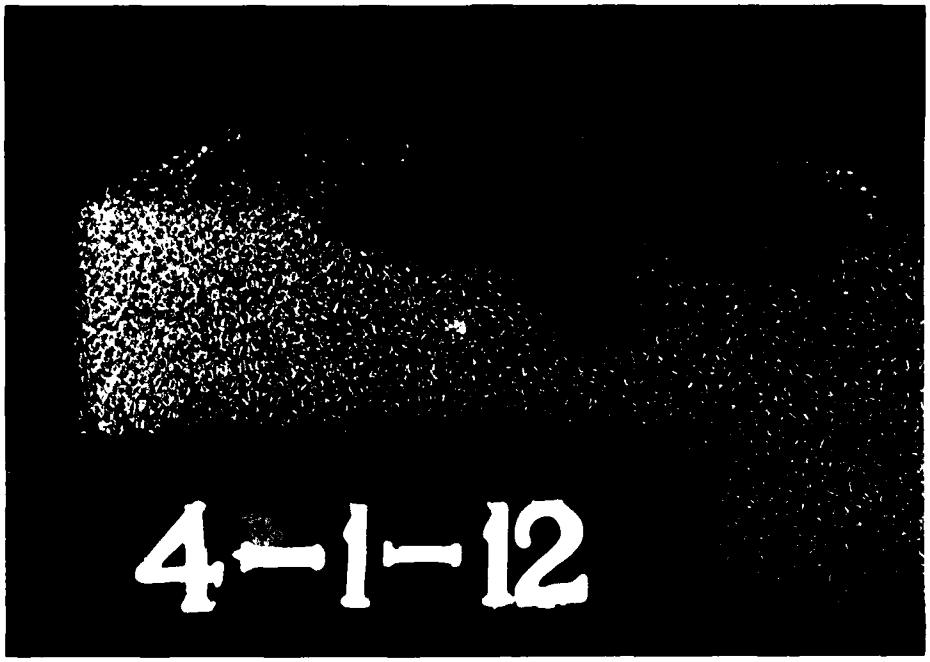


Figure 16. Cross-sectional view of red foam specimen from sustained horizontal top-burning experiments.

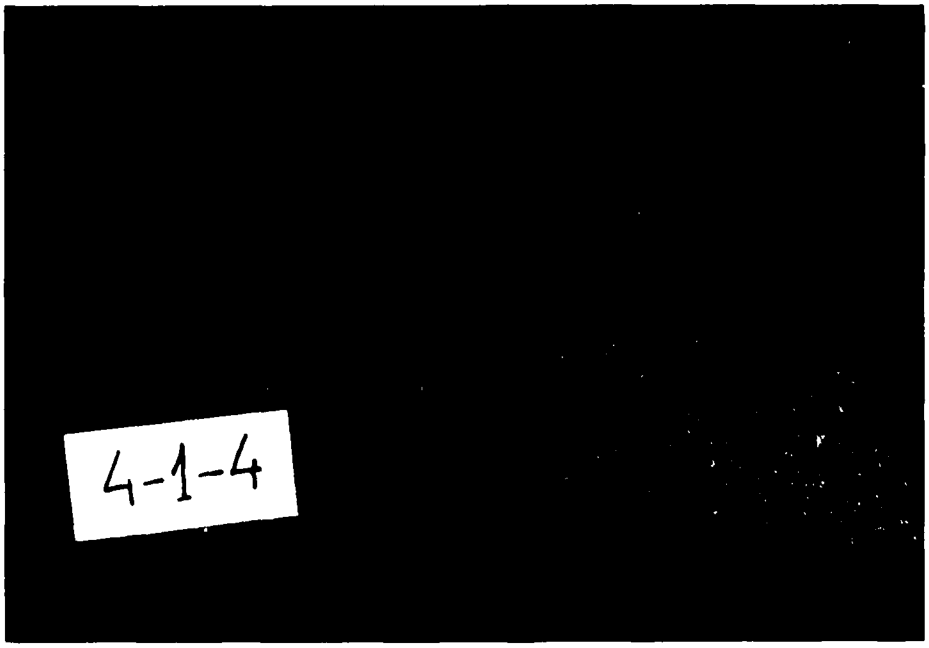


Figure 17. Cross-sectional view of fuel-soaked blue foam specimen that had been involved in sustained burning in horizontal position.

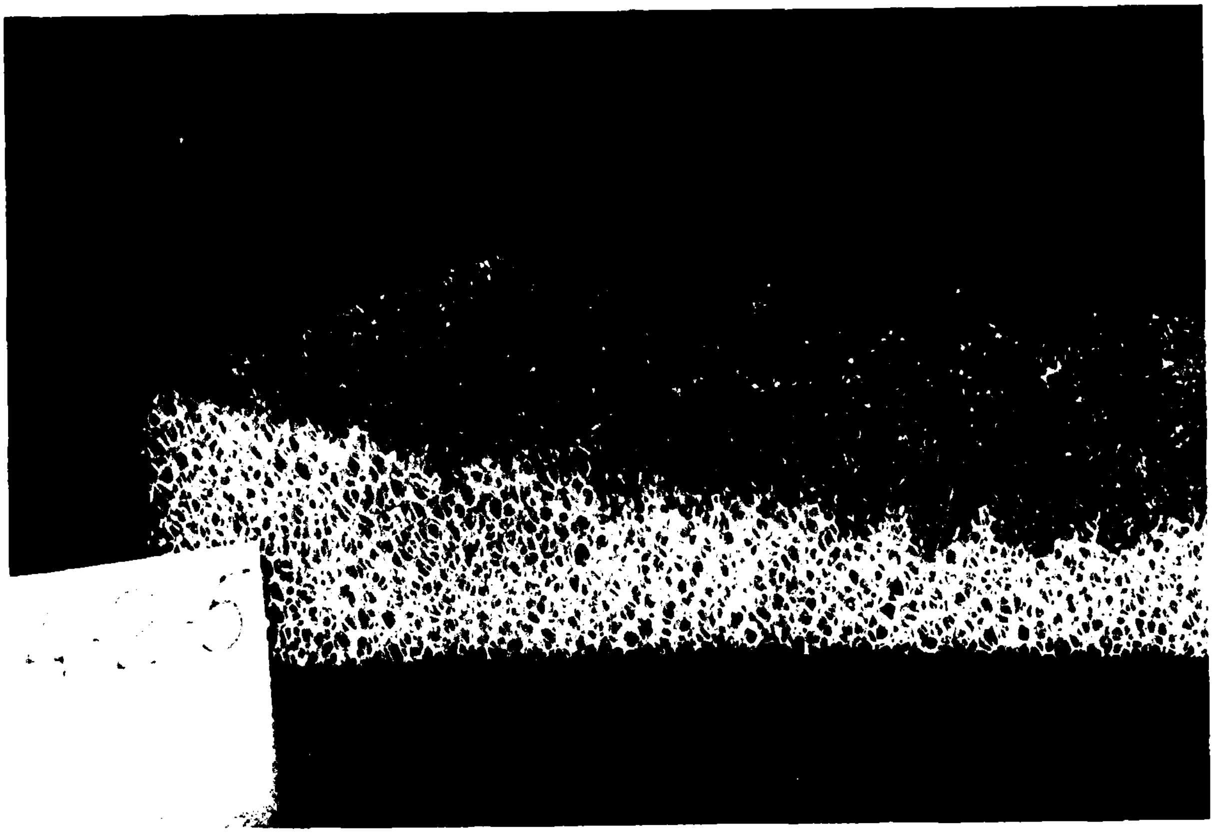


Figure 18. Cross-sectional view of fuel-soaked blue foam specimen that had been involved in sustained burning in vertical position.

3.1.9 Summary of Observed Effects of Aging and Simulated Sunlight, Heat, and Fire Exposure on Polyurethane Foams

For a concise overview of incident simulation test results, highlights of Sections 3.1.1 through 3.1.8 have been summarized in Table 11. It is hoped that investigators will be able to develop accident scenarios more rapidly and reliably with the help of this table and the figures to which references are made therein.

3.2 FLASH FIRE EXPOSURE

The flash fire experiments were designed to explore the effects of certain system variables on foam involvement and flame propagation. These simulation tests were performed at the Aero Propulsion Laboratory. The following variables were encompassed in this investigation:

(1) Foam geometry
(2) Foam type
(3) Propane concentration in air
(4) Dry and fuel-wetted conditions
(5) Nonvented versus vented enclosure
(6) Initial pressure

Forty-three tests were conducted; the results are summarized in Table 12. The first seven tests were performed without a channel being cut into the foam between the voided spaces. For the remaining tests, a channel was cut into the foam to ensure flame propagation into both voids.

Individual foam specimens from twenty-one experiments were subsequently photographed. The experimental data for these experiments, and observations made at the time and subsequent to experiments, are summarized in Table 12. Photographs depicting

TABLE 11. SUMMARY OF OBSERVED EFFECTS OF AGING, AND SIMULATED SUNLIGHT, HEAT, AND FIRE EXPOSURE ON POLYURETHANE FOAMS

Exposure	Effects	Figure(s)
Accelerated aging in air	Discoloration, progressing uniformly throughout the sample. Reduction of flexibility. Eventual breakdown and disintegration of foam structure.	5-7
Accelerated aging in JP-5	Discoloration, progressing uniformly throughout the sample. The rate of discoloration is slower with samples immersed in fuel than upon aging in air. Reduction of flexibility.	8
Simulated sunlight exposure	Discoloration, progressively diminishing from the surface exposed to light source toward the interior of the foam. Reduction of flexibility, especially at the surface.	9
Hot wire cut	Effects depend upon cutting speed. When cut at normal speed (10 ft/min), signs of melting and resolidification of polymeric strand ends can be observed upon magnification. Surface degradation, recession of foam, and beading of darkened, degraded polymer mass is observable subsequent to cutting at reduced rates.	10
Hot air impingement	Localized discoloration, melting, degradation, and foam recession. Solidified droplets of polymer mass may be observable on the walls of the recession. Since hot air diffuses into the foam structure, discoloration, without change of foam physical structure, is observable below shrunken and degraded foam mass.	11 & 12

(continued)

TABLE 11 (continued)

Exposure	Effects	Figure(s)
Radiant heating	Localized discoloration, surface degradation and melting, depending upon the severity of exposure. The depth of the discolored zone, below the surface, is shallower than upon exposure to hot air impingement.	13
Brief flame impingement	Localized degradation and darkening, restricted to sample surface. No damage affected below the surface.	14
Sustained burning	Localized degradation, darkening of foam, and beading of solidified mass mainly limited to foam surface. Little damage in areas adjacent to and below the burn zone. Severe darkening of foam surface during sustained burning of fuel-wetted foam.	15 & 16 21 & 22

TABLE 12. FLASH FIRE TESTS WITH FLAME TUBE[a]

Test No.	Foam type	Propane conc., vol. %	P_I, psia	T_I, °F	Pressure rise, ΔP, psid	Time to max. ΔP, sec.	Remarks
1	Blue	3.5	14.37	70	2.0	0.06	Severe burning in Void 1. No flame propagation to Void 2.
2	Blue	5.0	14.37	73	2.0	0.04	Heavy burning in Void 1. Minor damage in Void 2, probably caused by hot gas rather than flame.
3	Blue	6.5	14.31	69	2.0	0.17	Heavy burning in Void 1. Flame seen in Void 1 for about 10 seconds. No damage in Void 2.
4	Blue	3.5	14.31	68	3.5	0.11	Percent voiding increased to 32.5 by removing pieces A, V, CL, and CR from Void 1. Heavy burning in Void 1. No damage in Void 2.

(continued)

TABLE 12 (continued)

Test No.	Foam type	Propane conc., vol. %	P_I, psia	T_I, °F	Pressure rise, ΔP, psid	Time to max. ΔP, sec.	Remarks
5	Blue	5.0	17.70	68	12.0	0.18	Flame propagated through all the material. Minor damage in Void 1, moderate damage in Void 2.
6	Blue	3.5	17.70	68	2.0	0.06	Heavy burning and 5 second flame duration in Void 1. No damage in Void 2.
7	Blue	6.5	17.70	68	2.0	0.17	Heavy burning in Void 1. No damage, but foam ash (white) deposited in Void 2.
8	Blue	5.0	14.34	70	11.0	0.12	Little damage in both voids. Flame propagated through channel only.
9	Blue	3.5	14.43	70	3.0	0.25	Same results as test number 8. Foam ash deposited in both voids.
10	Blue	6.5	14.41	70	3.0	0.60	Heavy damage in Void 1. Severe damage in Void 2. Ash blown through piece D.
11	Yellow	3.5	14.42	75	3.5	0.14	Heavy burning and 10-12 second flame durations in both voids. All pieces fused together after test.
12	Yellow	5.0	14.41	75	4.5	0.20	Moderate damage in Void 1. Heavy damage in Void 2. Flame durations of 1 and 5 seconds, respectively.
13	Yellow	6.5	14.42	72	4.0	∿2.0	Severe damage in both voids. Flame duration about 8 seconds.

(continued)

TABLE 12 (continued)

Test No.	Foam type	Propane conc., vol. %	P_I, psia	T_I, °F	Pressure rise, ΔP, psid	Time to max. ΔP, sec.	Remarks
27	Blue	5.0	14.33	70	2.0	0.06	Heavy damage in both voids. Hot gas damage to areas of unburned foam.
28	Blue	6.5	14.33	70	0.5	0.14	Similar results as in test number 27.
29	Red	3.5	14.33	70	1.0	0.06	Minor damage in Void 1. Moderate damage in Void 2.
30	Red	5.0	14.44	70	1.5	0.06	Similar results as in test number 29. Hot gas damage to areas of unburned foam.
31	Red	6.5	14.40	70	2.0	0.07	Similar results as in test number 29.
32	Yellow	3.5	14.40		1.0	0.07	Moderate damage in both voids.
33	Yellow	5.0	14.38		1.0	0.07	Similar results as in test number 32.
34	Yellow	6.5	14.38		∼0	0.10	Minor damage in both voids.
35	Blue (wet)	3.5	14.31		1.0	0.01	Minor damage in both voids.
36	Blue (wet)	5.0	14.31		1.0	0.06	Minor damage in Void 1. Severe damage in Void 2.
37	Blue (wet)	6.5	14.31		0.5	0.11	Similar results as in test number 35.
38	Yellow (wet)	3.5	14.31		1.0	0.09	Moderate damage in both voids.
39	Yellow (wet)	5.0	14.36		1.0	0.06	Similar results as in test number 39.

(continued)

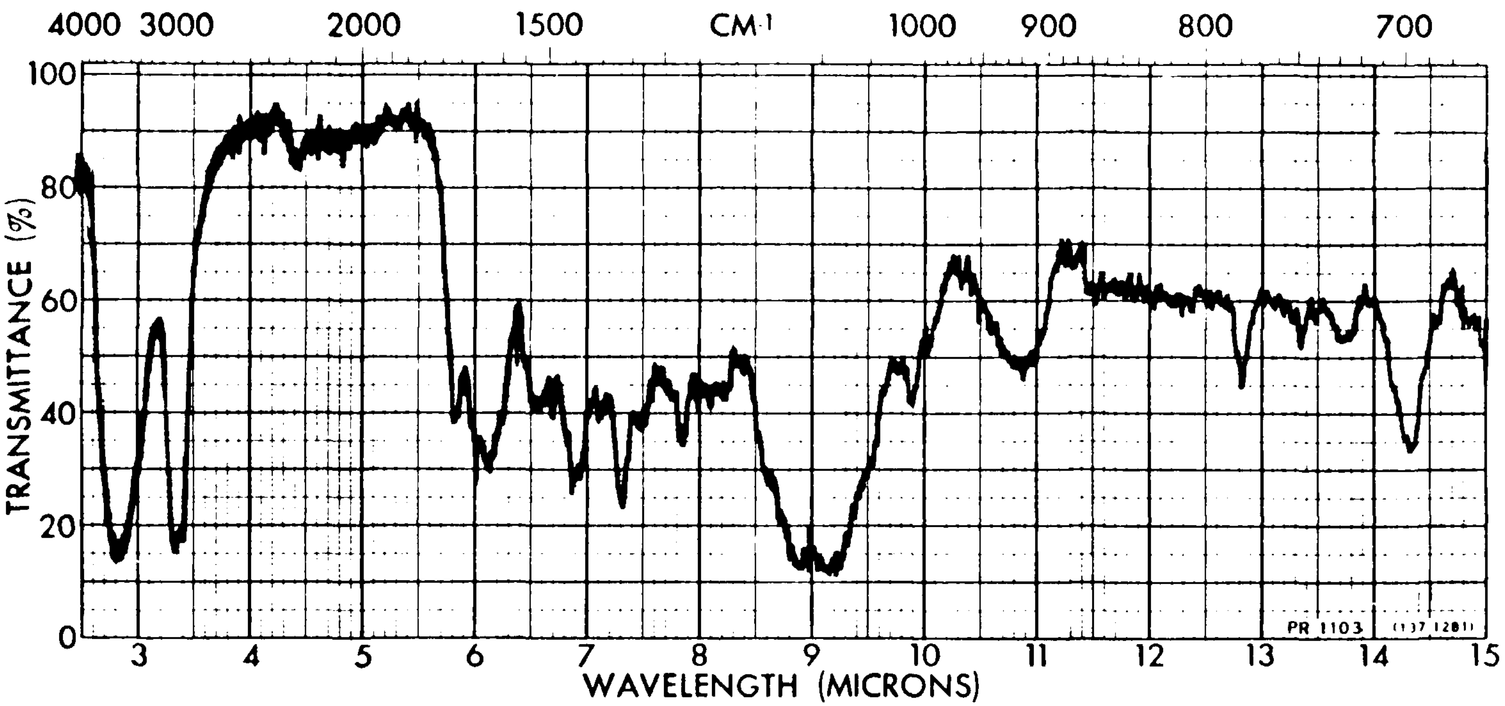


Figure 27. Infrared absorption spectrum of the liquid, brown-colored pyrolysis product formed from blue polyurethane foam.

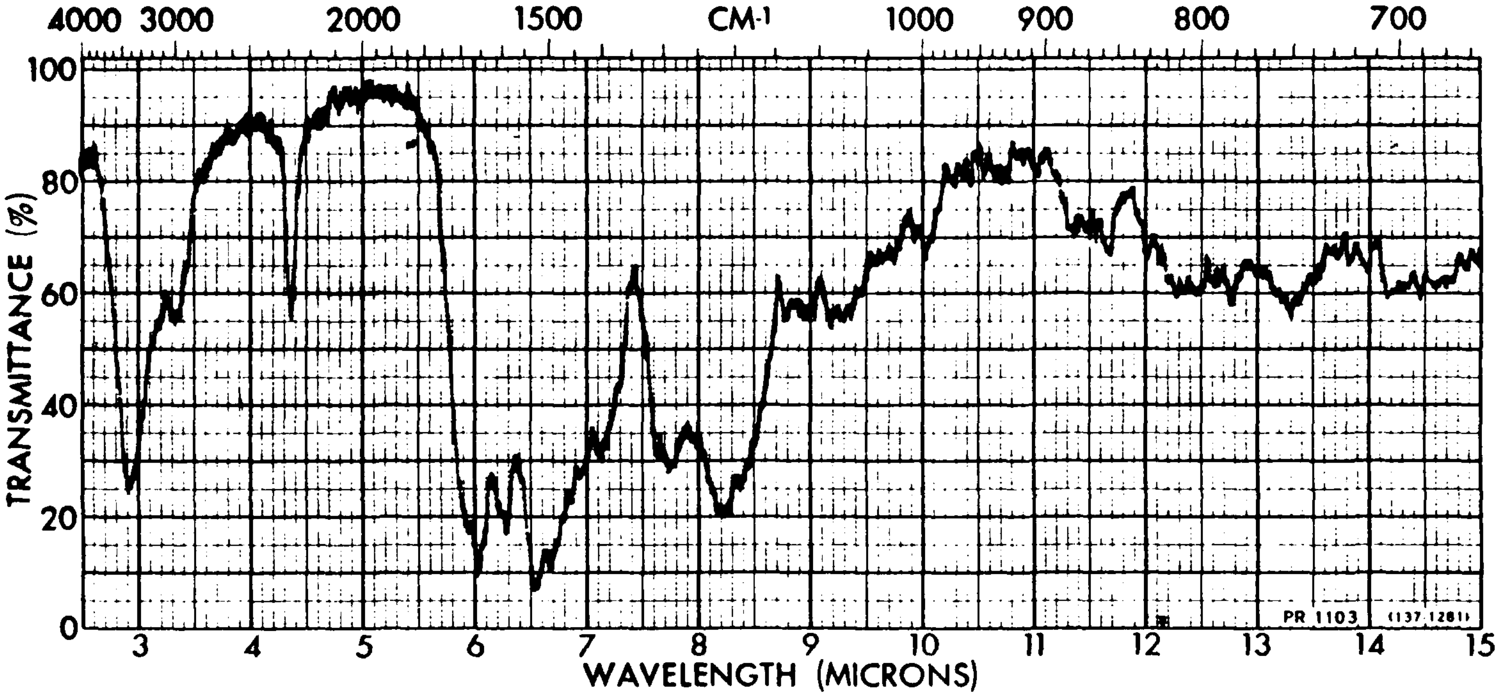


Figure 26. Infrared absorption spectrum of the solid, tan-colored pyrolysis product formed from blue polyurethane foam (in KBr matrix).

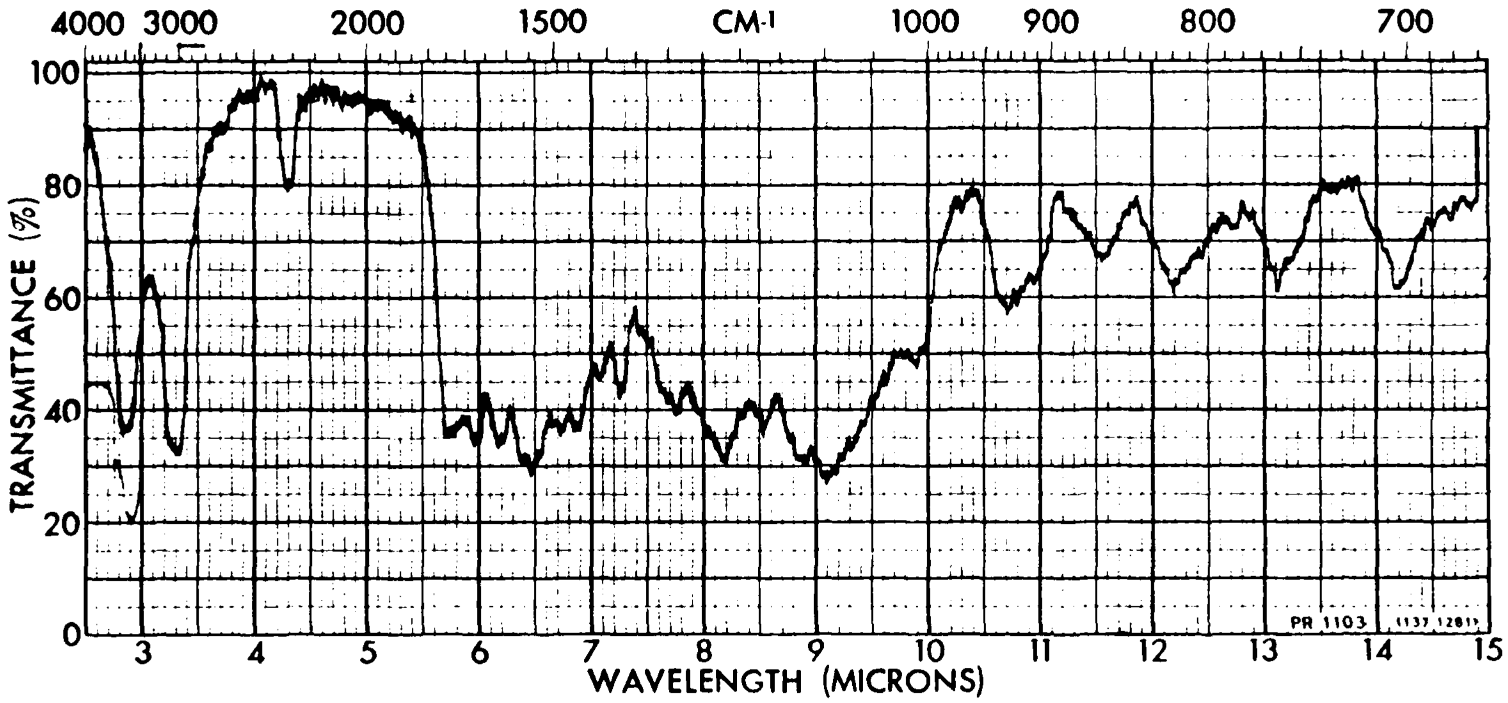


Figure 25. Infrared absorption spectrum of blue polyurethane foam (Scott Safety Foam SF 0025, Type 5, in KBr matrix).

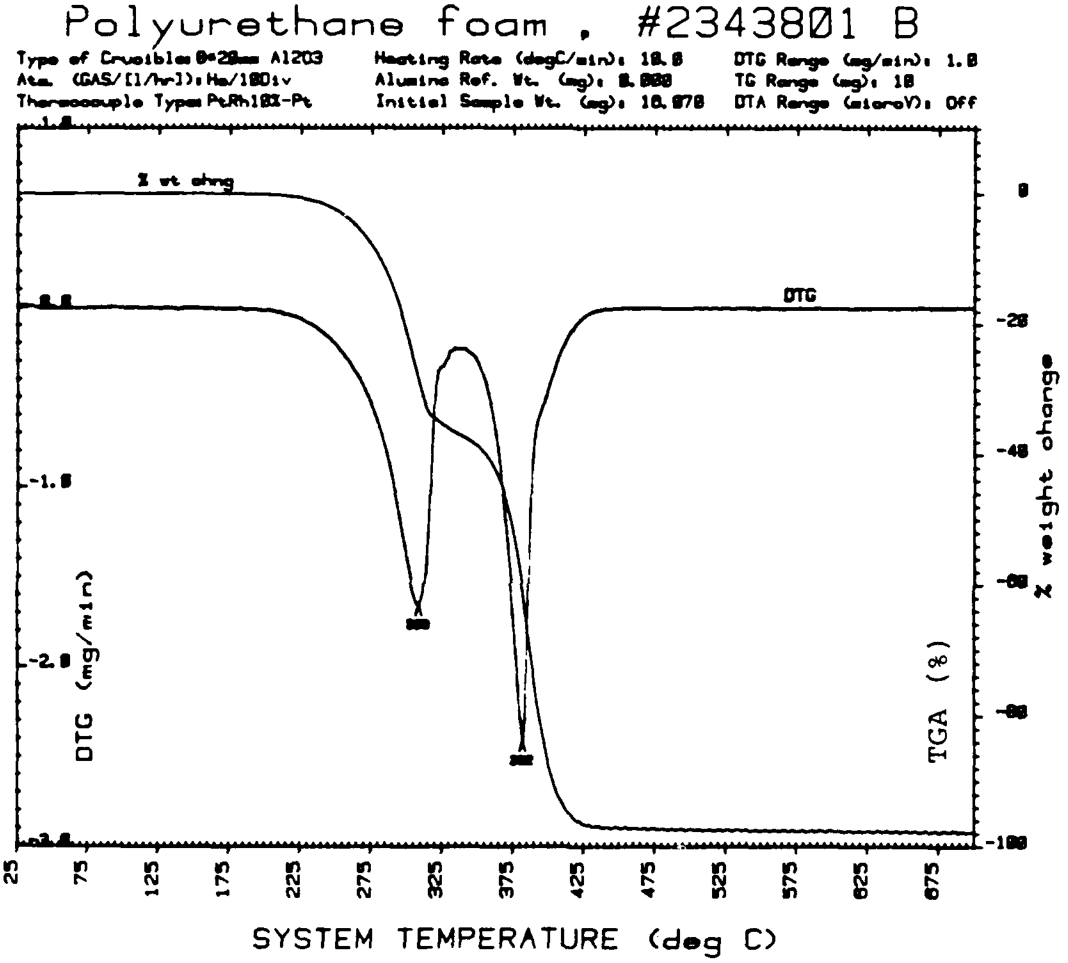


Figure 24. Thermogram and differential thermogram for degradation of blue polyurethane foam in helium.

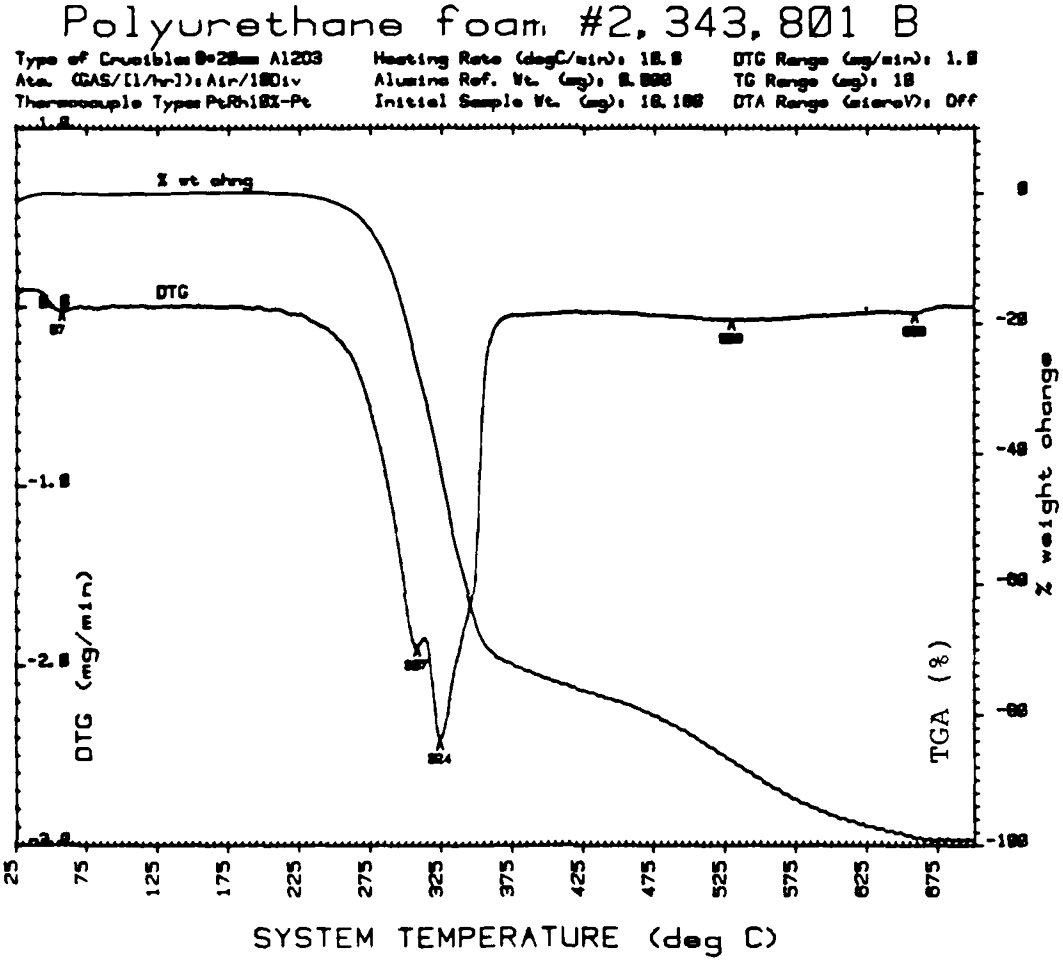


Figure 23. Thermogram and differential thermogram for degradation of blue polyurethane foam in air.

TABLE 13. SUMMARY OF TGA AND DTG DATA FOR BLUE POLYURETHANE FOAM IN AIR AND HELIUM ATMOSPHERES

	In air	In He
First degradation step		
Onset, at °C	~195	~195
Maximum degradation rate, at °C	308	307
First step completed, at °C	~337	~360
Weight loss, %	37	~71
Second degradation step		
Maximum degradation rate, at °C	382	529
Second step completed, at °C	~435	~665
Weight loss, %	~61	~28
Residue, weight, %	2	1

reference to the two diisocyanate unit nitrogen atoms, is represented approximately by the empirical formula $C_9H_{11}N_2O$. The solid degradation product differs from the original foam by loss of volatiles represented approximately by the C_3H_{10} atomic ratio.

The yield of the tan solid was found to increase with diminishing oxygen concentration and reduced exposure of degradation products to oxygen during pyrolysis.

The composition of the black reticulated char formed in Experiment 3 (see Table 11) indicates extensive oxidative removal of hydrogen during prolonged heating of foam in air.

3.3.3 Infrared Spectroscopic Analysis of Degradation Products

The infrared absorption spectrum of the reference sample of unused, blue foam is shown as Figure 25. The spectrum of the tan, solid pyrolysis product from Experiment 1 is presented in Figure 26; the spectrum of the liquid degradation product from the same experiment is shown in Figure 27.

V_c = combustion volume
V_r = relief volume
N = specific heat ratio

When the flame propagates through the material, the combustion overpressure is slightly higher than with a flame arrestor system having the same combustion volume and configuration.

In Test 5, the damage to the foam in both voids was minimal compared to the damage in other tests (see Figures 19 and 20). This was due to the short duration of combustion and complete depletion of oxygen, as discussed in Section 3.2.3.

In the experiments in which the flame was arrested, severe damage occurred in the first void. This damage resulted from extended burning of residual fuel/air mixture in this void. These gases moved into Void 1 by convection. Under those burning conditions, the effects of initial pressures were negligible.

3.3 LABORATORY-SCALE, CONTROLLED DEGRADATION EXPERIMENTS WITH BLUE POLYURETHANE FOAM

3.3.1 Thermogravimetric Analysis

The thermogravimetric analysis and differential thermogravimetric curves indicated that the degradation proceeded in two steps. The data from thermogravimetric analyses are summarized in Table 13 and presented graphically in Figures 23 and 24.

3.3.2 Pyrolysis and Thermo-Oxidative Degradation of Blue Foam Under Controlled Conditions

Controlled degradation experiments were performed with the blue foam at temperatures ranging from 500° to 842°F (260° to 450°C). A light tan, solid degradation product was isolated (see Tables 10 and 11, and Figure 5). Its composition, calculated with

3.2.5 Effect of Pressure

The effect of pressure was investigated with the blue foam in Experiments 1-3 and 5-7 (see Table 12). At 14.4 psia pressure, flames did not propagate through the foam, although finely divided solids were deposited. Severe hot gas damage, resulting in charring, was caused at the higher pressure (17.7 psia) to specimen D. In these experiments, the foam acted as a flame arrestor in all tests, except for Experiment 5. In the latter test, a 5 vol.-% propane mixture with air was ignited at an initial pressure of 17.7 psia; the resulting flame propagated throughout the chamber. The combustion overpressure of 12 psid was much higher than in most other tests, in which the flame did not propagate through the foam, therefore not igniting the gases in the second void. The 5 vol.-% propane air mixture also resulted in maximum combustion overpressure for a propane and air mixture at the given initial pressure.

The combustion overpressure is a function of the fuel/air ratio, the initial pressure and temperature, the tank geometry, and the amount of explosion suppression material. For an empty chamber (constant volume), the maximum overpressure occurs at a slightly fuel rich mixture; it is approximately 8 times the initial pressure. For a chamber filled with an explosion suppression material that will arrest the flame (flame does not propagate through the material), the combustion overpressure is predicted by (Ref. 10):

$$\frac{P_C}{P_I} = \left[\frac{(V_r/V_C) + 1}{(T_I/T_C)^{1/N} + (V_r/V_C)}\right]^N$$

where P_C = combustion pressure
P_I = initial pressure
T_C = combustion temperature (°K)
T_I = initial temperature (°K)

consumption of oxygen through the oxidation of hydrocarbon species in vapor phase occurs more rapidly than by the burning of the polymeric foam. For the foam to burn, it must be thermally or thermo-oxidatively degraded. The volatile degradation products subsequently burn in the vapor phase. Consequently, the higher the CH_n content from hydrocarbon sources in the vapor phase, the less foam damage through burning will occur.

In view of results from Experiment 20, one can envision circumstances under which most of the oxygen in an aircraft fuel vent system will be consumed in flash fire supported by fuel vapors, with minimal evidence of foam damage. This is demonstrated in a photograph of Sample 1-1-20 in Appendix A1-10.

3.2.4 Effect of Venting

Some observations regarding the effect of venting on foam damage were included in the Experimental section.

In experiments performed in the vented mode, 6.5 vol-% propane in air produced the largest flame plume, in what appeared visually to be the most energetic reaction. However, reactions that occurred under those conditions produced less overpressure since most of the reaction occurred outside of the test chamber.

White smoke was seen puffing from the vent line in experiments conducted with dry foam in vented mode. Eventually, the puffing and pressure fluctuation in the system stopped without external intervention. The pressure increase was caused by the expansion of gases, composed of combustion and degradation products, out of the chamber. Internal pressure diminished upon cooling. Fresh air entered the chamber and caused reignition of fuel vapors. With fuel-wetted foam, it was necessary to extinguish the fire by blocking the vent tube after the test.

dropped to the bottom of the chamber, causing further damage to the foam samples. Examples of this phenomenon are shown in the photographs in Appendix A1-10.

3.2.3 Effect of Hydrocarbon Vapor Concentration; Dry vs. Fuel-Wetted Foam

The experiments were performed at fuel concentrations in vapor phase between lower and upper flammability limits. The lower flammability limit for propane in air is 2.1 vol-%; the upper flammability limit is 9.5 vol-% (Ref. 9). In two experiments (Exps. 22 and 25) listed in Table 12, the propane concentration (2.0 vol-%) was below the lower flammability limit for that hydrocarbon. However, fuel-wetted foam was used in these experiments. Thus, the total combustible hydrocarbon concentration was in the flammable range.

Foam damage due to surface burning at atmospheric pressure was related inversely to propane concentration (see figures pertaining to Exps. 1 and 10, 11 and 12, 14 and 16, and 23 and 25 in Appendix A1-10). Since there was no air flow into the chamber, the extent of burning was oxygen-limited.

The effect of the presence of aircraft fuel on foam damage was also investigated. For this purpose, foam samples were wetted with JP-5. In experiments performed under identical conditions, except for the presence of fuel, less extensive foam damage occurred with wetted material. It should be noted that this comparison applies to experiments performed both in the unvented and in the vented mode.

It is suggested that the reason for reduced foam damage from surface burning, observed upon increase of propane concentration in vapor, or introduction of fuel vapors, is analogous. The total extent of burning in the enclosed space is oxygen-limited. The

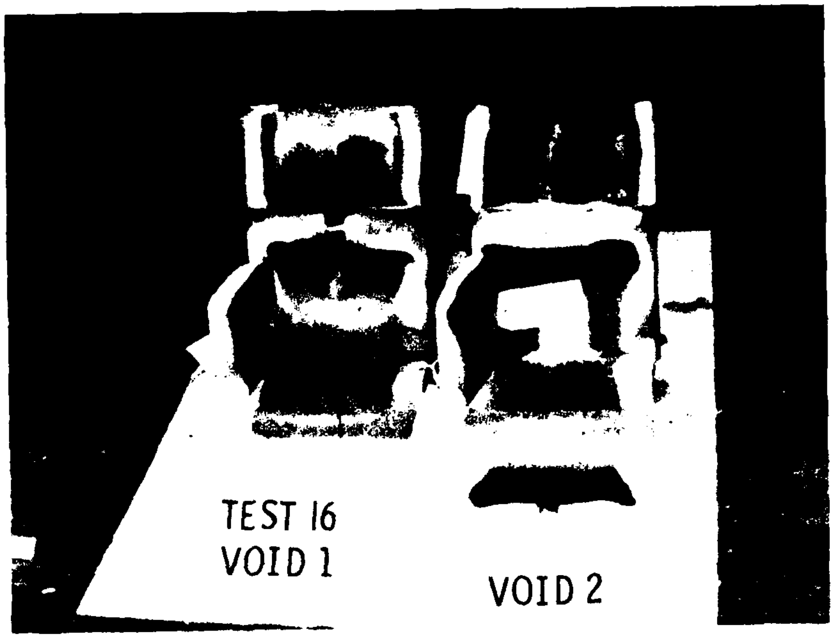


Figure 21. Red foam damage pattern, Test 16.

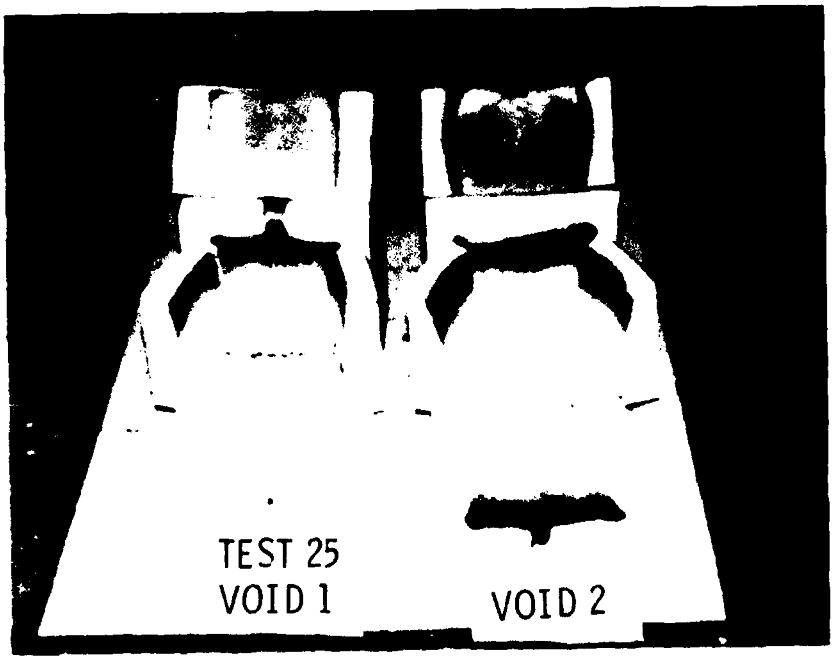


Figure 22. Yellow foam damage pattern, Test 25.

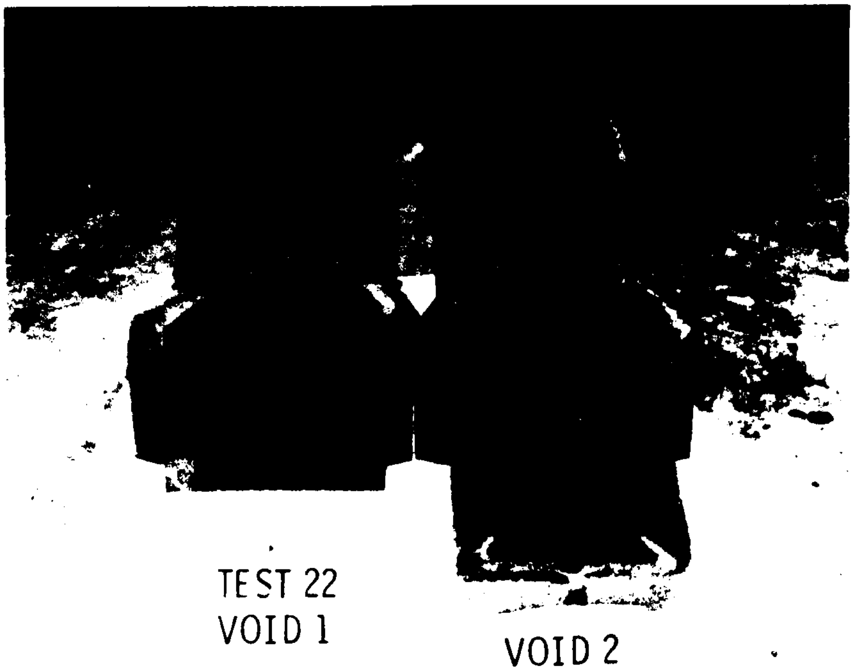


Figure 19. Blue foam damage pattern, Test 22.

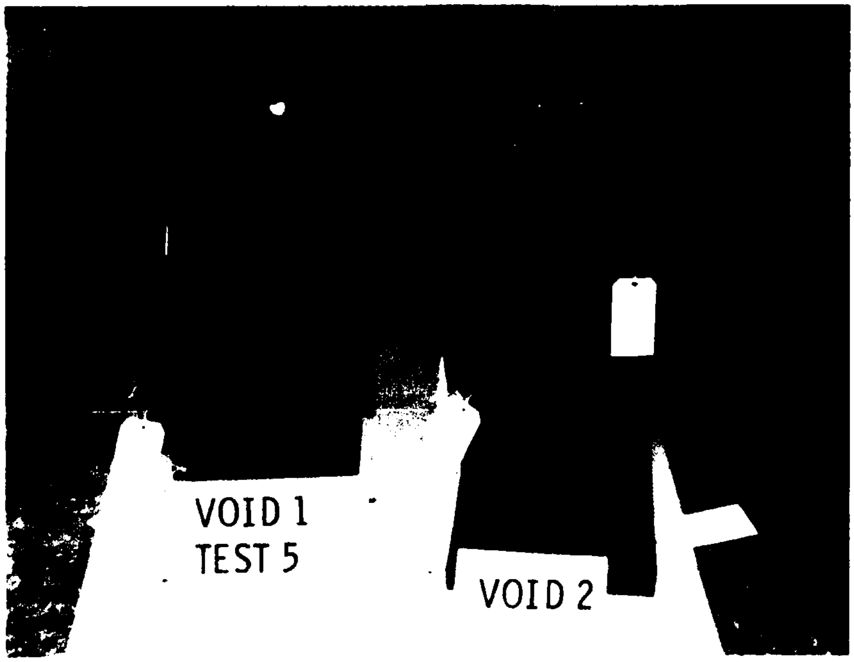


Figure 20. Blue foam damage pattern, Test 5.

Typically, the vertical foam pieces 1 and 3 were most severely damaged (see Figures 1 and 19 through 22). They were located on the downstream side, with reference to the flame path direction, of each void. The vertical piece 2, located at the upstream side of Void 2, was in general less severely damaged than pieces 1 and 3. Foam pieces A and E, located at the top of each void, were also severely damaged due to the rise of hot gases (and flame) during and after combustion.

Pieces B and F, located at the bottom of each void, sustained little damage from the combustion. However, they were subsequently damaged when hot polyurethane from pieces A and E dripped onto these pieces.

Pieces D and H, which were not exposed to the voided sections, did not show evidence of burning, except along the flame propagation channel. They were damaged by the traversing hot gases.

For the foam to show evidence of burning, it must be exposed to a voided section. In some cases, burning occurred between two adjoining foam pieces, probably because the pieces were in loose contact or slightly separated from each other.

The damage to the flame propagation channel extended from unnoticeable to severe. The affected surface was typically coated with a tan-colored deposit from the foam degradation.

3.2.2 Effect of Foam Type

The two foam types, the blue polyether and the red and yellow polyester, degrade differently when exposed to flash fire impingement. The degradation products of the polyether-based foam were slightly tacky; the molten and subsequently solidified droplets of polymer mass contracted into small clusters. In contrast, the polyester-based foams formed droplets that did not solidify. They

TABLE 12 (continued)

Test No.	Foam type	Propane conc., vol. %	P_I, psia	T_I, °F	Pressure rise, ΔP, psid	Time to max. ΔP, sec.	Remarks
40	Yellow (wet)	6.5	14.36		0.5	0.07	Minor damage in both voids.
41	Red (wet)	3.5	14.21		0.5	0.08	Minor damage in both voids.
42	Red (wet)	5.0	14.21		1.0	0.06	Moderate damage in both voids.
43	Red (wet)	6.5	14.34		0.5	0.13	Minor damage in both voids.

---

[a] Void volumes totaled 20%; 10% for each void. In the vented tests, the vent tube increased the total voiding to 22%. Tests 8-43 had a channel cut through at the top from Void 1 to Void 2. All test samples were dry, except where noted. Tests 1-25 were conducted with a closed chamber, in tests 26-43, the chamber was vented.

samples from flash fire exposure experiments are presented in Appendix A1-10 of this report.

The charred foam surfaces indicate that sustained burning occurred in all twenty-one experiments. Combustible gas concentration in the confined spaces was the major factor that controlled the extent of foam burning.

3.2.1 Effect of Foam Geometry

Foam configuration was a critical factor in affecting the extent of damage inflicted on foam samples. In general, foam in Void 2 was more severely damaged than foam in Void 1. This may have been caused by ignition in the second void at a higher pressure, caused by the burning in the first void.

The infrared spectrum of the solid degradation product (see Figure 26) indicated the presence of urethane (-NH-CO-) functionality (NH stretch at 2.9 μ, NH bend at 6.6 μ and CO stretch at 6.0 μ). This spectrum also indicates that the solid degradation product lacks most of the ether functionality (C-O-C stretch at 9.1 μ) present in the original polyurethane. The tan solid also contains some N=C=O functionality (band at 4.35 μ).

The C-O-C functionality from the foam appears in the liquid degradation product (see Figure 27). That product also contains OH and/or NH functionality (band at 2.8 μ).

3.4 EXAMINATION AND ANALYSIS OF POLYURETHANE FOAM SAMPLES RECOVERED FROM AIRCRAFT INCIDENT SITES

The work presented in this report was pursued as a follow-up to some aircraft incident investigations. It was learned in controlled simulation experiments, in conjunction with these investigations, that the physical effects of aging, and simulated sunlight, heat and flame exposure upon the polyurethane foam differ. The type of unwanted exposure can often be deduced by close examination of specimens. To illustrate this, the appearances of some specimens recovered from incident sites, and their probable exposure conditions will be discussed.

3.4.1 Foam from Fuel Vent Tanks

All three specimens (Specimens 1-3; see Figures 28-30) exhibited surface degradation in an irregular pattern. Pieces of char adhered to the affected surface. In most of the affected areas, foam damage did not extend deep below the surface (see Figure 31). Consequently, it is concluded that this damage was caused by burning of the foam.

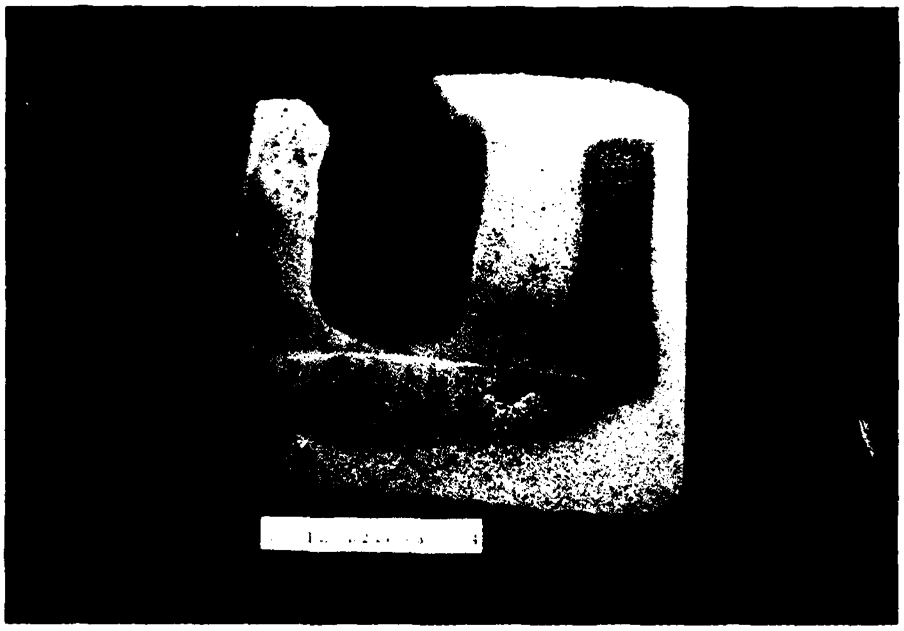


Figure 28. Fuel vent tank foam, left half, A/C 78-717 (Specimen No. 1).

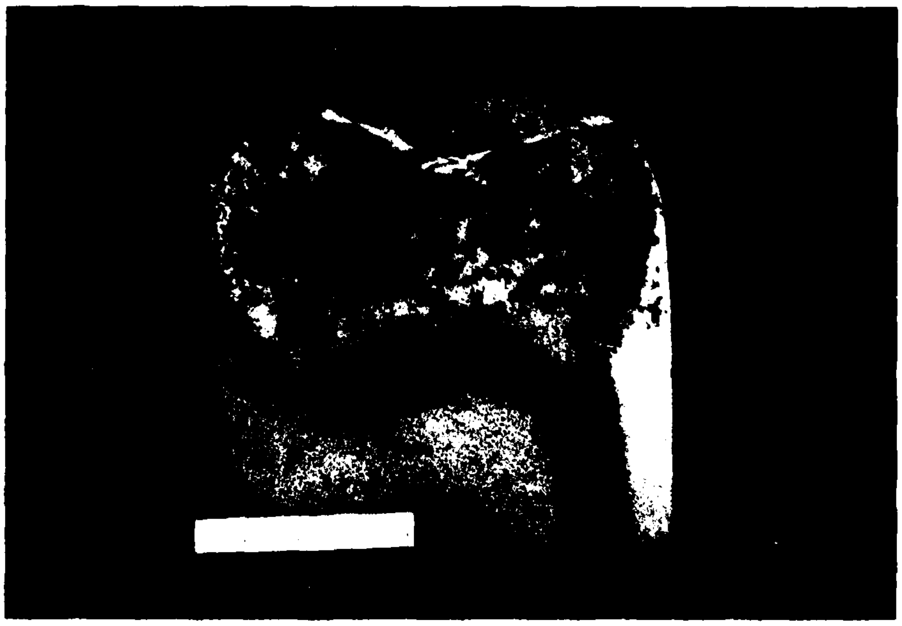


Figure 29. Fuel vent tank foam, right half, A/C 78-717 (Specimen No. 2).

Figure 30. Fuel vent tank foam, left half, A/C 78-704 (Specimen No. 3).

Figure 31. Close-up view of the damaged segment of fuel vent tank foam from A/C 78-704 (Specimen No. 3).

In addition to degradation through combustion, there appears to have been exposure to radiant heating. This caused surface charring, on front faces of specimens, without sharp lines of demarcation. The pattern of the charred area (see Figure 32) may be indicative of the shape and location of the heat source. The severity and depth of heat-induced damage are seen to diminish with distance from the exposed surface (as positioned in Figures 28 to 30, and 32).

A coating of white, powdery substance was observed on the right hand side of two pieces recovered from A/C 78-717 (see Figures 28 and 33). That powder had been deposited from a gas stream in directional manner (from lower right in Figure 28), as evidenced by the nonuniformly distributed coating on foam strands. Instrumental surface analysis revealed subsequently that this white coating consisted almost entirely of potassium carbonate. The incident pattern appears to have repeated itself with a different aircraft (see Figure 34).

Potassium carbonate on the foam is believed to have been deposited from gun gases. Gunpowder contains potassium nitrate, carbon, and sulfur (see Appendix 3). Formation of potassium oxide, carbon dioxide, nitrogen oxides, and sulfur oxides should be anticipated upon detonation. Potassium oxide and carbon dioxide would partially combine, to yield potassium carbonate. In diving maneuvers, the finely divided potassium carbonate powder could be drawn into the fuel vent tank, where it would deposit on the foam surface.

3.4.2 Fuel Tank Foam

The inside surface of the depicted assembly of void filling foam (Specimen No. 4; see Figures 35 to 37) had been exposed to flash fire(s) of short duration. The surfaces of foam pieces were singed. The damage did not extend into the foam.

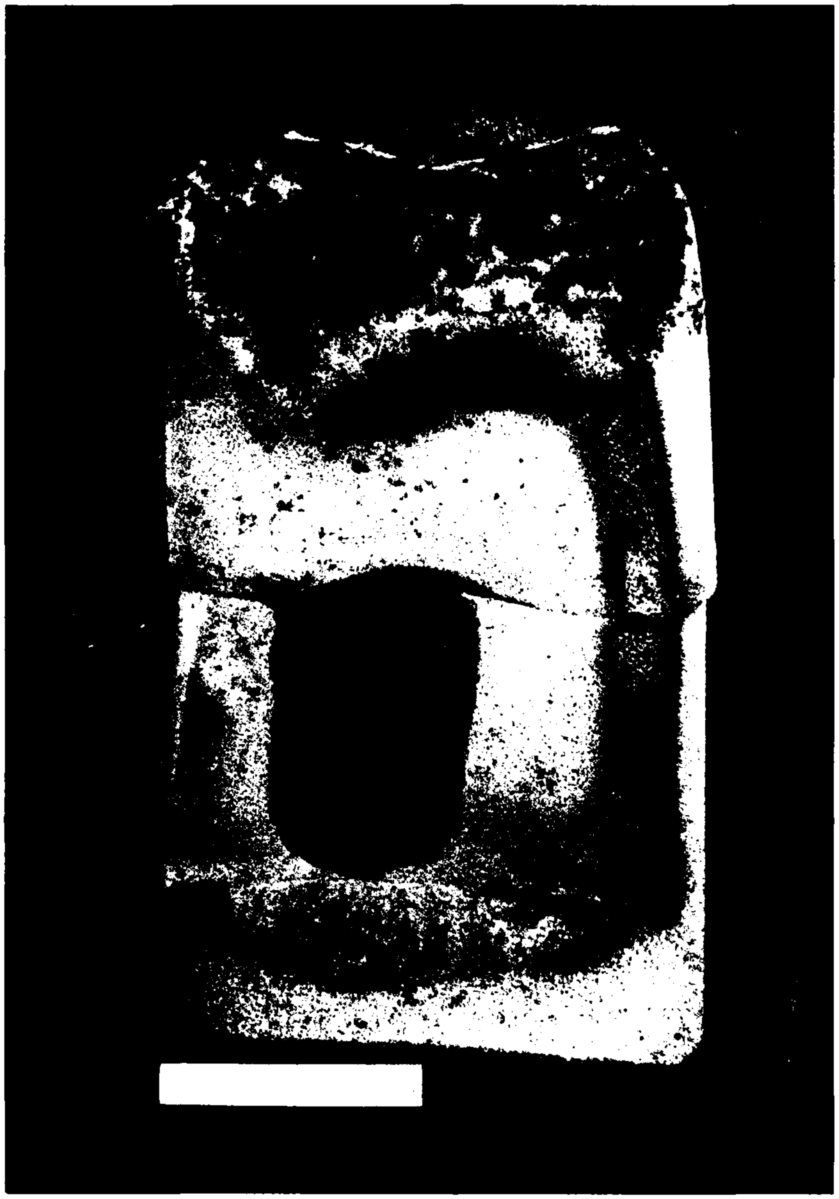


Figure 32. Two halves of fuel vent tank foam from A/C 78-717 (Specimens Nos. 1 and 2) placed together.

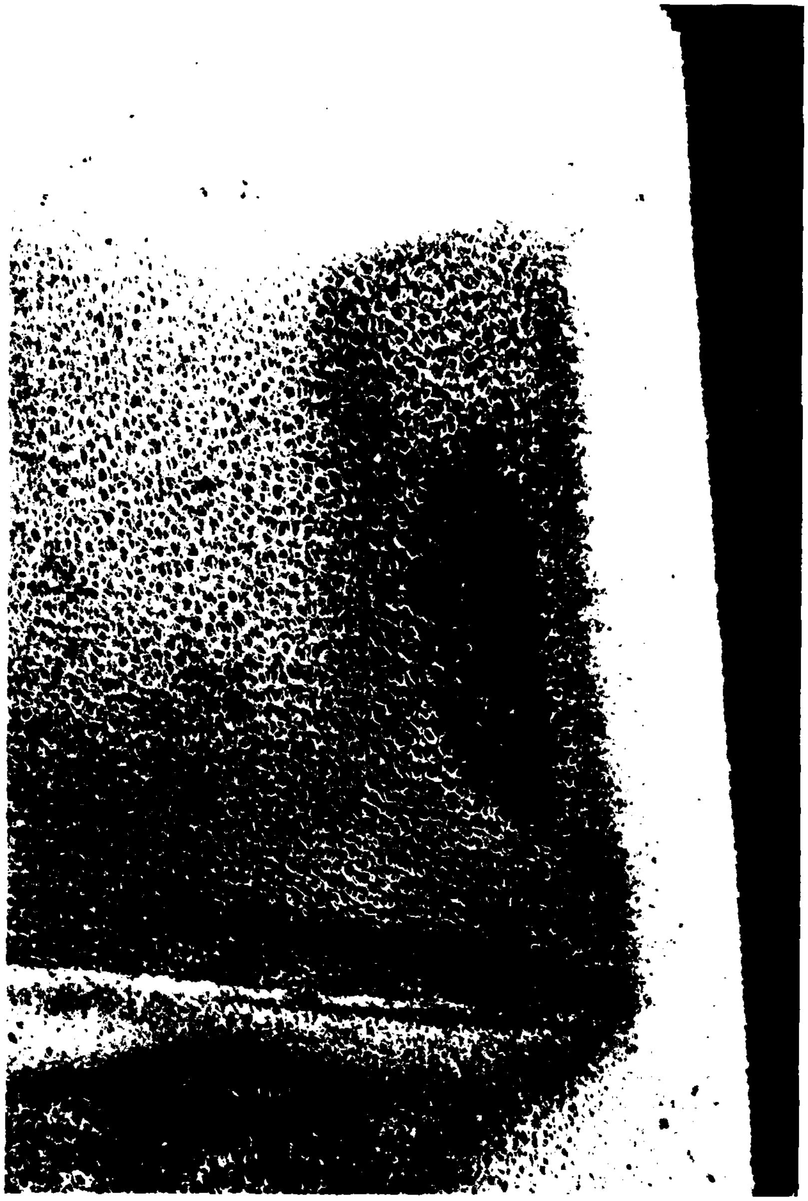


Figure 33. Close-up view of white powder deposit on the surface of fuel tank foam (Specimen No. 1).

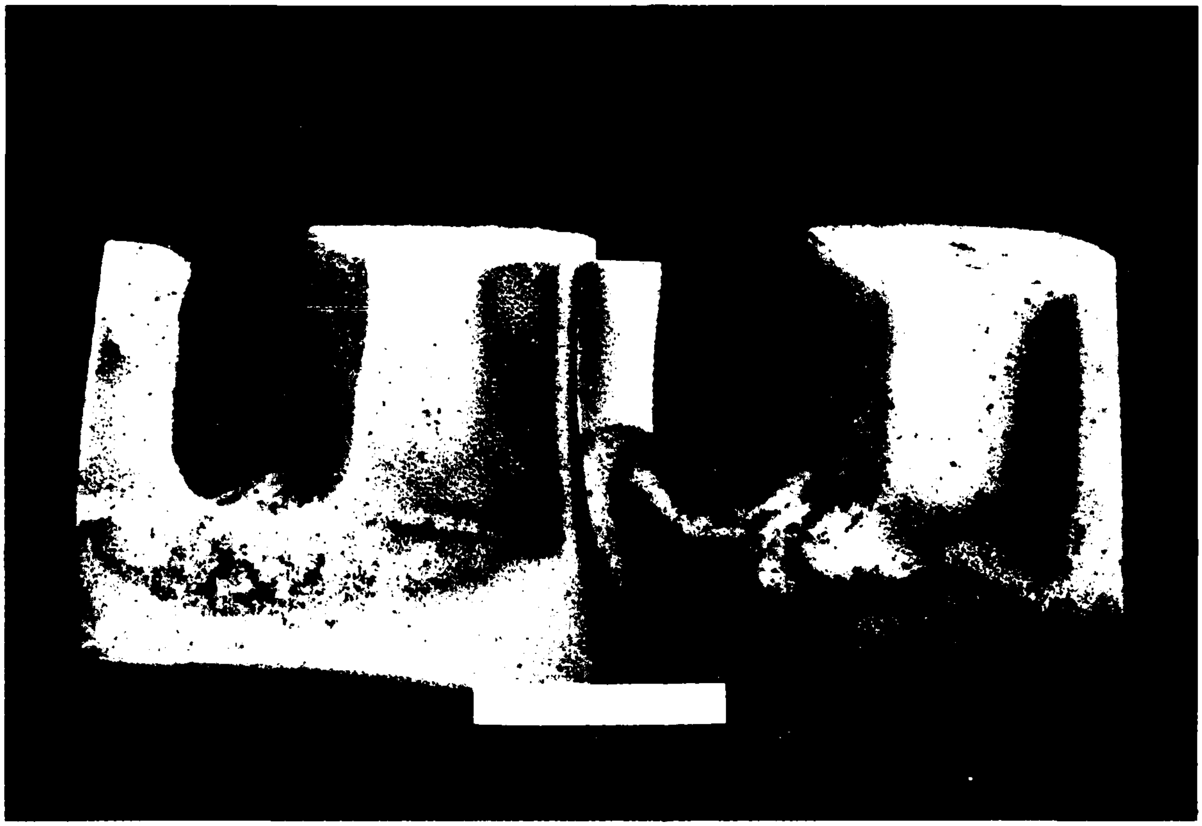


Figure 34. Left halves of fuel tank foam from A/C-s 78-704 and 78-717.

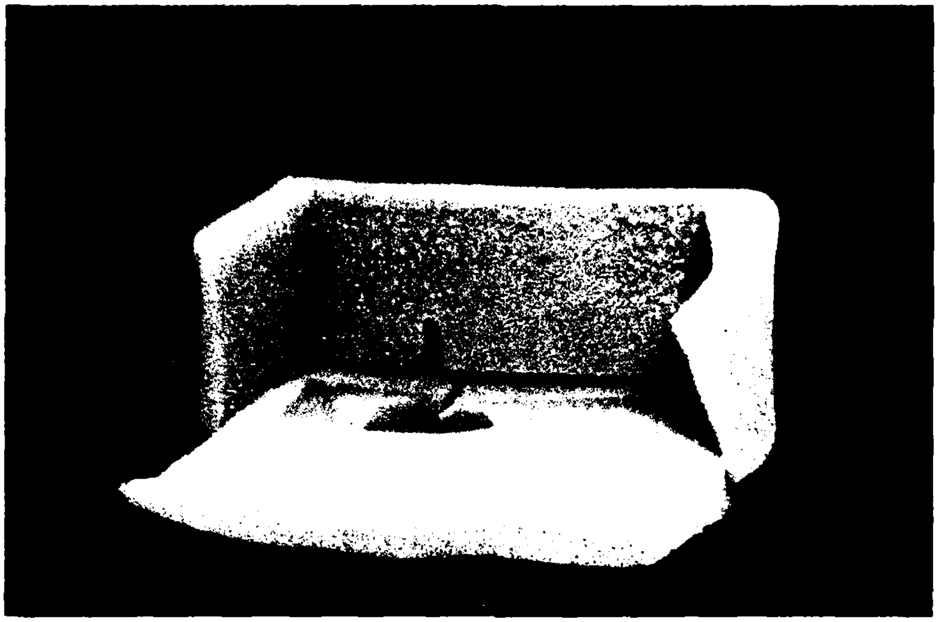


Figure 35. Wing tank foam, A/C 78-717 (Specimen No. 4).

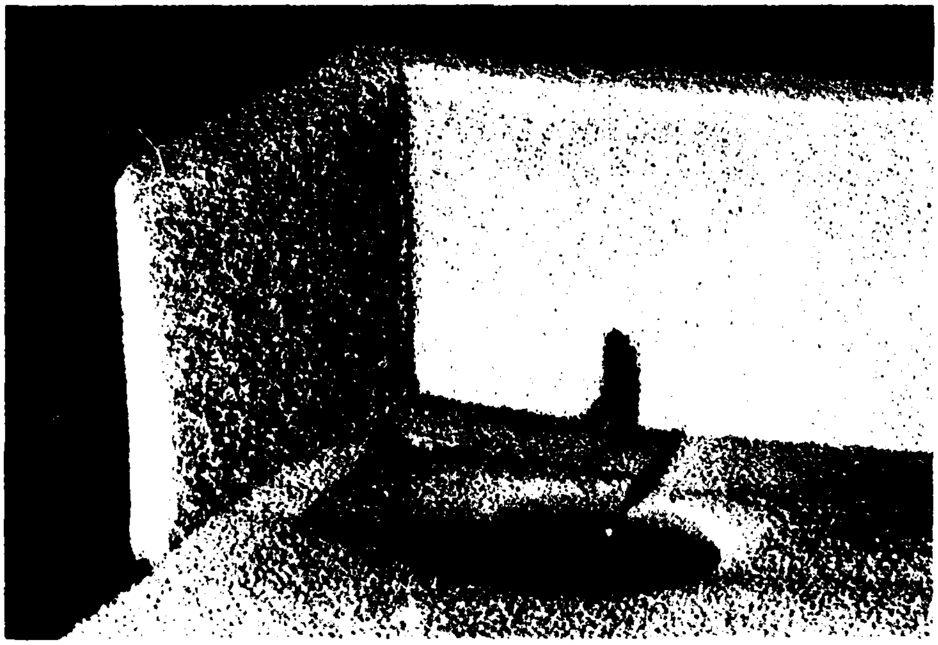


Figure 36. Fire-damaged surface of fuel tank foam (Specimen No. 4).

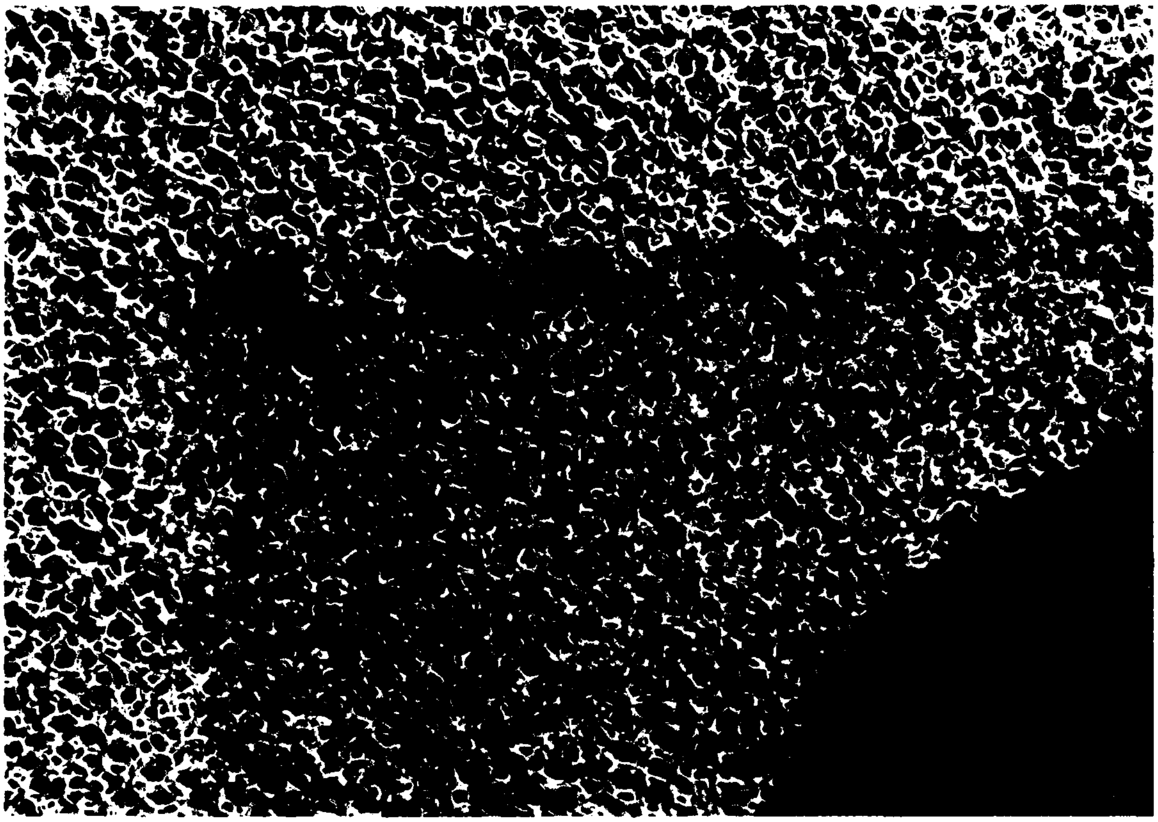


Figure 37. Close-up view of the fire-damaged surface of fuel tank foam (Specimen No. 4).

Four pieces of foam from void space around the vent outlet in a wing tank of A/C 78-717 are shown in Figure 38; a closer view of one of these pieces is presented in Figure 39. Foam surfaces protected by contact with metal appear bright blue. Most of the exterior surface of these specimens is faded blue in color. This appearance may stem from prolonged exposure to air currents. The tan coloration in some areas of the surface can be attributed to flash fire of very short duration, that did not affect the entire exposed foam surface area in the same manner, or to foam degradation products from foam burning in the vent tank which are drawn into the wing vent outlet area.

Most extensive discoloration is believed to be related to most severe exposure to the flash fire (see the upper left corner of the specimen in Figure 39). By exposing a cross-sectional area below the tan surface, it was learned that the damage did not extend deep below the surface (≤1/8 in.). Microscopic examination of the affected surface revealed degradation and darkening of polymer strands, especially at the ends formed in hot wire cutting. The shallow penetration of damage, and evidence of thermal degradation and darkening at the surface, are characteristic signs of hot wire cutting and flash or brief duration fire exposure (see Table 11).

3.4.3 Wipings from Vent Masts and from Right Side Vent, Tank Dome

The wipings of surface contaminants from the vent systems (Specimens Nos. 11-16) were contained on pieces of gauze. Only the solids in Specimens Nos. 11, 14, and 16 were essentially free of oily or greasy contaminants. They consisted of finely divided, tan-colored solid. This substance was very similar in physical appearance to the solid polyurethane degradation product whose composition is presented in Table 11. The infrared spectra of the solids from Specimens 11, 14, 15, and 16 (see Figure 40 for

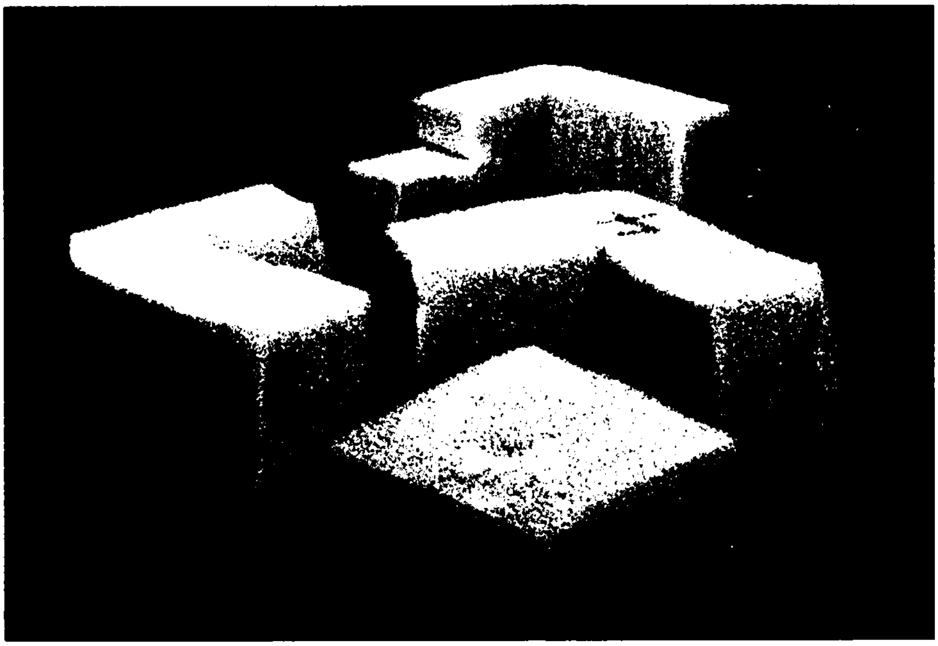


Figure 38. Foam pieces from the wing tank of A/C 78-717 (Specimens Nos. 5-8).

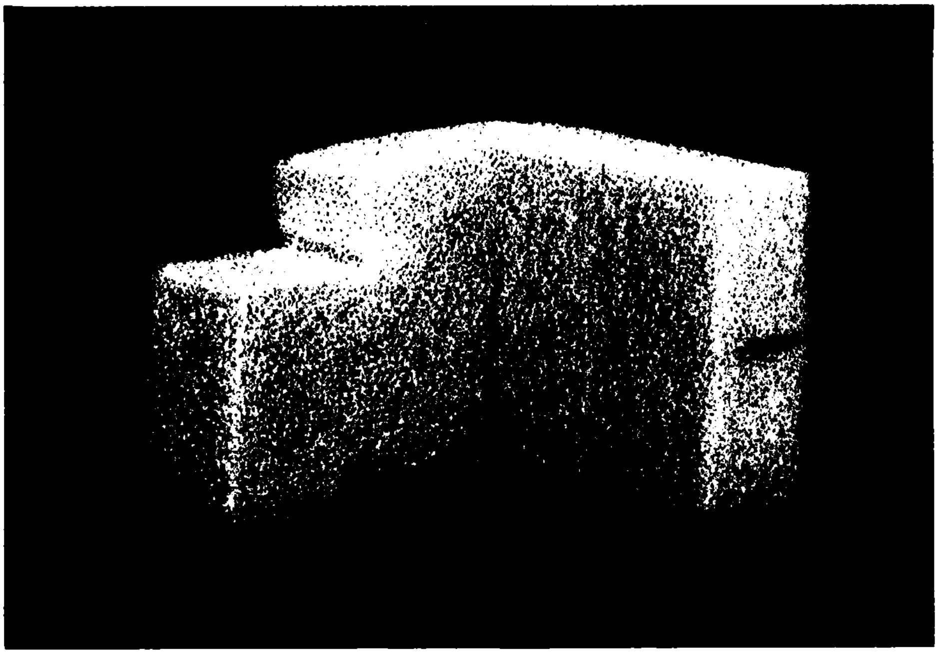


Figure 39. Inside view of foam specimen from the wing tank of A/C 78-717.

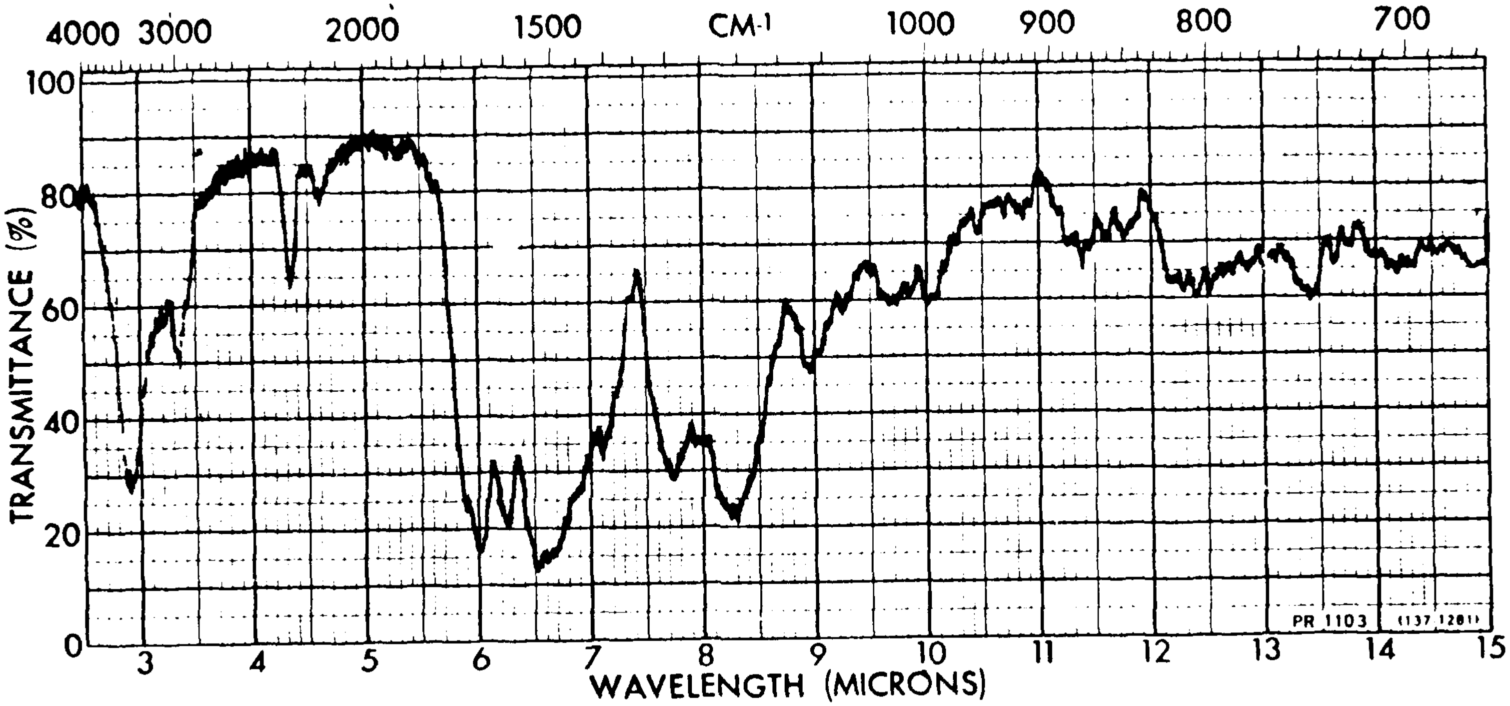


Figure 40. Infrared spectrum of wipings from vent mast of A/C 78-704 (Specimen No. 11; in KBr matrix).

the spectrum of Specimen No. 11) resemble closely that of the solid formed upon degradation of polyurethane foam under controlled conditions (see Figure 26). Specimens 12 and 13 did not yield sufficient quantities of powdered solid for spectroscopic characterization.

It is concluded that the finely divided tan-colored solid substances, recovered as wipings from the fuel vent mast surfaces, are composed of solid thermal degradation products of polyurethane foam.

3.4.4 Emission Spectrographic Analysis of Specimens from Aircraft Incident Sites

In search for metallic contaminants, that could be of assistance in tracing the incident scenarios, emission spectrographic analyses were performed on the following specimens:

1. Polyurethane foam from vent tank of A/C 78-717. Two samples were taken. One from the surface with the white deposit (see Figure 33); the other sample was taken as reference approximately one inch below the surface.

2. Filter paper used for collection of particulate solids from Specimen 14 (wipings from the vent mast of A/C 78-717).

3. Filter paper used for collection of particulate solids from Specimen 16 (wipings from dome of the right side vent tank, A/C 78-717).

An unused filter paper served as the blank sample for the latter two specimens. The emission spectrographic analyses were performed by Bowser-Morner Testing Laboratories, Inc. The report is included as Appendix 6.

The analyses of the foam revealed the presence of potassium, sodium, aluminum, iron, silicon, and lead as major contaminants. Relatively smaller amounts of calcium, magnesium, manganese, and titanium were also detected. See Appendix 2 for analytical data on the metals, and Appendix 3 for data on gun gases.

No significant quantities of metallic contaminants were detected in the wipings from the fuel vent systems.

3.4.5 Surface Analysis of Foam Specimen from Aircraft No. 78-717 Fuel Vent Tank

After detection of metallic contaminants in the foam sample recovered from the aircraft at the incident site, efforts were pursued to establish the distribution of the metals in the specimen. Surface analysis techniques were used for this purpose. These analyses were performed at the University of Dayton Research Institute. A copy of the report covering this work is included as Appendix 7.

It was established by scanning electron microscopy (SEM) that the white coating on the foam specimen, to which reference was made earlier (see Figures 28, 33, and 41-44) is composed of an agglomerate of particles approximately 2 μm in diameter.

Energy dispersive X-ray analysis (EDXA) revealed the presence of potassium as the major metallic constituent in the surface deposit. It was established by X-ray photoelectron spectroscopy that carbonate is the prevalent anionic species in the surface deposit.

Using the combination of surface analysis techniques, it was thus determined that the white deposit observed on the foam specimen surface (see Figure 33) is potassium carbonate (see Appendix 3). The other detected metals (i.e., aluminum, silicon, iron, and lead; see Appendix 2) constitute less than three percent of deposit composition on the basis of EDXA measurements.

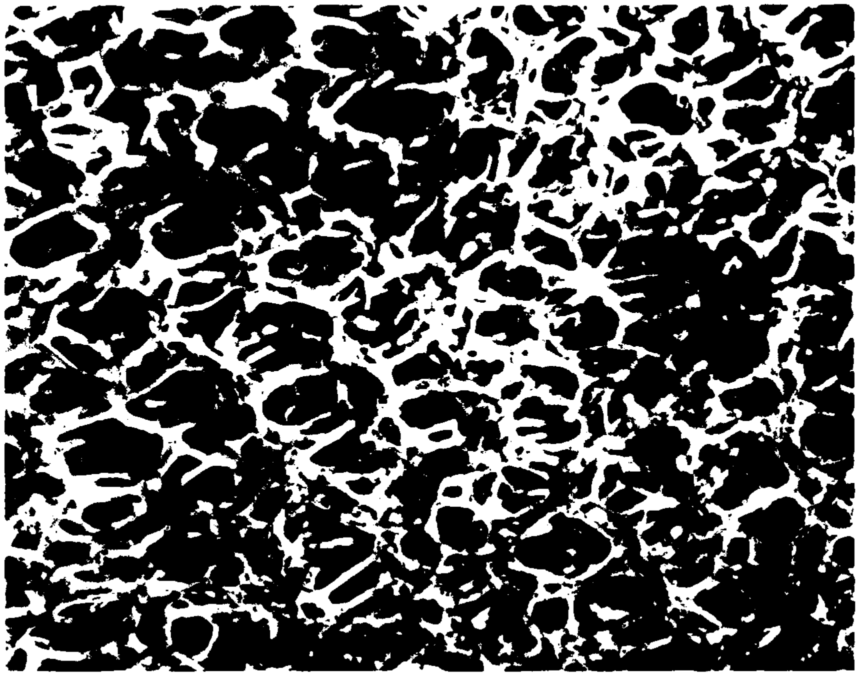


Figure 41. Light microscope photograph of deposit (white areas) on vent tank foam from A/C 78-717 (5OX).

Figure 42. Scanning electron photomicrograph of deposit on vent tank foam from A/C 78-717 (100X).

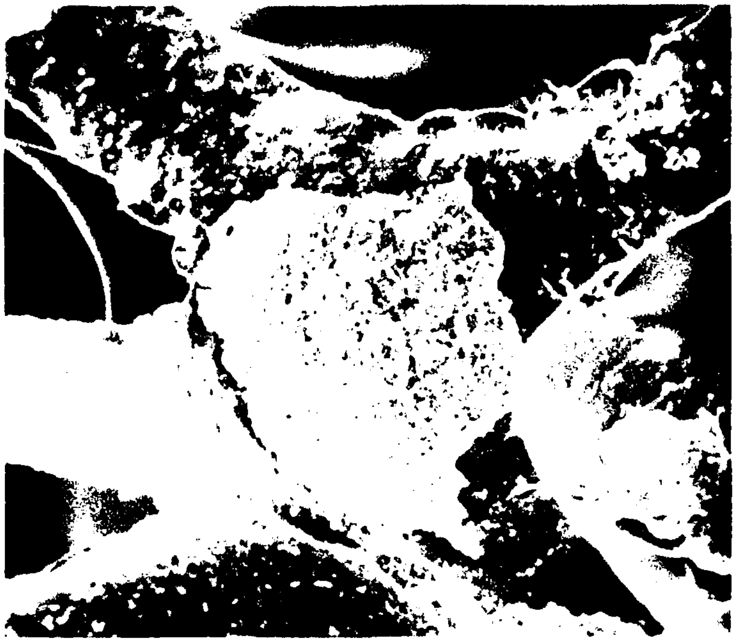


Figure 43. Scanning electron photomicrograph of deposit on vent tank foam from A/C 78-717 (100X).

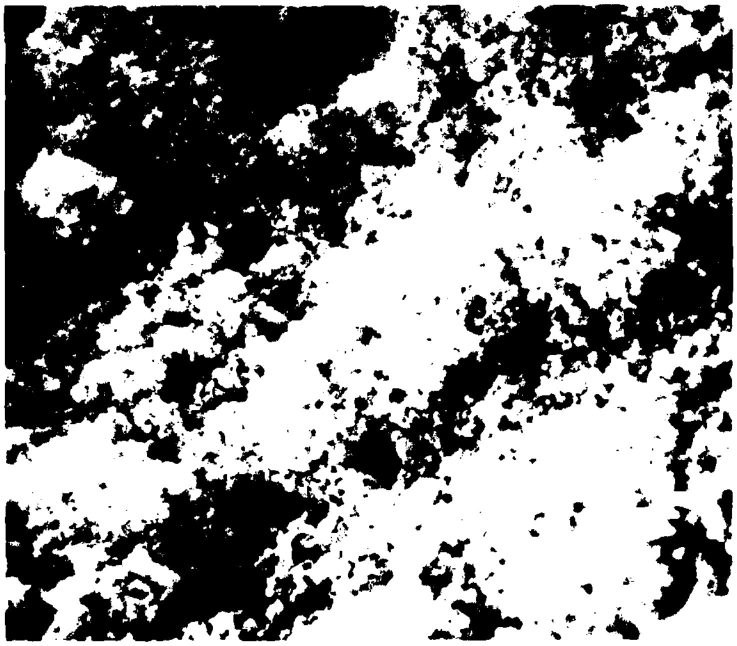


Figure 44. Scanning electron photomicrograph of deposit on vent tank foam from A/C 78-717 (1000X).

4. CONCLUSIONS

It was demonstrated that physical damage caused to reticulated polyurethane foams by different environmental exposures is often indicative of the type of exposure. Characteristics of damage caused by accelerated aging of foams in air and in liquid fuel (JP-5), simulated sunlight exposure, hot wire cutting, hot air impingement, flame impingement, and sustained burning were established and documented photographically. They are summarized in Table 11.

Flash fire experiments with foam samples in a flame tube served to simulate fire propagation in fuel vent systems. Combinations of damage effects (e.g., hot air impingement, brief flame impingement, and sustained burning) could be detected on foam specimens surrounding a vapor cavity. Similarly, exposures to different fire environments were evident in specimens originating from aircraft incidents.

Information about polyurethane foam damage characteristics, caused by controlled exposures, is expected to be useful for aircraft accident and fire investigators in developing incident scenarios.

Light tan solid deposits, collected as wipings from vent mast surfaces of aircraft that had been involved in incidents, were identified as polyurethane foam thermal degradation products.

White deposits on some pieces of damaged fuel vent tank foam were found to contain potassium carbonate. This substance may have originated from gun gases, and deposited onto foam surface during diving maneuvers.

REFERENCES

1. T. O. Reed and W. D. Vahle, "Qualification Test Results for Scott Paper Co. Blue Hybrid Polyether Foam," Aeronautical Systems Division Technical Memorandum ENFEF-TM-79-08, December 1979.

2. B. H. Wilt and J. M. Swieshelm, "Hydrolytic Stability of Reticulated Foams," University of Dayton Research Institute Report UDR-TR-81-74, August 1981.

3. D. Kelley, Scott Paper Company, telephone communication to L. Parts, 7 February 1983.

4. Sunlighter IV test chamber had been manufactured by Test-Lab Apparatus Company, Amherst, New Hampshire.

5. L. Parts and R. G. Olt, "High Temperatre (1649°C, 3000°F) Surface Ignition Test Apparatus for Fluids," AFWAL-TR-82-2110, November 1982.

6. T. A. Hogan and C. Pedriani, "Flame Tube and Ballistic Evaluation of Explosafe Aluminum Foil for Aircraft Fuel Tank Explosion Protection," AFWAL-TR-80-2031, April 1980.

7. H. W. G. Wyeth and T. W. Dickson, "Environmental Tests of Reticulated Plastics Foam for Use in Aircraft Fuel Tanks," Royal Aircraft Establishment Report 71194, September 1971.

8. B. H. Wilt, University of Dayton Research Institute, communication to L. Parts, June 1983.

9. Anon., "Fire Hazard Properties of Flammable Liquids, Gases, Volatile Solids," NFPA Publication 325M, National Fire Protection Association, Boston, 1977, p. 163.

10. Q. C. Malmberg, "Integrated Aircraft Fuel Tank Fire and Explosion Protection Systems. Phases I and II," AFAPL-TR-75-93, July 1975.

APPENDIX 1

PHOTOGRAPHIC DOCUMENTATION OF TEST SPECIMENS

A1.1. INTRODUCTION

Appendix 1 of this report contains most of the photographic documentation relevant to the discussion in the preceding text. The photographs depict damage caused to polyurethane foam specimens by aging, simulated sunlight exposure, heat, and fire. The foams in the incident simulation experiments were those used by Air Force as void-filling and flame propagation inhibiting materials in aircraft fuel systems.

The photographs are presented in nine sections of this appendix. The sequence and numbering are identical with those used in the text.

In the beginning of each section is a table. Information pertaining to exposure conditions for all experiments of a specific type is summarized in that table. It serves as reader's guide for that section. To communicate information concisely, sample identifications and exposure conditions are often presented in captions by means of a three-number code system, X-Y-Z.

The first number, X, designates the test type as follows:

1 - flash fire
2 - hot wire cutting
3 - brief flame impingement
4 - sustained burning
5 - hot air impingement
6 - radiant heat exposure
7 - accelerated aging in simulated sunlight
8 - accelerated aging in air
9 - accelerated aging in jet fuel

The second number, Y, in conjuncton with the first, designates a group of tests performed under identical, specified conditions (e.g., exposure duration, temperature, cutting rate, site of ignition, etc.). It may involve several foams. However, test conditions remained identical for all samples carrying the same first two numbers.

The third number, Z, was used for sequential identification of samples. In some instances (e.g., experiments with aged foam samples), insufficient sample material was available for performing all initially planned tests. In those instances, all sequential numbers do not appear in the tables.

For flash fire experiments, the second number identifies the sample location in the flame tube (see Figures A1-142 and A1-143 in this appendix). The third code number (Z) identifies the sequential test number.

It is suggested that the readers familiarize themselves with the meaning of the second number of the sample code system before viewing photographs in a section. That information is presented in column headings in the tables. Thus, the figure captions will often provide information regarding the exposure history of samples in shorthand form.

Magnified views of the structures of the three foams used in present work are shown in the following three figures.

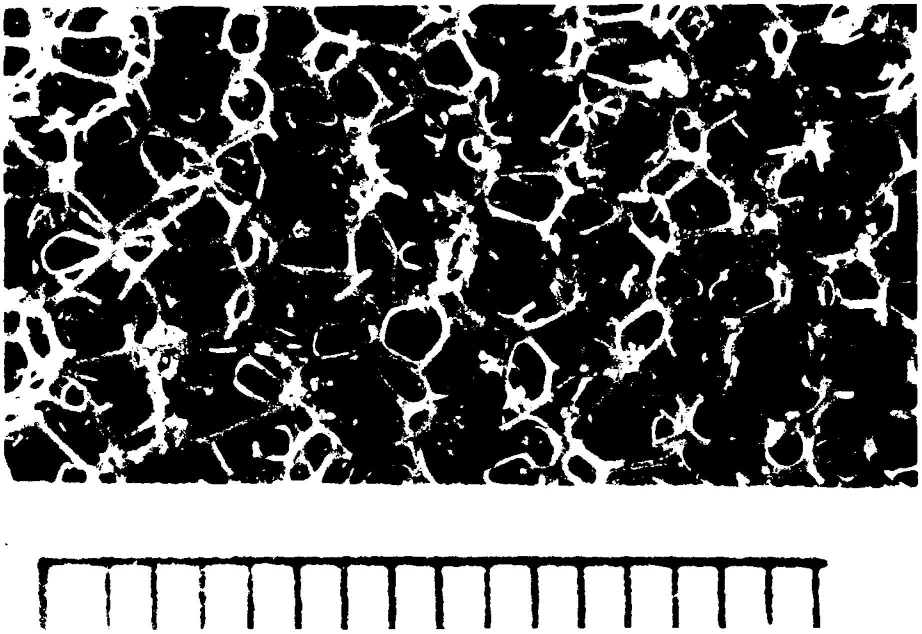


Figure A1-1. Magnified view of the Type IV blue foam structure. (Each scale subdivision is 1/16 in. long.)

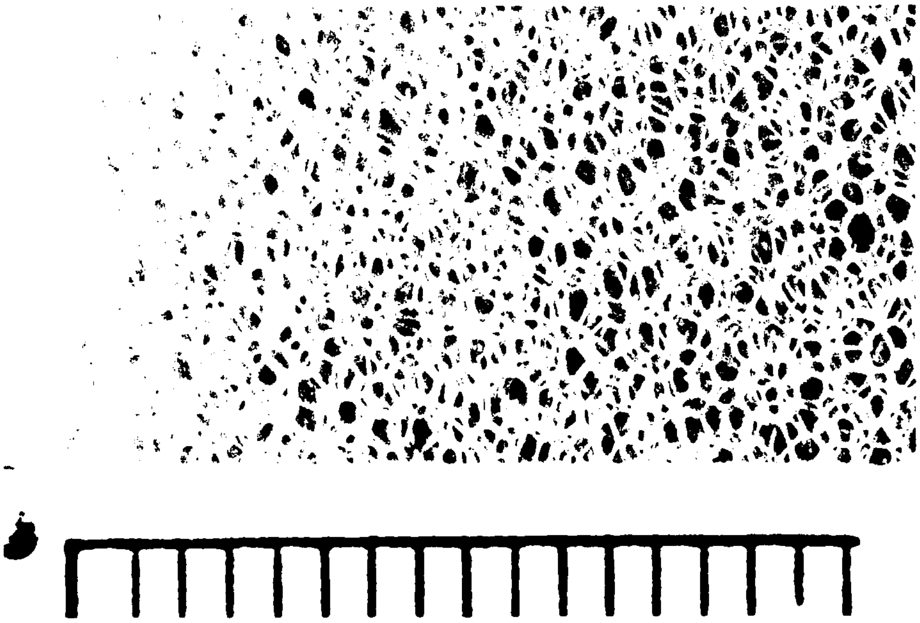


Figure A1-2. Magnified view of the red foam structure. (Each scale subdivision is 1/16 in. long.)

Figure A1-3. Magnified view of the yellow foam structure.
(Each scale subdivision is 1/16 in. long.)

A1.2. FIGURES DEPICTING FOAM SAMPLES FROM ACCELERATED AGING TESTS IN AIR

The exposure history of foam samples, used for aging tests in air, is summarized in Table A1-1.

TABLE A1-1. CODE FOR FOAM SPECIMENS PRODUCED BY ACCELERATED AGING IN AIR[a]

Foam	Sample size, in.	Exposure time, weeks 1	2	3	4	5
Blue, dry, new	3x3x2	8-1-1	8-2-1	8-3-1	8-4-1	8-5-1
	3x3x2	8-1-2	8-2-2	8-3-2	8-4-2	8-5-2
	3x3x2	8-1-3	8-2-3	8-3-3	8-4-3	8-5-3
	3x3x2	8-1-4	8-2-4	8-3-4	8-4-4	8-5-4
Red, dry, new	3x3x2	8-1-5	8-2-5	8-3-5	8-4-5	8-5-5
	3x3x2	8-1-6	8-2-6	8-3-6	8-4-6	8-5-6
Yellow, dry, new	3x3x2	8-1-7	8-2-7	8-3-7	8-4-7	8-5-7
	3x3x2	8-1-8	8-2-8	8-3-8	8-4-8	8-5-8

---

[a] Samples were exposed to air at 200°F (93°C) and 95% relative humidity in these accelerated aging tests.

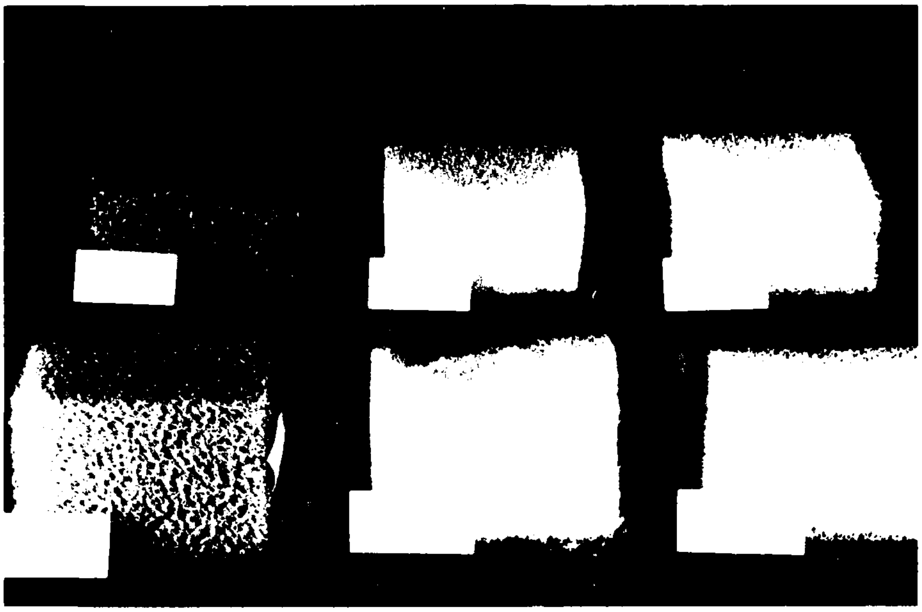


Figure A1-4. Cross-sectional views of blue, red, and yellow foam specimens, subjected to accelerated aging in air (8-5-1), five weeks; 8-2-5, two weeks; 8-2-7, two weeks).

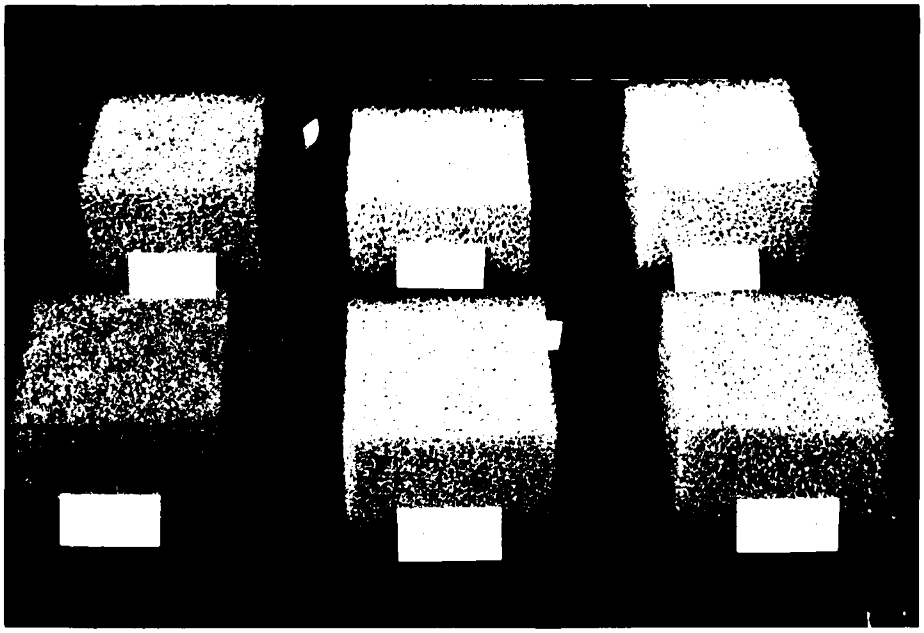


Figure A1-5. Specimens of blue foam, subjected to accelerated aging in air at 200°F (93°C) for one to five weeks. (Reference sample of unexposed foam is also shown.)

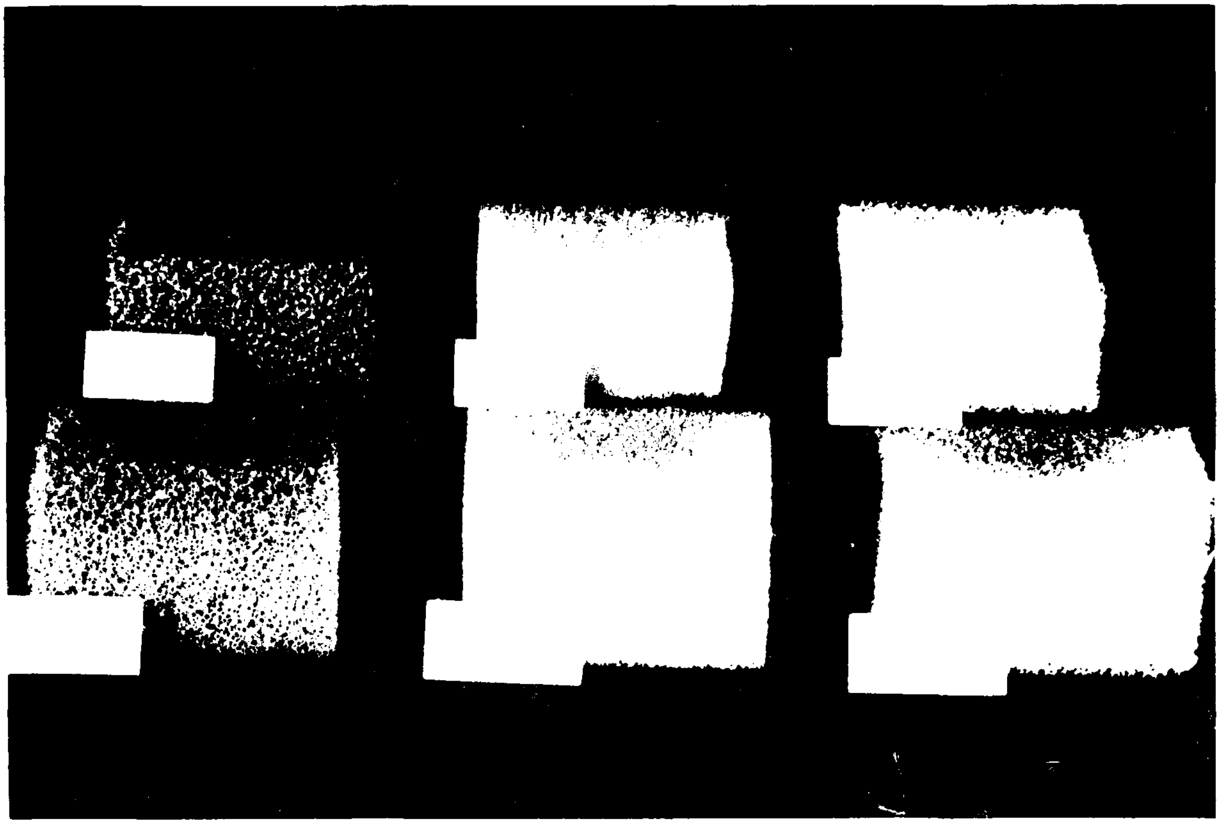


Figure A1-27. Specimen of yellow foam, subjected to accelerated aging in JP-5 at 200°F (93°C) for one to five weeks.

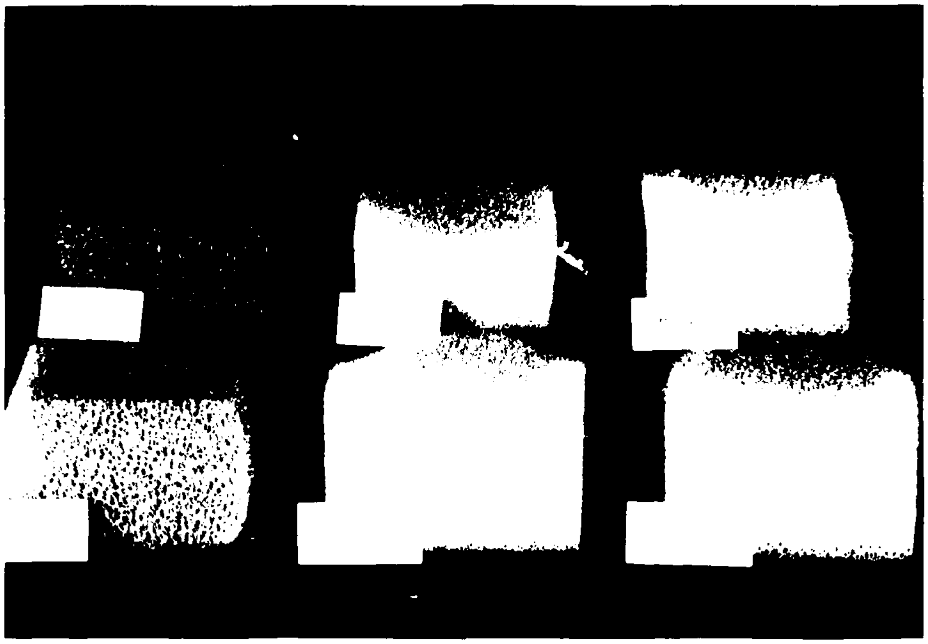


Figure A1-25. Sample 9-5-5, perspective view.

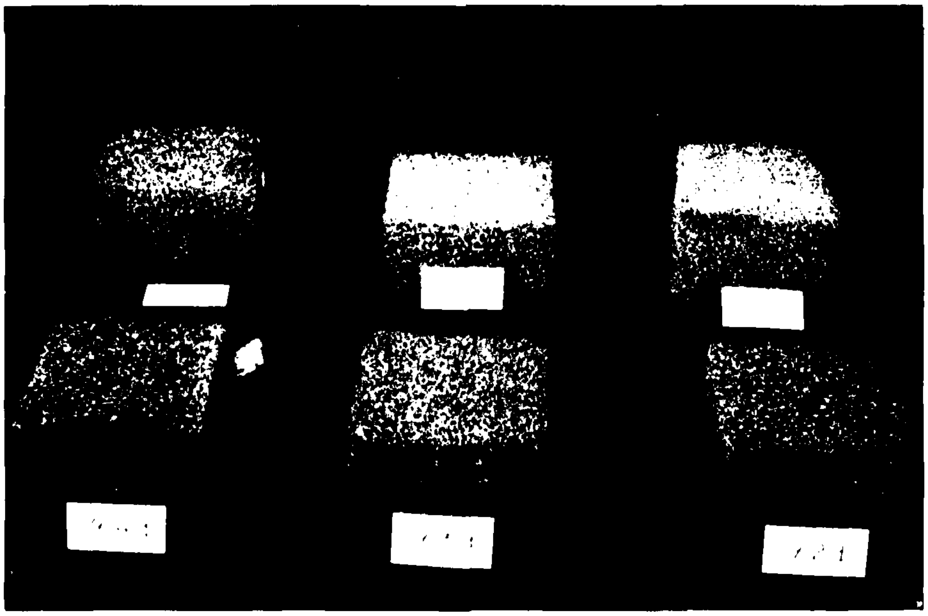


Figure A1-26. Sample 9-5-5, cross-sectional view.

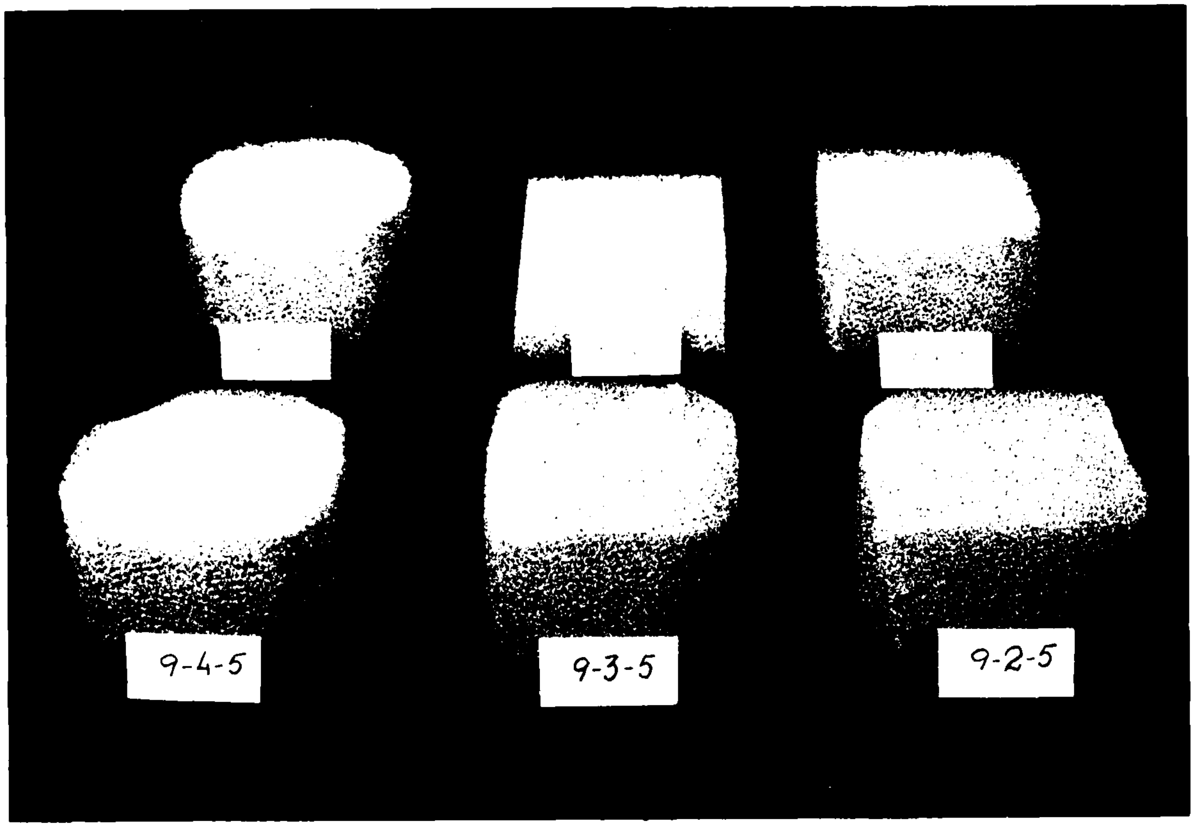


Figure A1-24. Specimens of red foam, subjected to accelerated aging in JP-5 at 200°F (93°C) for one to five weeks.

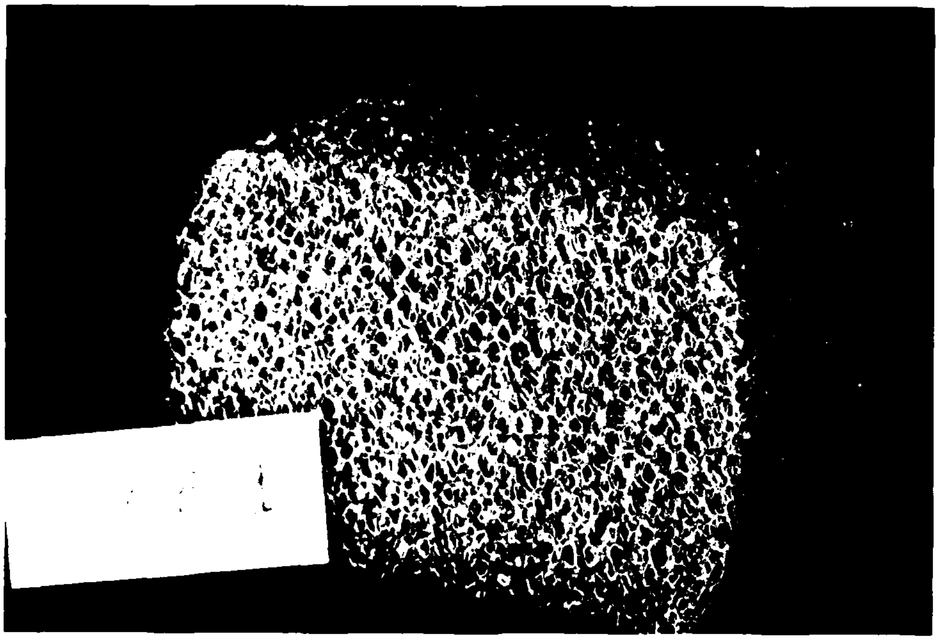


Figure A1-22. Sample 9-5-1, perspective view.

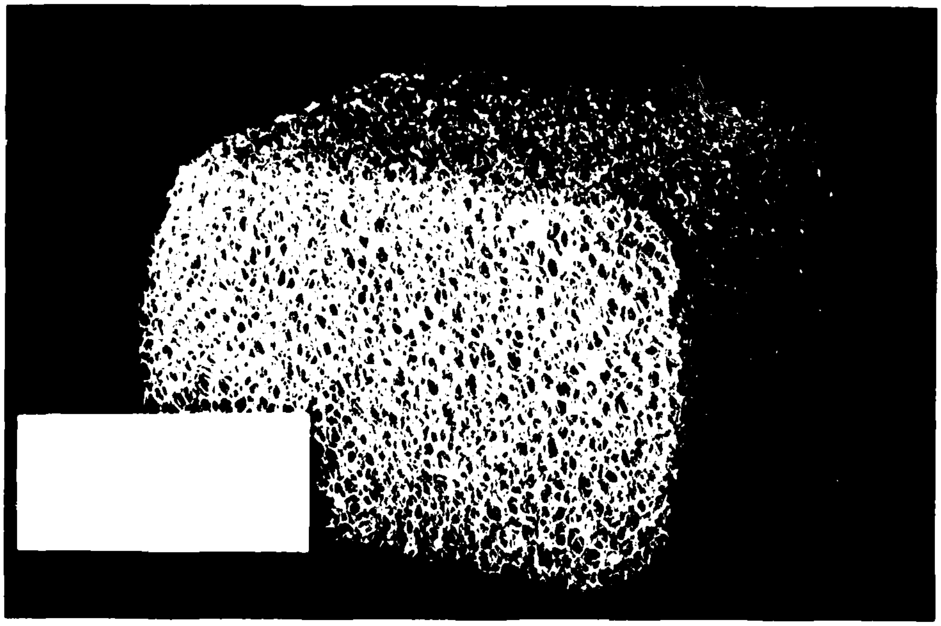


Figure A1-23. Sample 9-5-1, cross-sectional view.

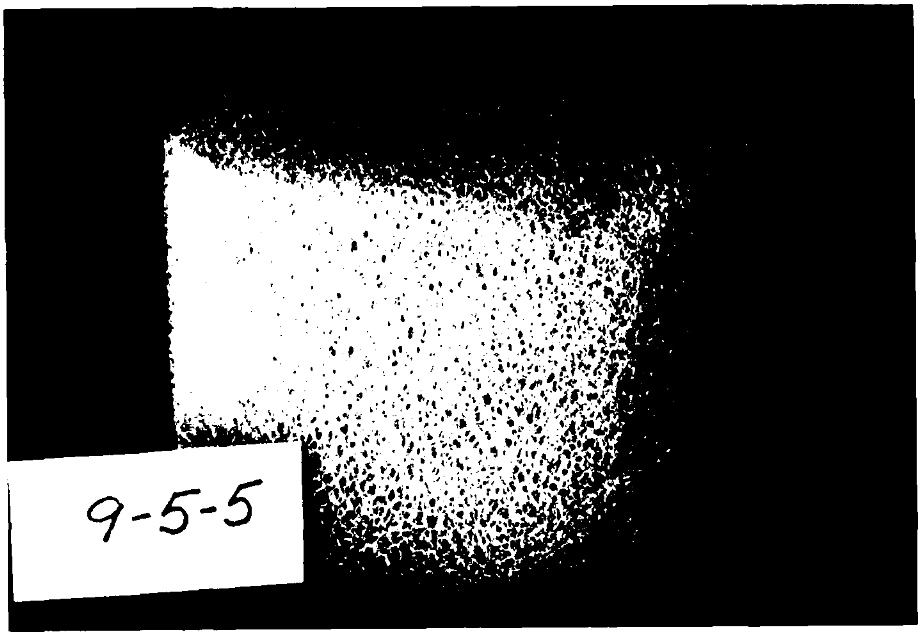


Figure A1-20. Cross-sectional view of blue, red, and yellow foam specimens, subjected to accelerated aging in JP-5 for five weeks.

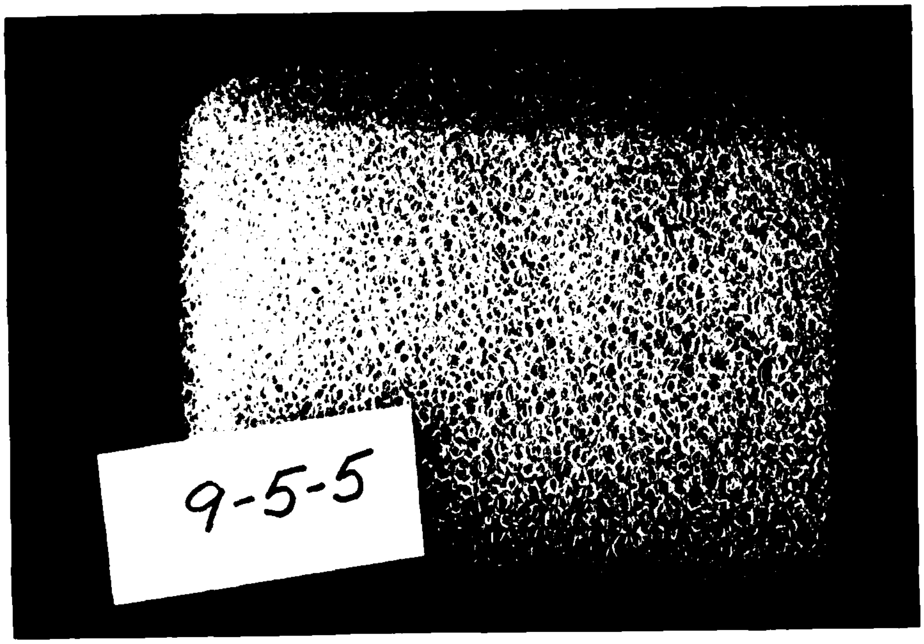


Figure A1-21. Specimens of blue foam, subjected to accelerated aging in JP-5 at 200°F (93°C) for one to five weeks.

A1.3. FIGURES DEPICTING FOAM SAMPLES FROM ACCELERATED AGING TESTS IN JP-5

Foam sample identifications, from aging test in JP-5, are listed in Table A1-2.

TABLE A1-2. CODE FOR FOAM SPECIMENS PRODUCED BY ACCELERATED AGING TESTS IN JP-5[a]

Foam	Sample size, in.	Exposure time, weeks 1	2	3	4	5
Blue, dry, new	3x3x2	9-1-1	9-2-1	9-3-1	9-4-1	9-5-1
	3x3x2	9-1-2	9-2-2	9-3-2	9-4-2	9-5-2
	3x3x2	9-1-3	9-2-3	9-3-3	9-4-3	9-5-3
	3x3x2	9-1-4	9-2-4	9-3-4	9-4-4	9-5-4
Red, dry, new	3x3x2	9-1-5	9-2-5	9-3-5	9-4-5	9-5-5
	3x3x2	9-1-6	9-2-6	9-3-6	9-4-6	9-5-6
Yellow, dry, new	3x3x2	9-1-7	9-2-7	9-3-7	9-4-7	9-5-7
	3x3x2	9-1-8	9-2-8	9-3-8	9-4-8	9-5-8

---

[a] Samples were tested at 200°F (93°C).

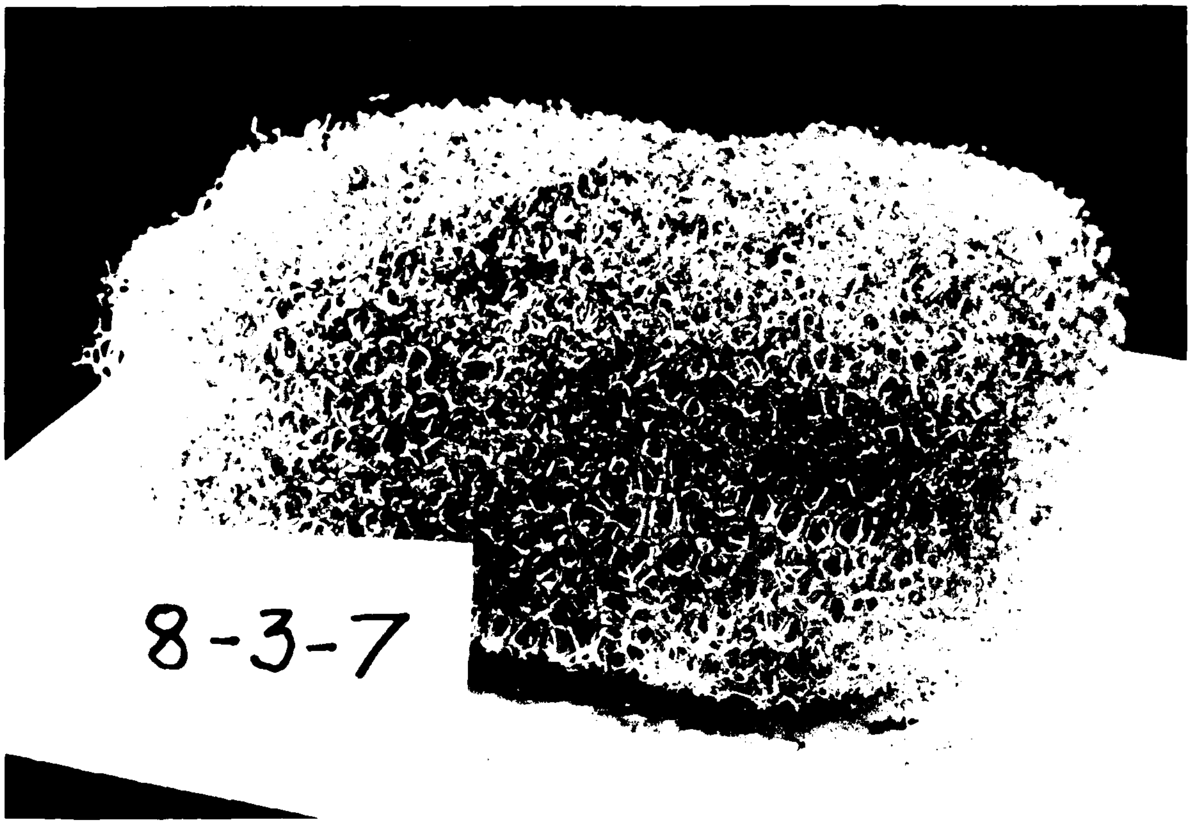


Figure A1-19. Yellow foam specimen 8-3-7, after three weeks of accelerated aging in air at 200°F (93°C).

Figure A1-17. Sample 8-2-7, perspective view.

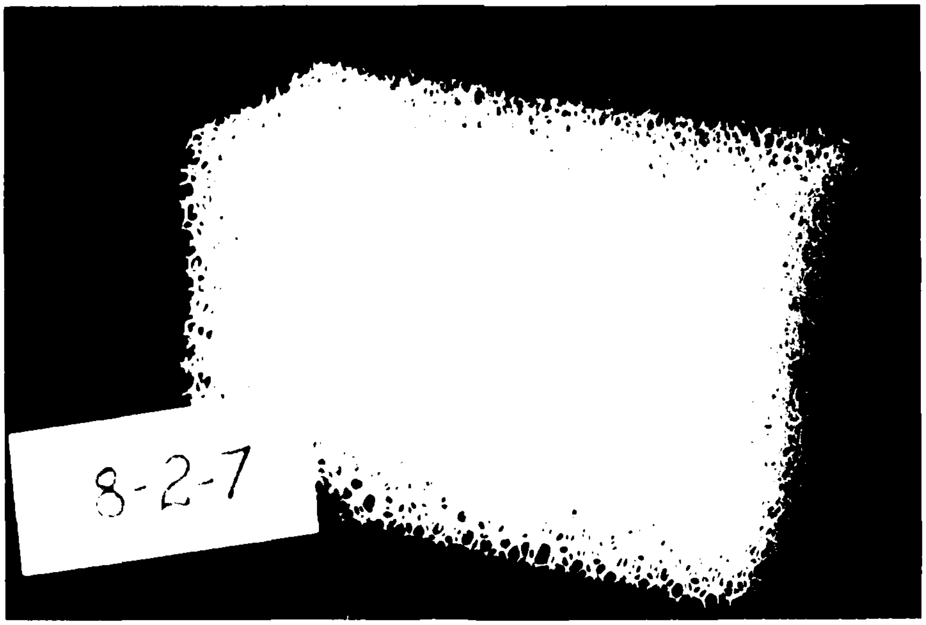


Figure A1-18. Sample 8-2-7, cross-sectional view.

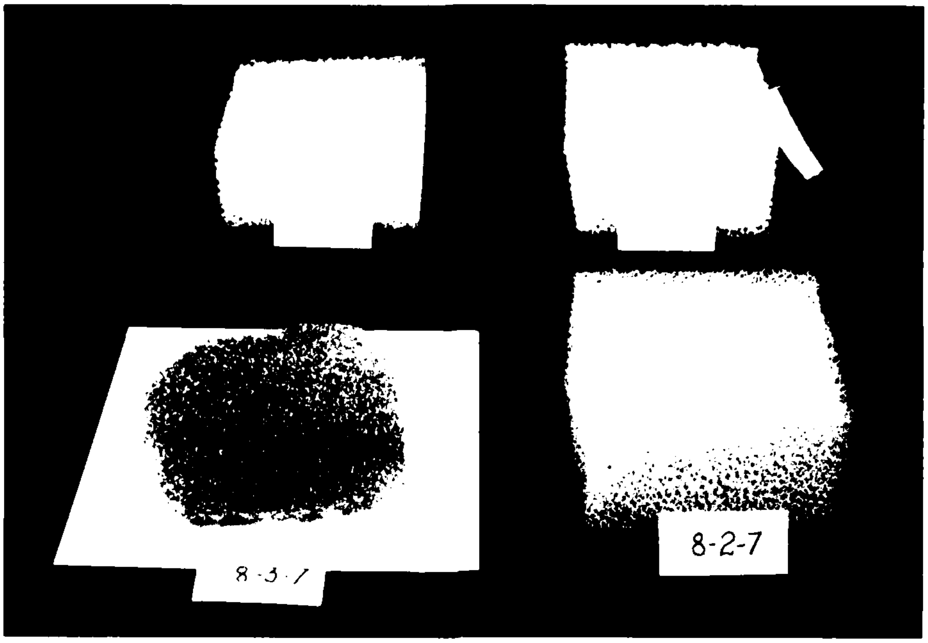


Figure A1-15. Specimens of yellow foam, subjected to accelerated aging in air at 200°F (93°C) for one to three weeks.

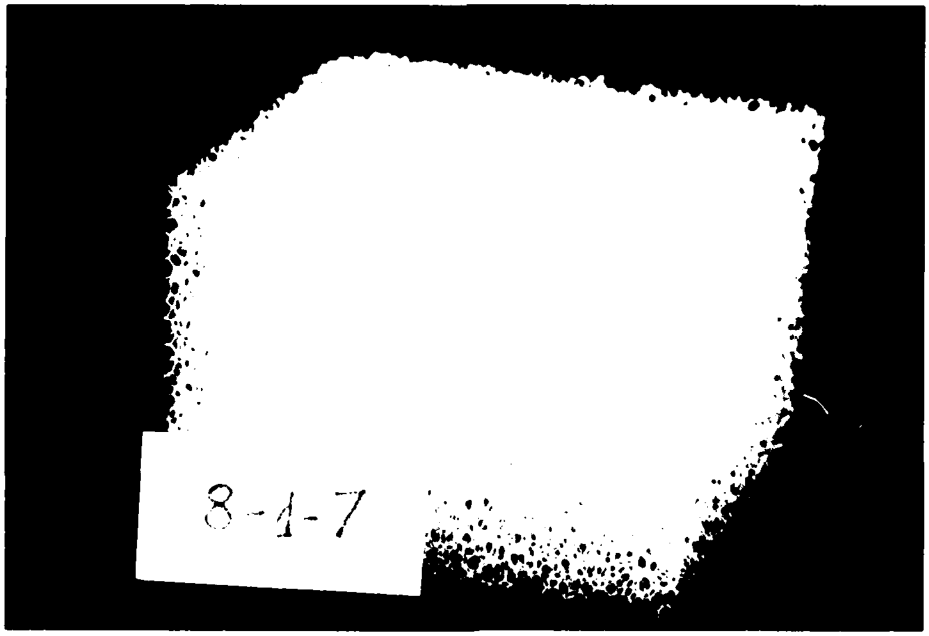


Figure A1-16. Sample 8-1-7, perspective view.

Figure A1-14. Red foam specimen 8-3-5, after three weeks of accelerated aging in air at 200°F (93°C).

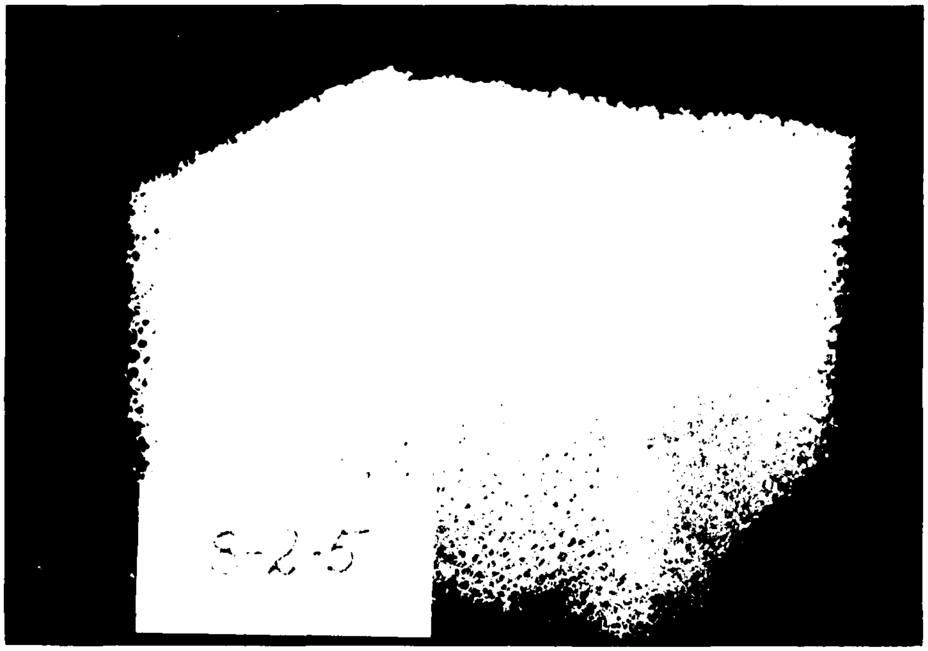


Figure A1-12. Sample 8-2-5, perspective view.

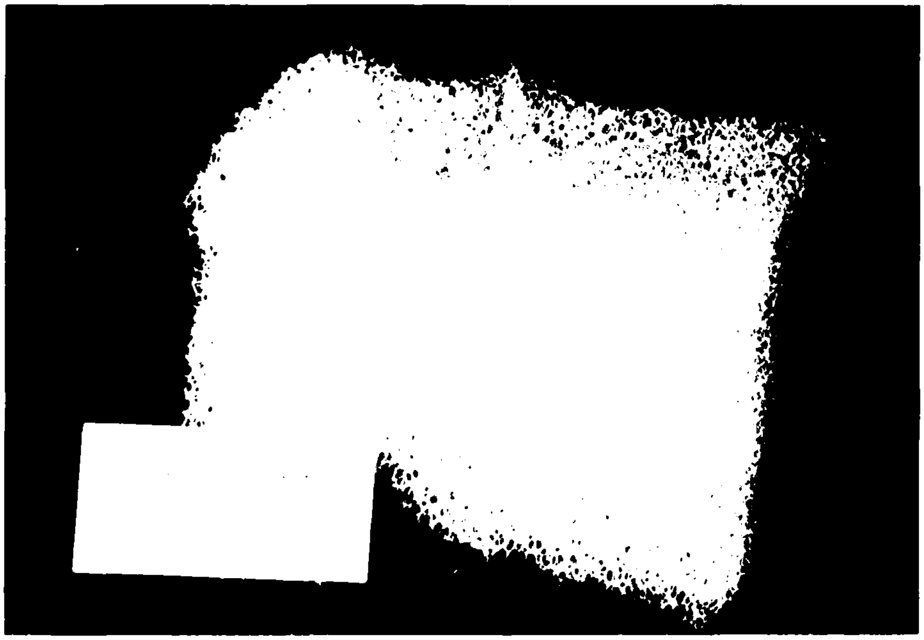


Figure A1-13. Sample 8-2-5, cross-sectional view.

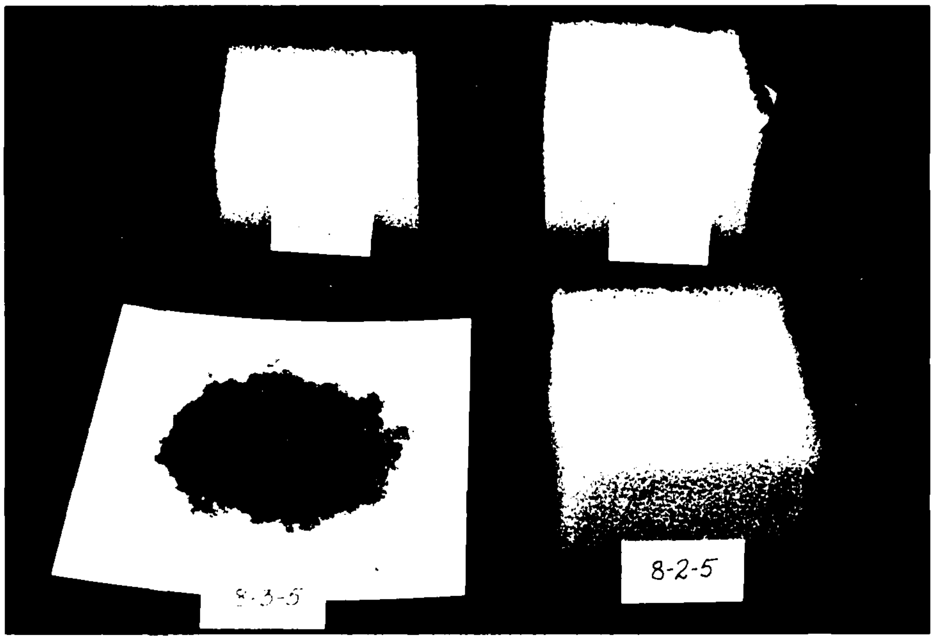


Figure A1-10. Specimens of red foam, subjected to accelerated aging in air at 200°F (93°C) for one to three weeks.

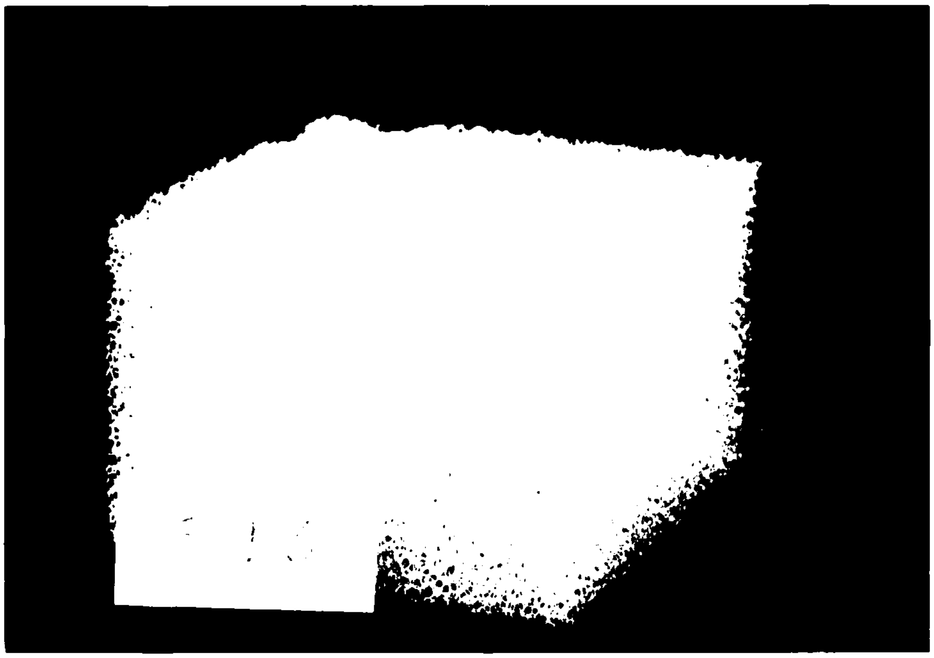


Figure A1-11. Sample 8-1-5, perspective view.

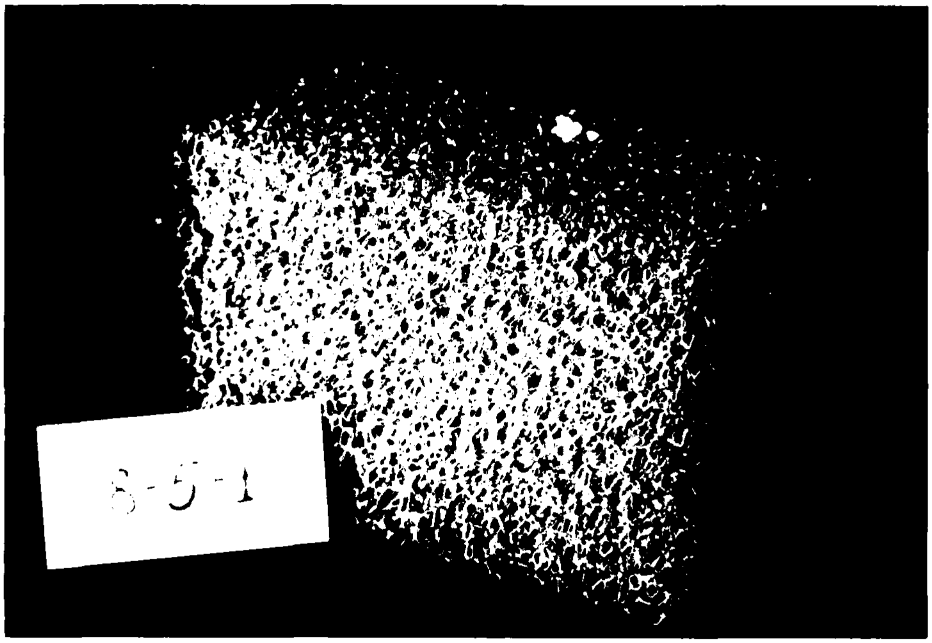


Figure A1-8. Sample 8-5-1, perspective view.

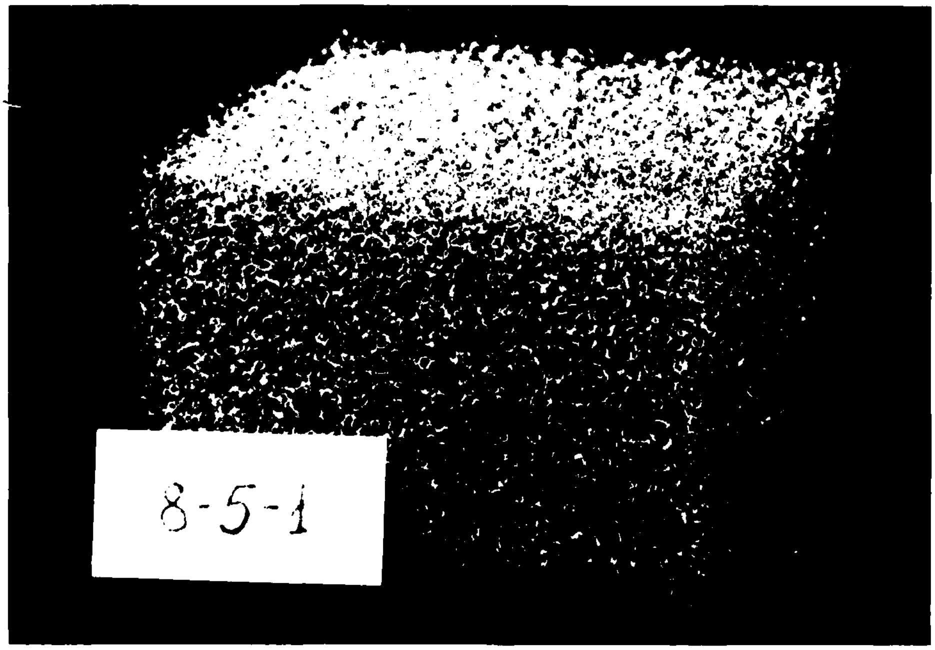


Figure A1-9. Sample 8-5-1, cross-sectional view.

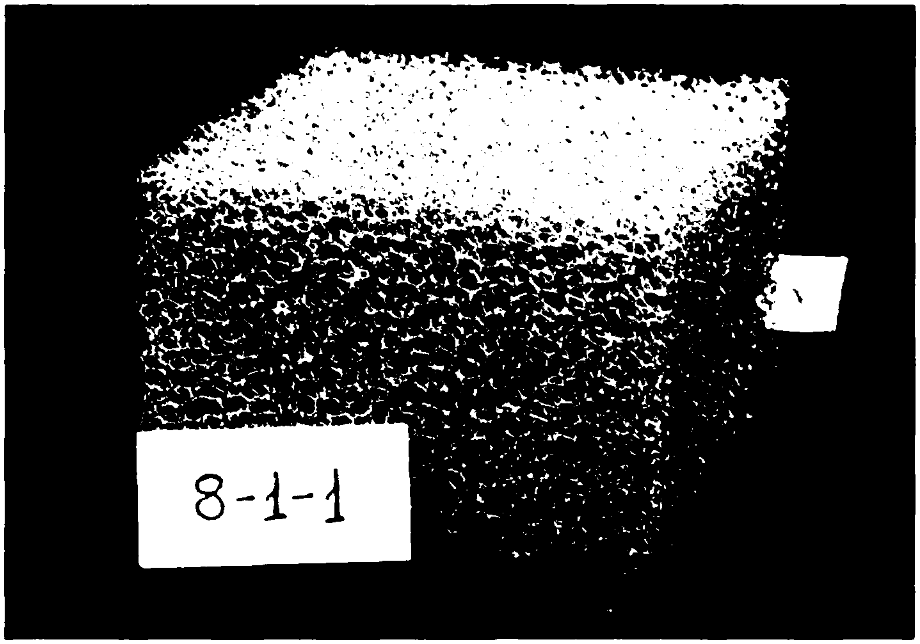


Figure A1-6. Sample 8-1-1, perspective view.

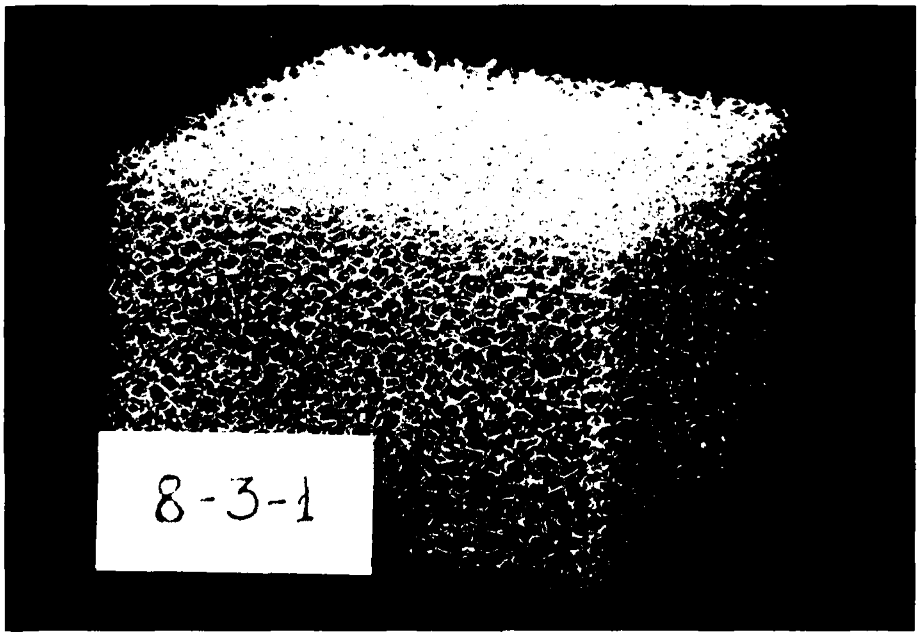


Figure A1-7. Sample 8-3-1, perspective view.

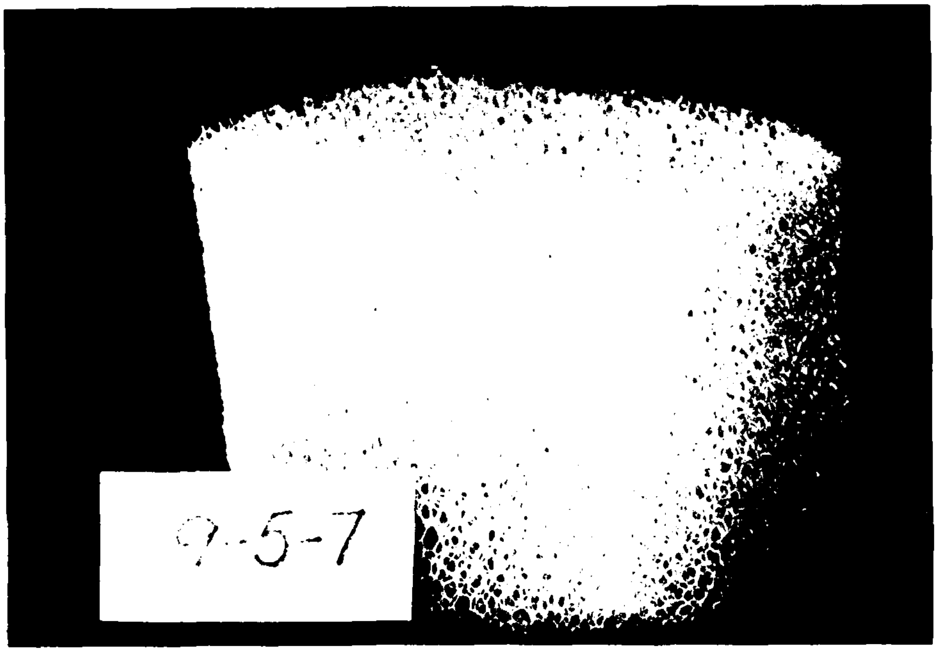


Figure A1-28. Sample 9-5-7, perspective view.

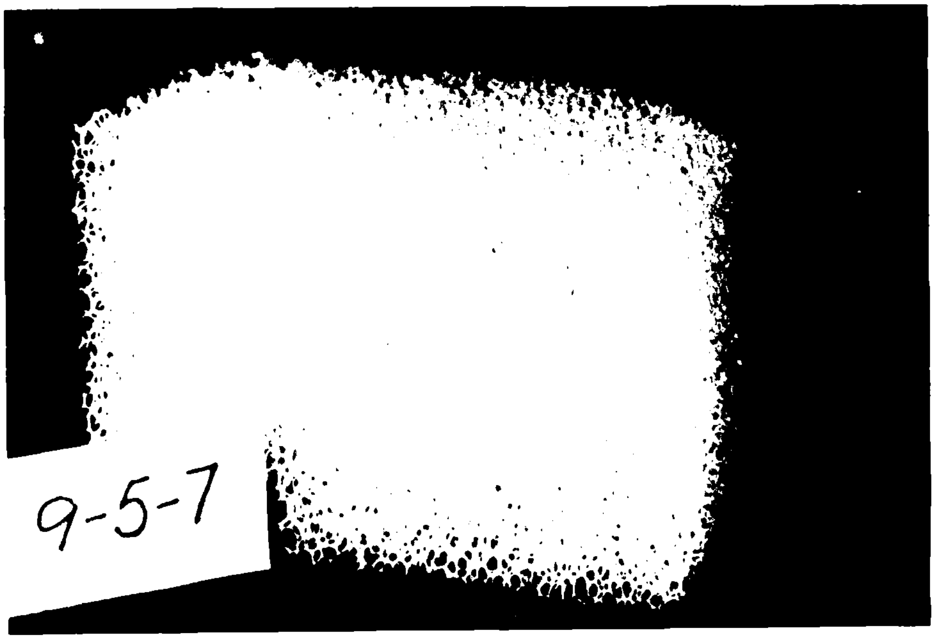


Figure A1-29. Sample 9-5-7, cross-sectional view.

A1.4. FIGURES DEPICTING FOAM SAMPLES FROM SIMULATED SUNLIGHT EXPOSURE TEST

Identifications of samples, subjected to simulated sunlight exposure, are shown in Table A1-3.

TABLE A1-3. CODE FOR SPECIMENS PRODUCED BY SIMULATED SUNLIGHT EXPOSURE OF FOAM

Foam	Sample size, in.	Exposure time, hours 40	80	120	160	200
Blue, dry, new	3x3x2	7-1-1	7-2-1	7-3-1	7-4-1	7-5-1
	3x3x2	7-1-2	7-2-2	7-3-2	7-4-2	7-5-2
	3x3x2	7-1-3	7-2-3	7-3-3	7-4-3	7-5-3
	3x3x2	7-1-4	7-2-4	7-3-4	7-4-4	7-5-4
Red, dry, new	3x3x2	7-1-5	7-2-5	7-3-5	7-4-5	7-5-5
	3x3x2	7-1-6	7-2-6	7-3-6	7-4-6	7-5-6
Yellow, dry, new	3x3x2	7-1-7	7-2-7	7-3-7	7-4-7	7-5-7
	3x3x2	7-1-8	7-2-8	7-3-8	7-4-8	7-5-8

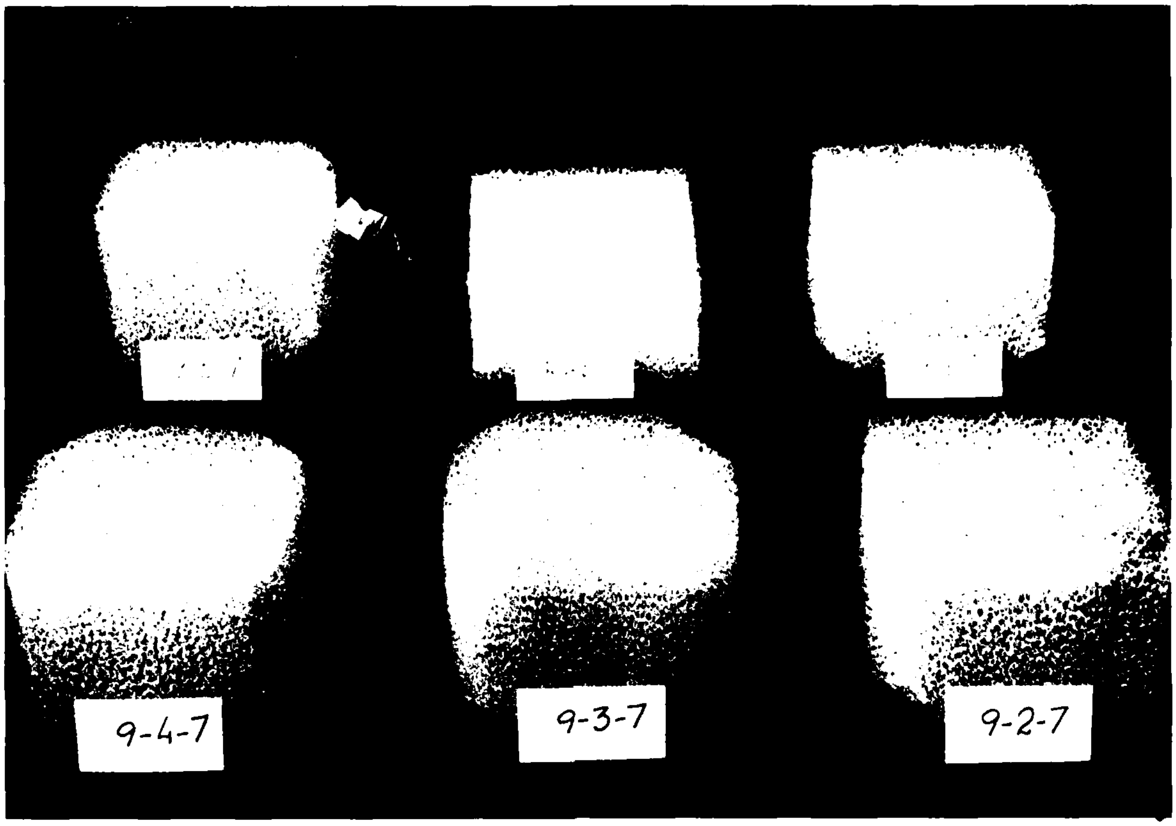


Figure A1-30. Cross-sectional view of blue, red, and yellow foam specimens, subjected to 200 hours of simulated sunlight exposure.

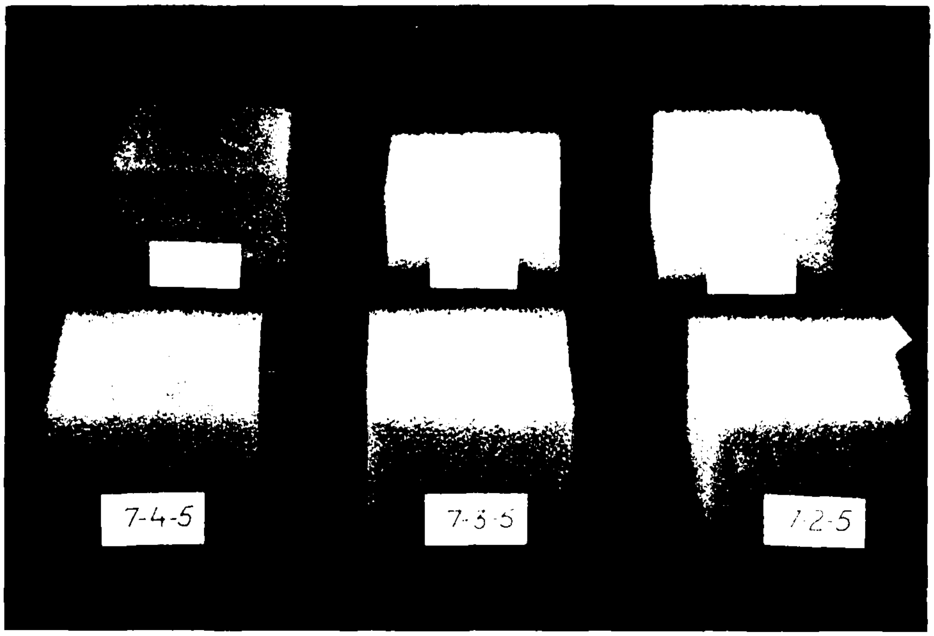


Figure A1-31. Specimens of blue foam, subjected to 40-200 hours of simulated sunlight exposure.

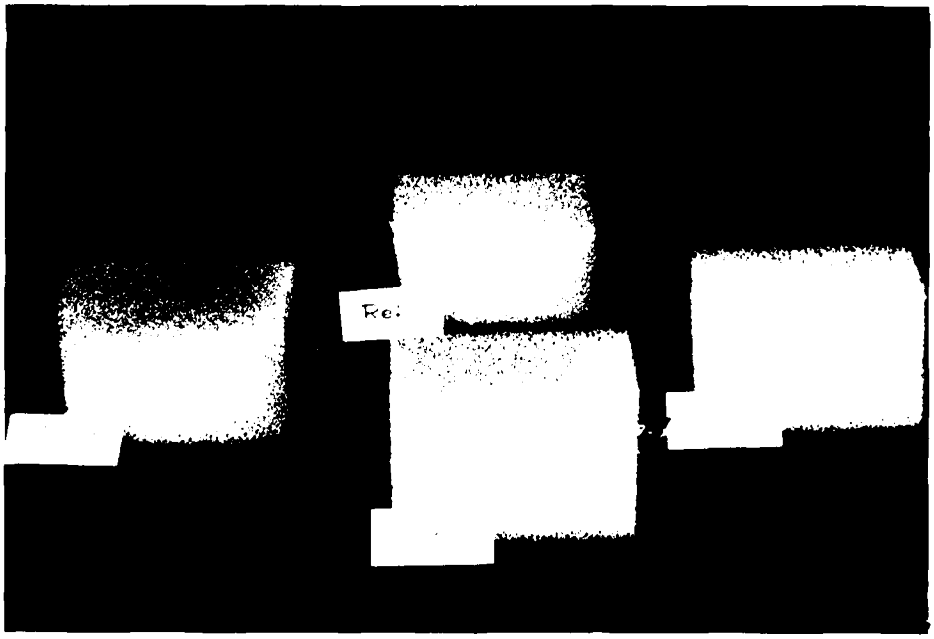


Figure A1-32. Cross-sectional view of blue foam specimens, subjected to 40, 120, and 200 hours of simulated sunlight exposure.

Figure A1-33. Sample 7-1-1, cross-sectional view.

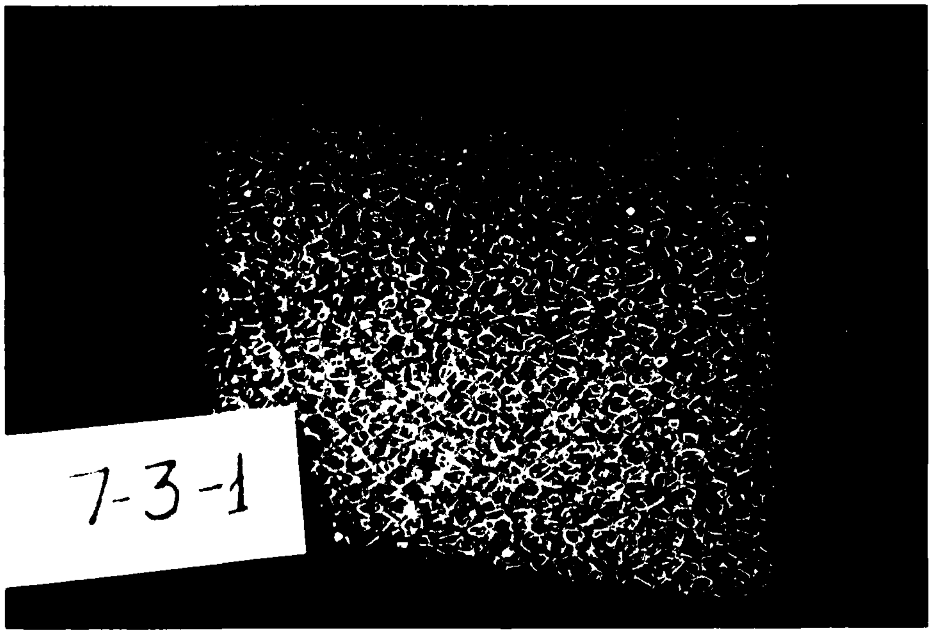


Figure A1-34. Sample 7-3-1, cross-sectional view.

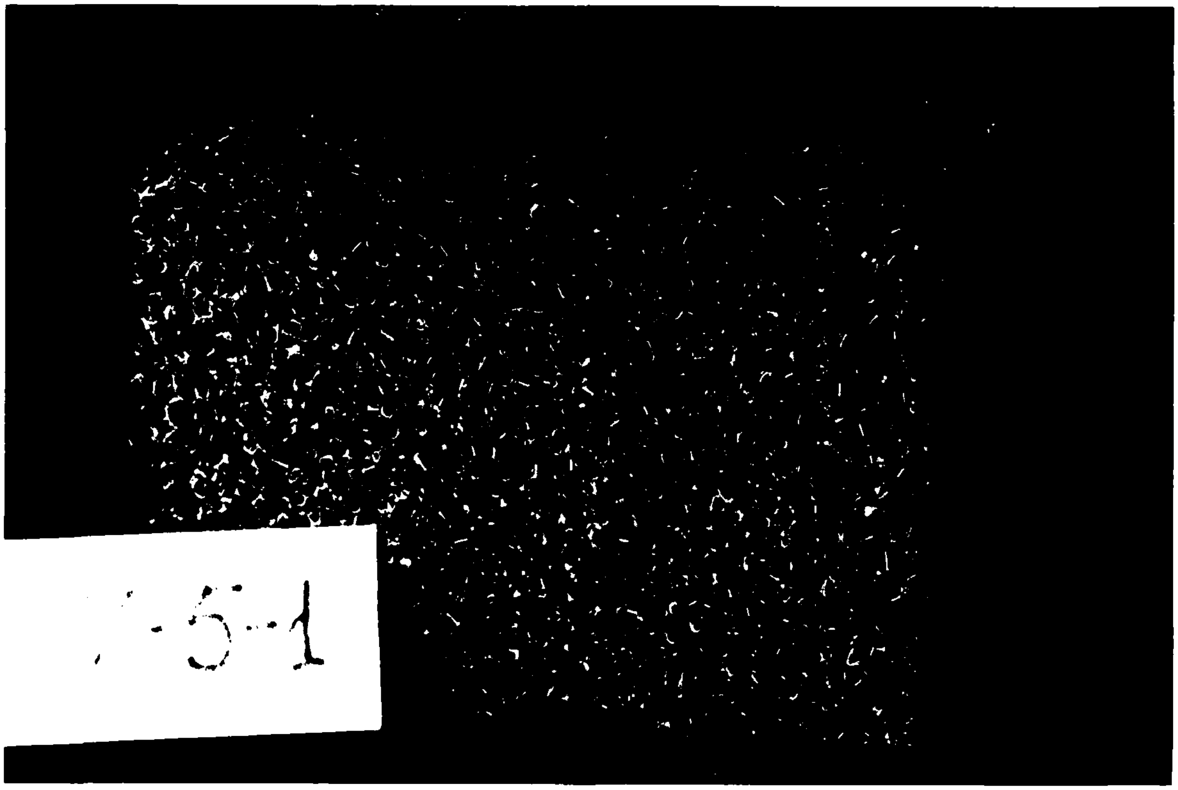


Figure A1-35. Sample 7-5-1, cross-sectional view.

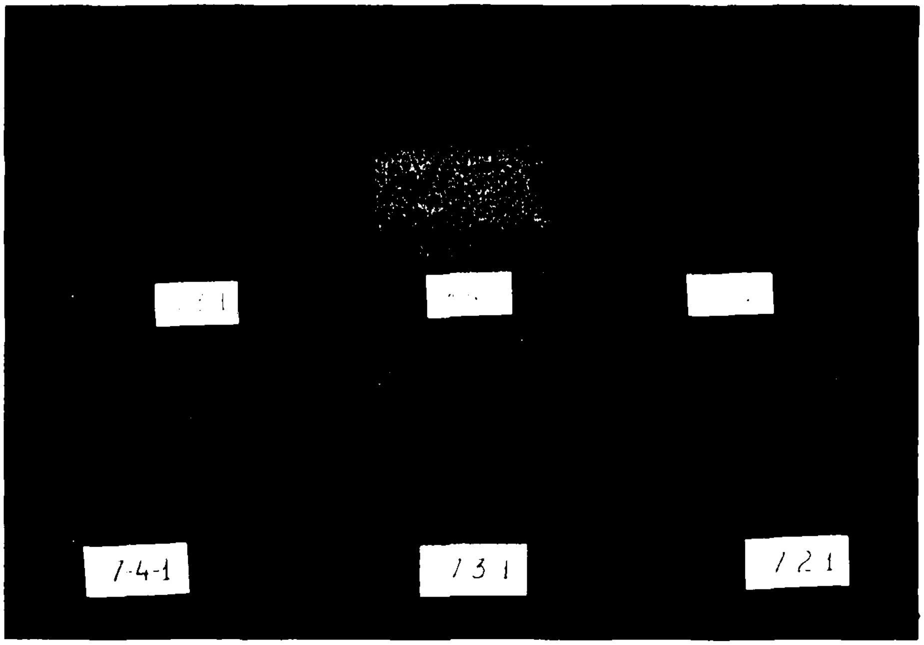


Figure A1-36. Specimens of red foam, subjected to 40-200 hours of simulated sunlight exposure.

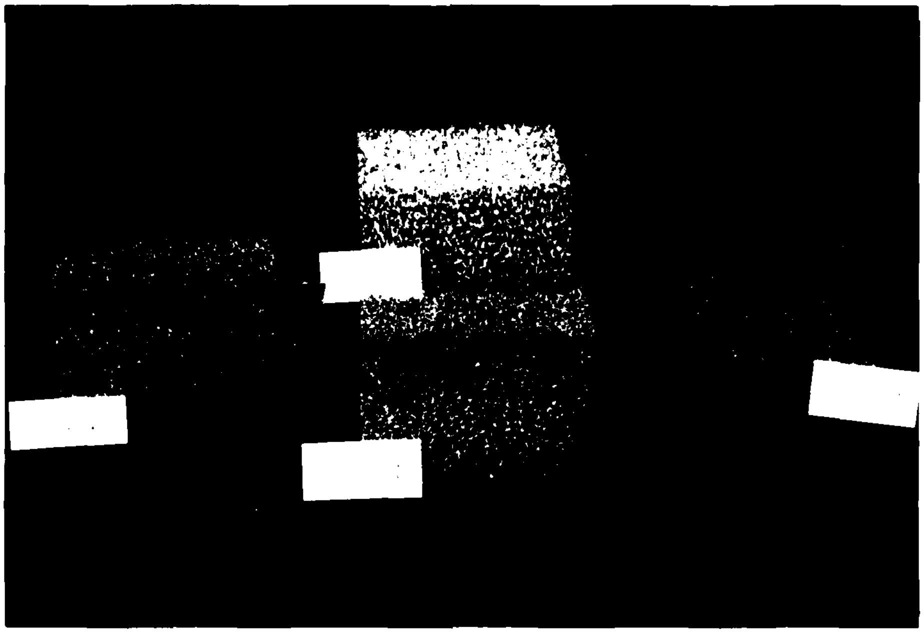


Figure A1-37. Cross-sectional view of red foam specimens, subjected to 40, 120, and 200 hours of simulated sunlight exposure.

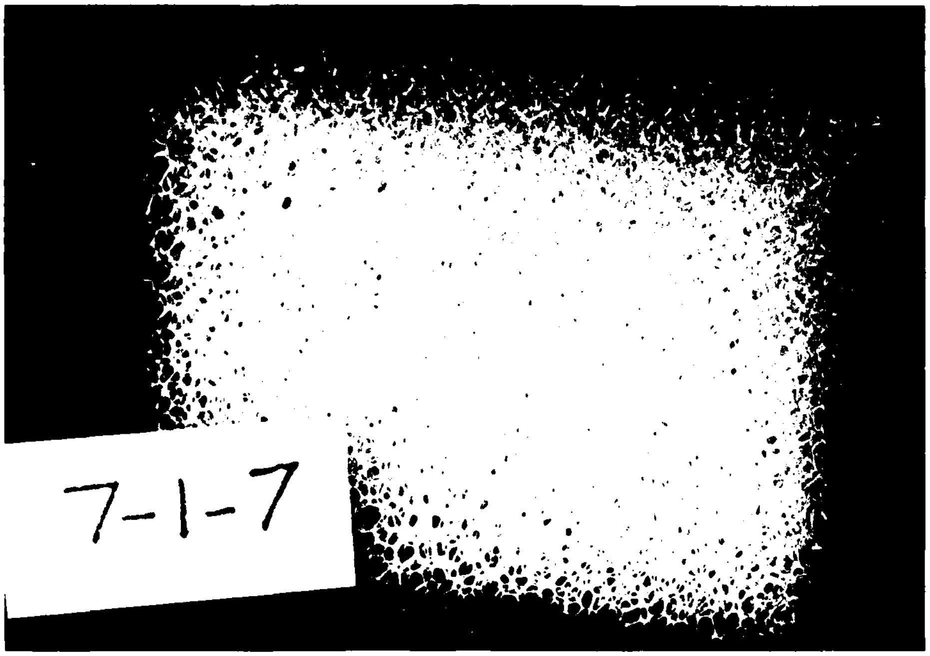


Figure A1-38. Sample 7-1-5, cross-sectional view.

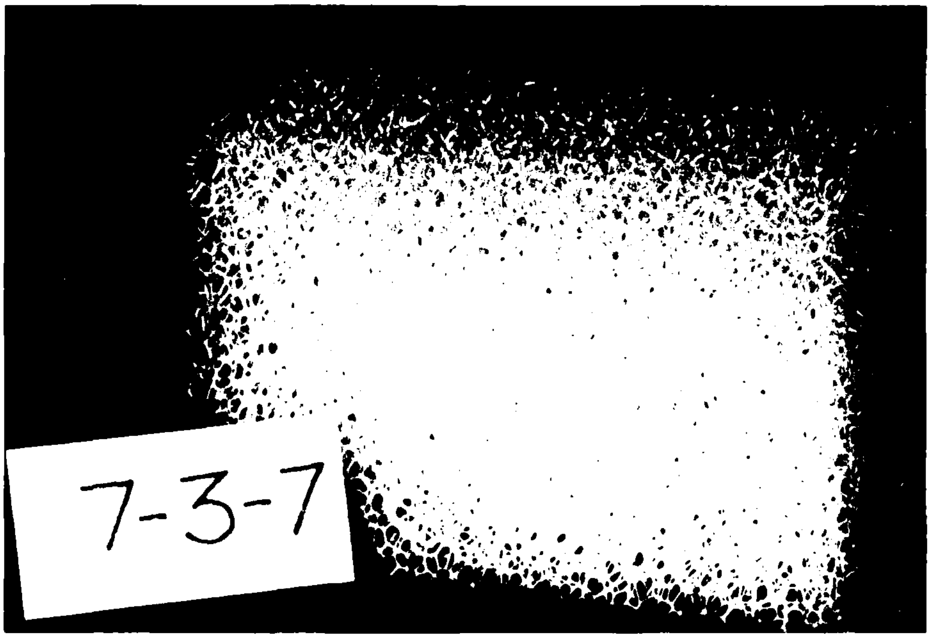


Figure A1-39. Sample 7-3-5, cross-sectional view.

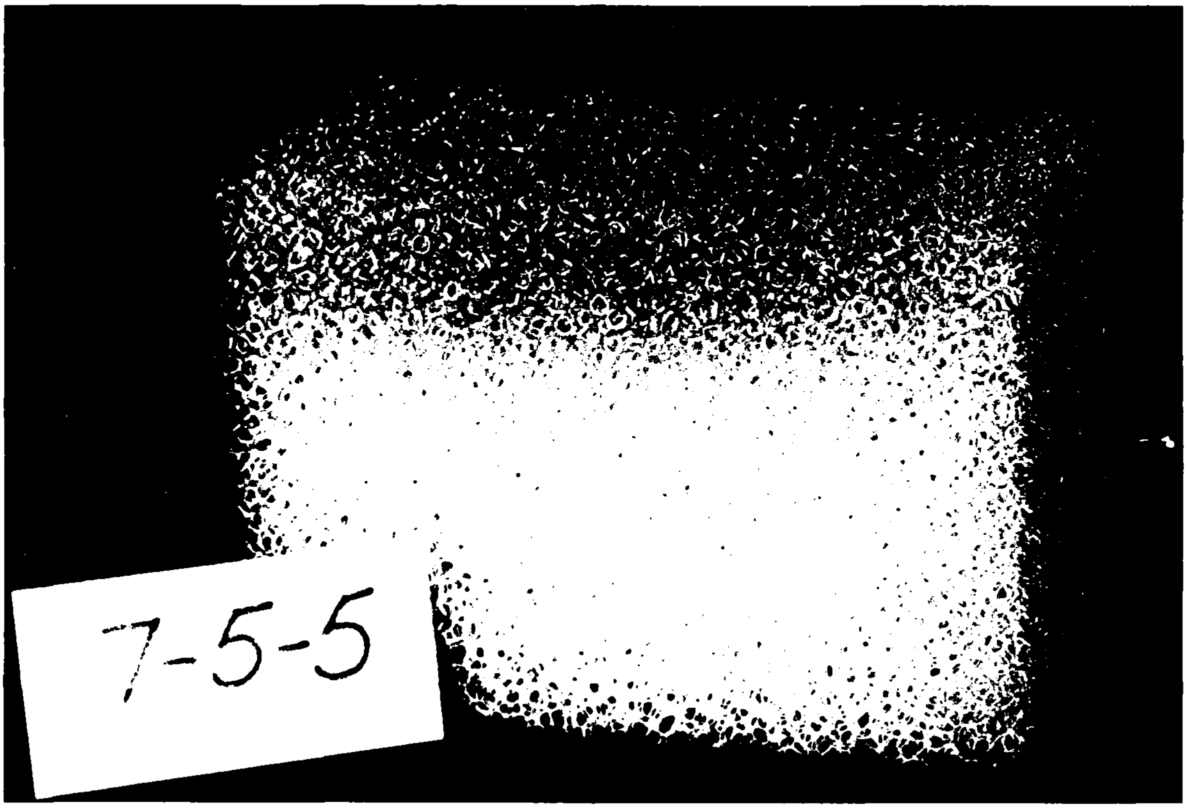


Figure A1-40. Sample 7-5-5, cross-sectional view.

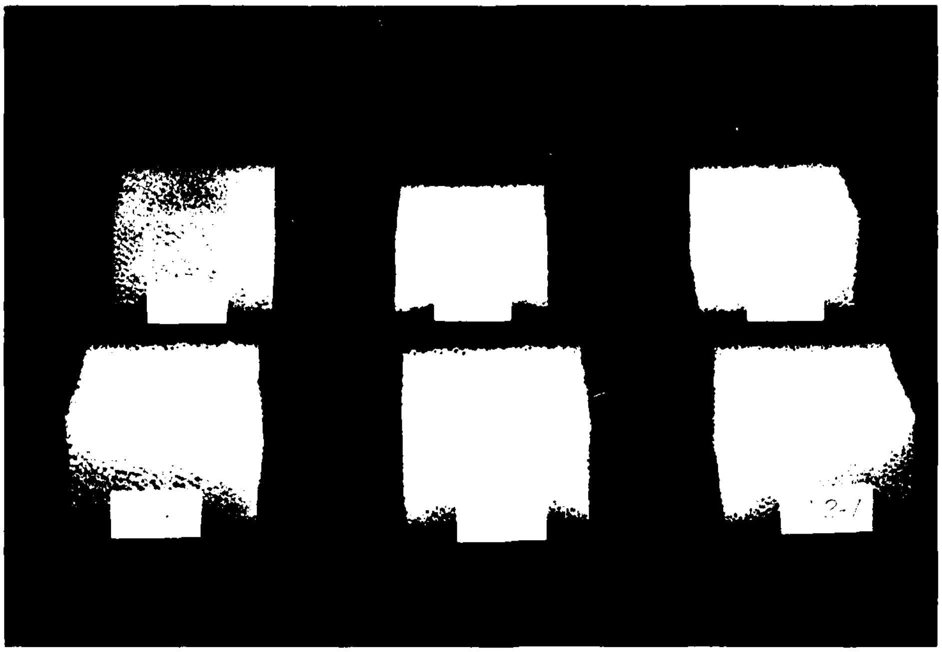


Figure A1-41. Specimens of yellow foam, subjected to 40-200 hours of simulated sunlight exposure.

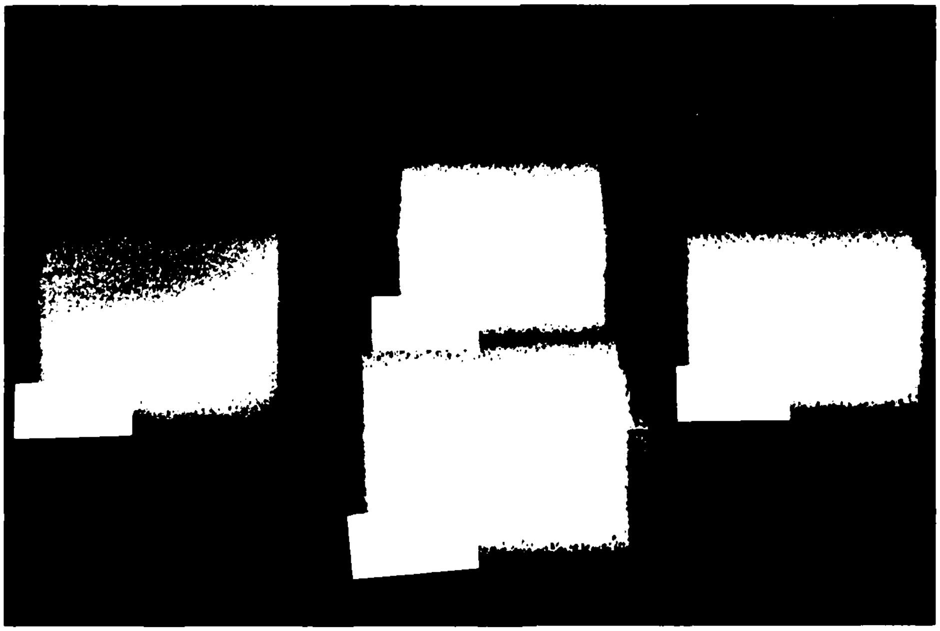


Figure A1-42. Cross-sectional view of yellow foam specimens, subjected to 40, 120, and 200 hours of simulated sunlight exposure.

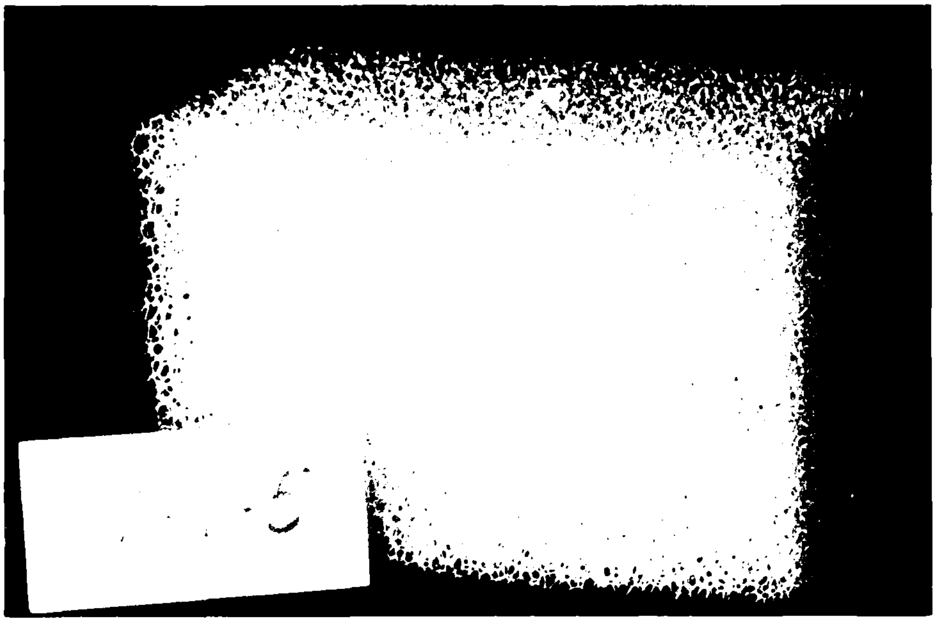


Figure A1-43. Sample 7-1-7, cross-sectional view.

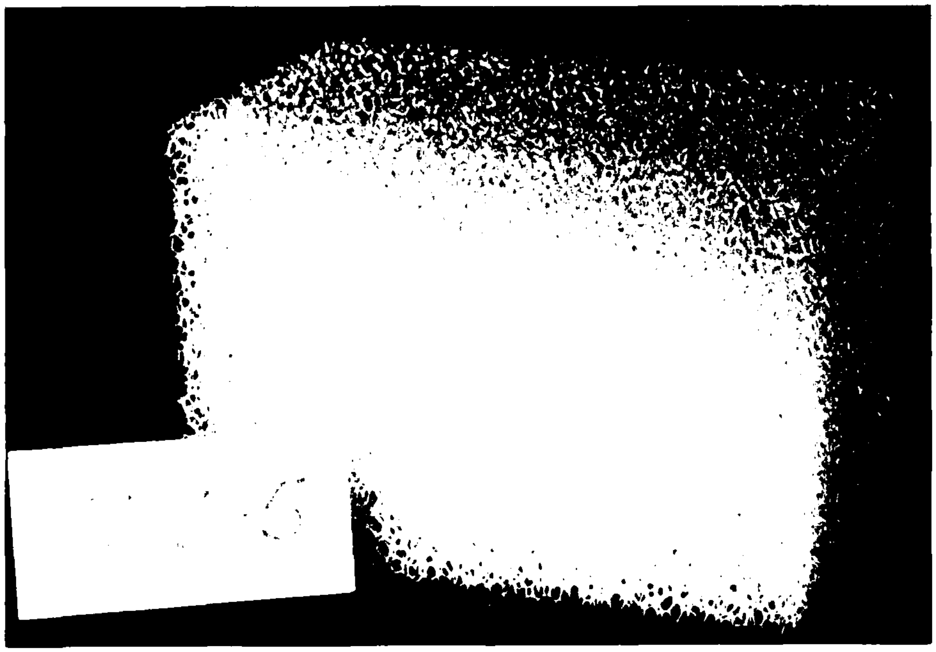


Figure A1-44. Sample 7-3-7, cross-sectional view.

Figure A1-45. Sample 7-5-7, cross-sectional view.

A1-5. FIGURES DEPICTING FOAM SAMPLES FROM HOT WIRE CUTTING EXPERIMENTS

Identification code for samples producted in hot wire cutting experiments is presented in the table below.

TABLE A1-4. CODE FOR FOAM SPECIMENS PRODUCED BY HOT WIRE CUTTING

Foam	Sample size, in.[a]	Cutting speed, ft/min 10	5	2.5
Blue, dry, new	12x12x2	2-1-1	2-2-1	2-3-1
Red, dry, new	12x12x2	2-1-2	2-2-2	2-3-2
Yellow, dry, new	12x12x2	2-1-3	2-2-3	2-3-3

---

[a] Size after hot wire cutting.

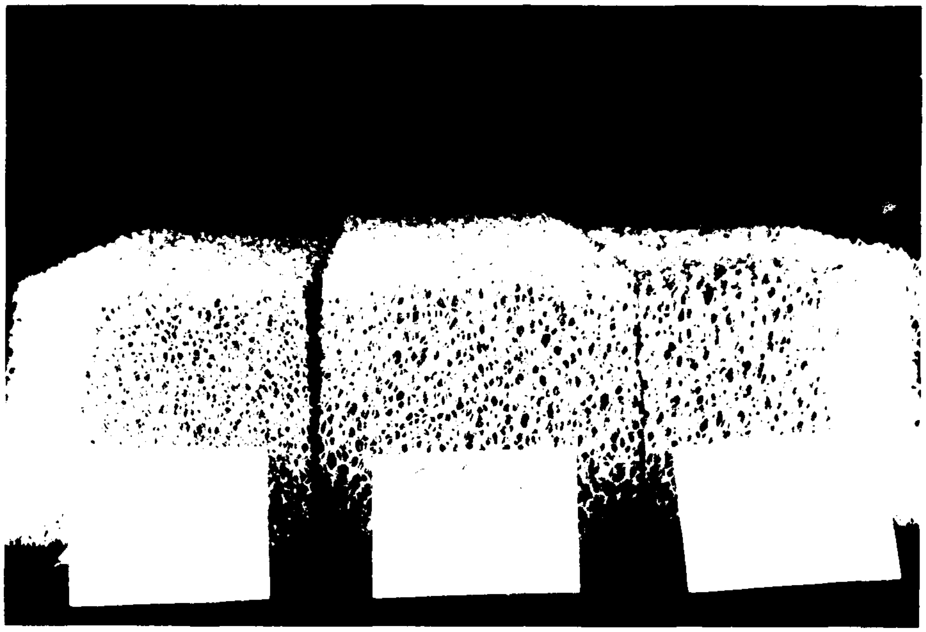


Figure A1-46. Specimens of blue foam, cut along the upper surface at 10, 5, and 2.5 ft/min, respectively.

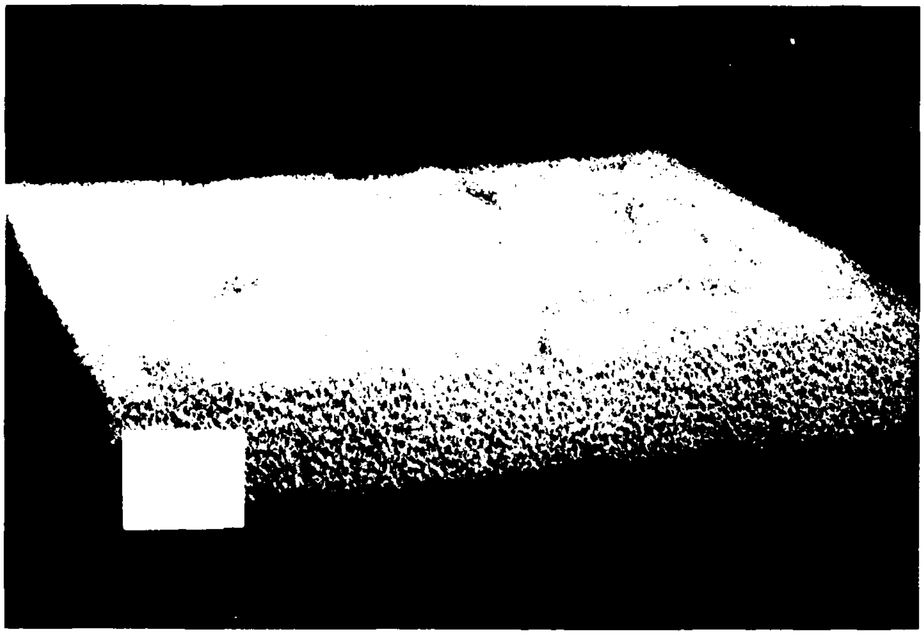


Figure A1-47. Sample 2-3-1, perspective view.

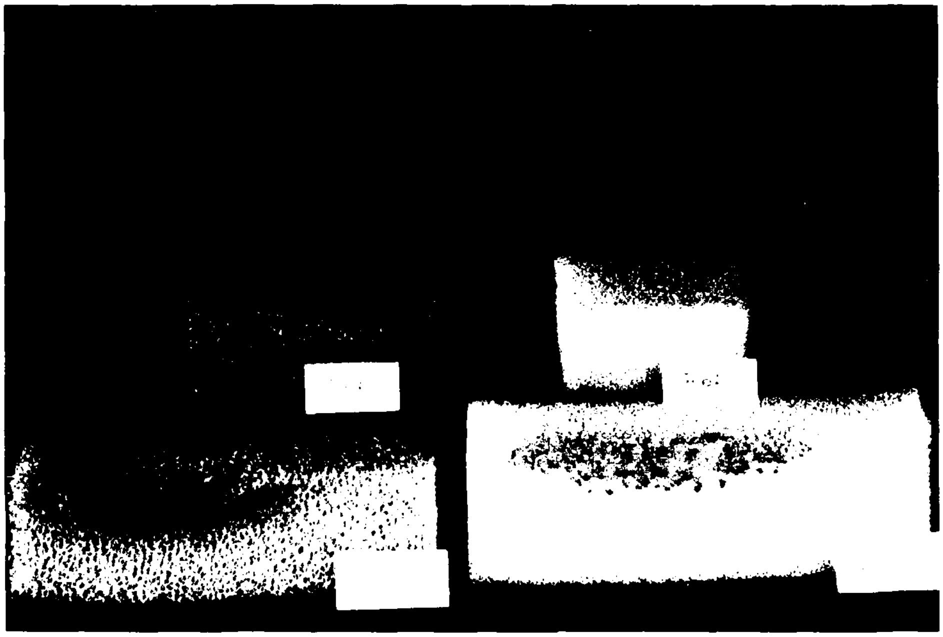


Figure A1-69. Cross-sectional view of blue and red foam specimens, subjected to radiant heat exposure for 10 seconds.

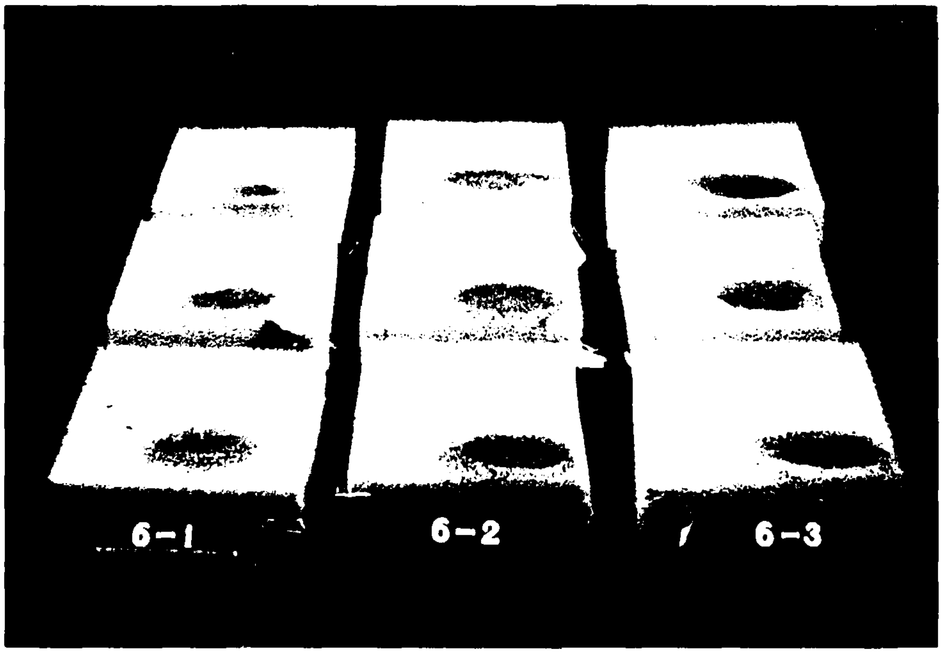


Figure A1-70. Perspective view of blue foam specimens, subjected to radiant heat exposure for 10, 20, and 30 seconds, respectively.

A1.7. FIGURES DEPICTING FOAM SAMPLES FROM RADIANT HEAT EXPOSURE EXPERIMENTS

Samples from radiant heat exposure experiments are identified in Table A1-6.

TABLE A1-6. CODE FOR FOAM SPECIMENS PRODUCED BY RADIANT HEAT EXPOSURE

Foam	Sample size, in.	Exposure time, sec 10	15	20
Blue, dry, new	6x6x2	6-1-1	6-2-1	6-3-1
	6x6x2	6-1-2	6-2-2	6-3-2
	6x6x2	6-1-3	6-2-3	6-3-3
Blue, dry, aged	3x3x2	6-1-4[a]		
Red, dry, new	6x6x2	6-1-7	6-2-7	6-3-7
	6x6x2	6-1-8	6-2-8	6-3-8
	6x6x2	6-1-9	6-2-9	6-3-9

---

[a] This sample had been subjected to accelerated aging in air at 200°F (93°C) for five weeks.

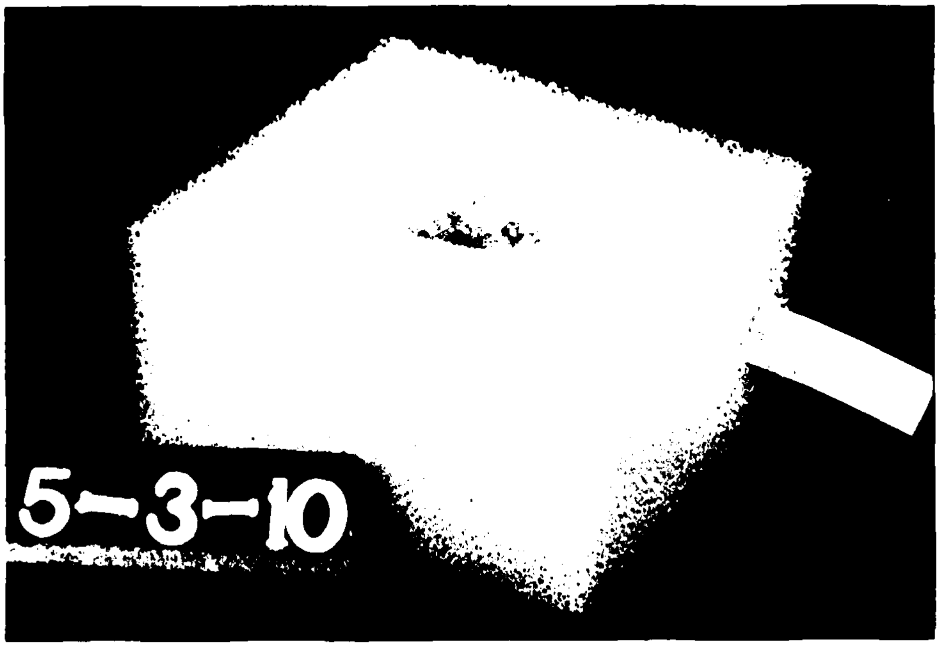


Figure A1-67. Sample 5-3-10, perspective view.

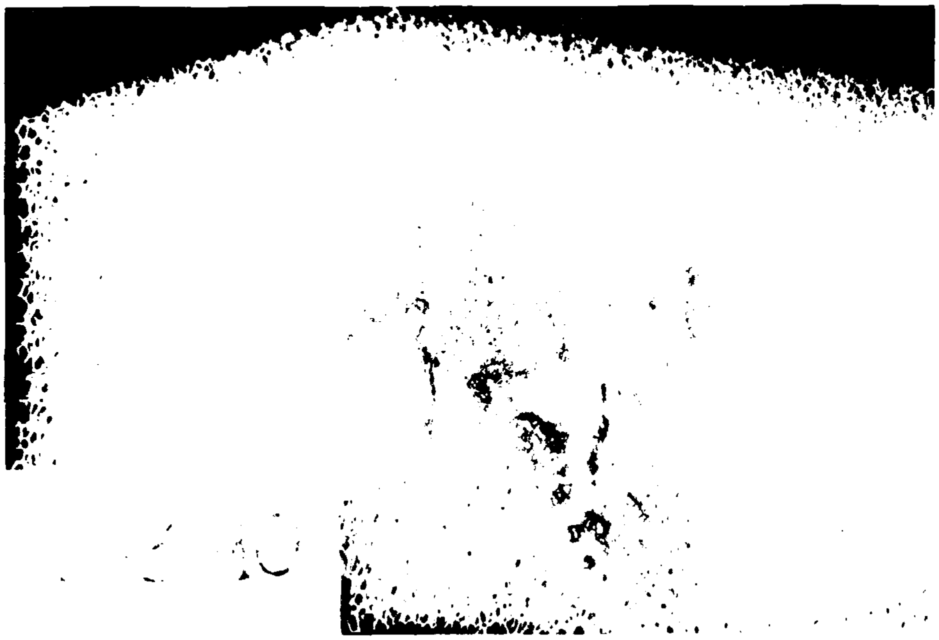


Figure A1-68. Sample 5-3-10, cross-sectional view.

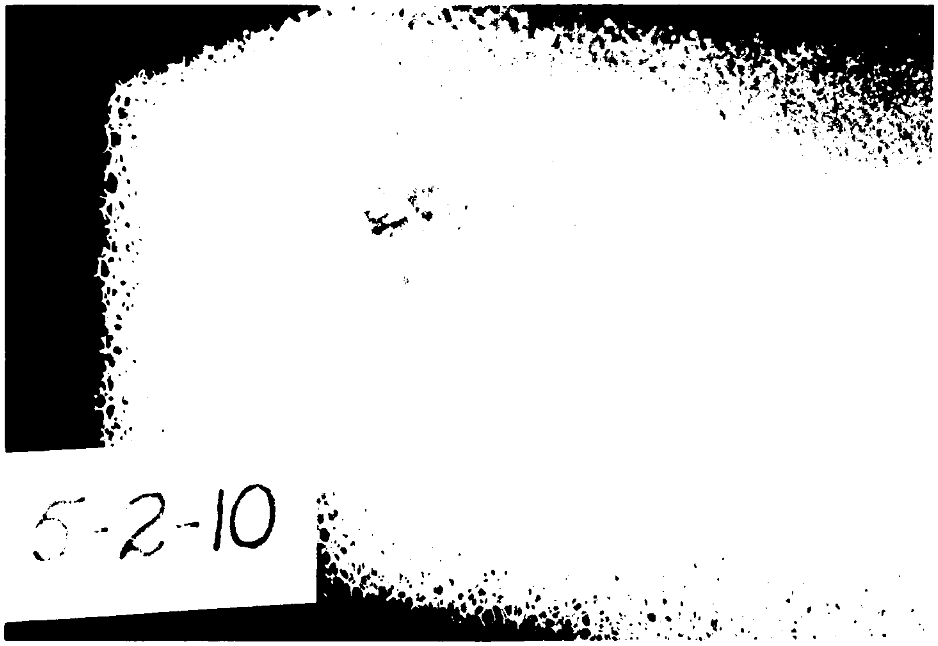


Figure A1-65. Sample 5-2-10, perspective view.

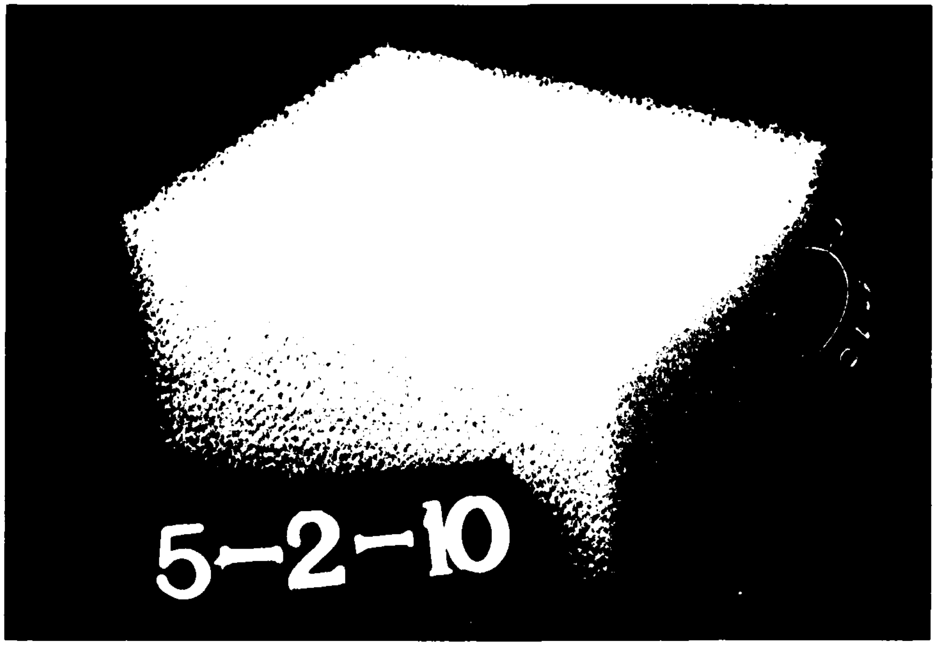


Figure A1-66. Sample 5-2-11, cross-sectional view.

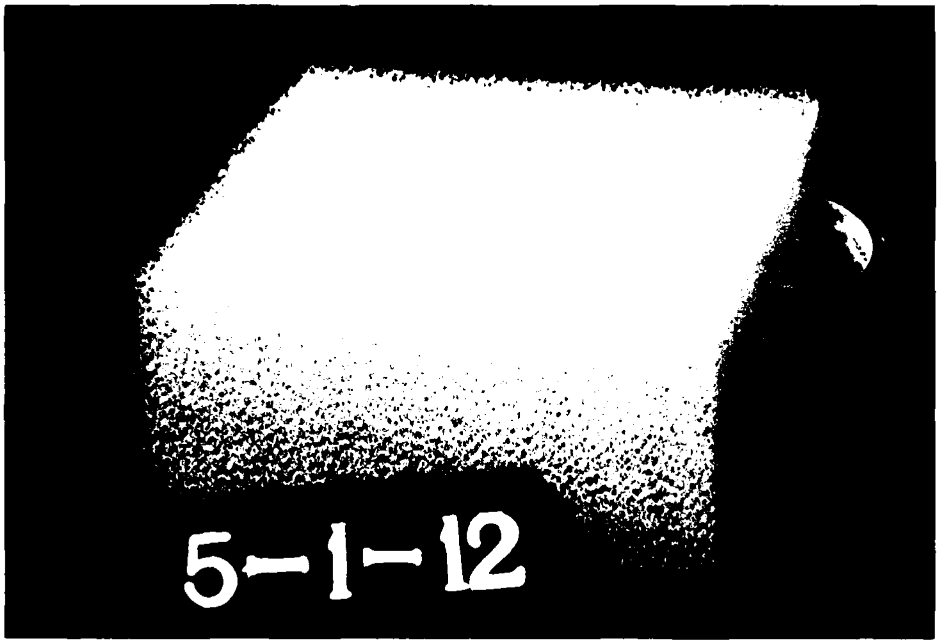


Figure A1-63. Sample 5-1-12, perspective view.

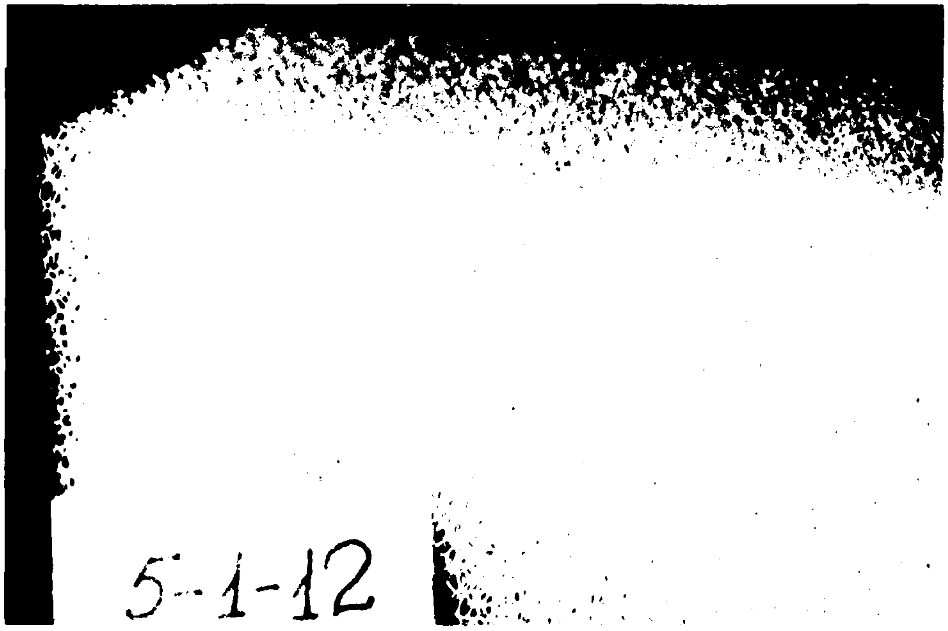


Figure A1-64. Sample 5-1-12, cross-sectional view.

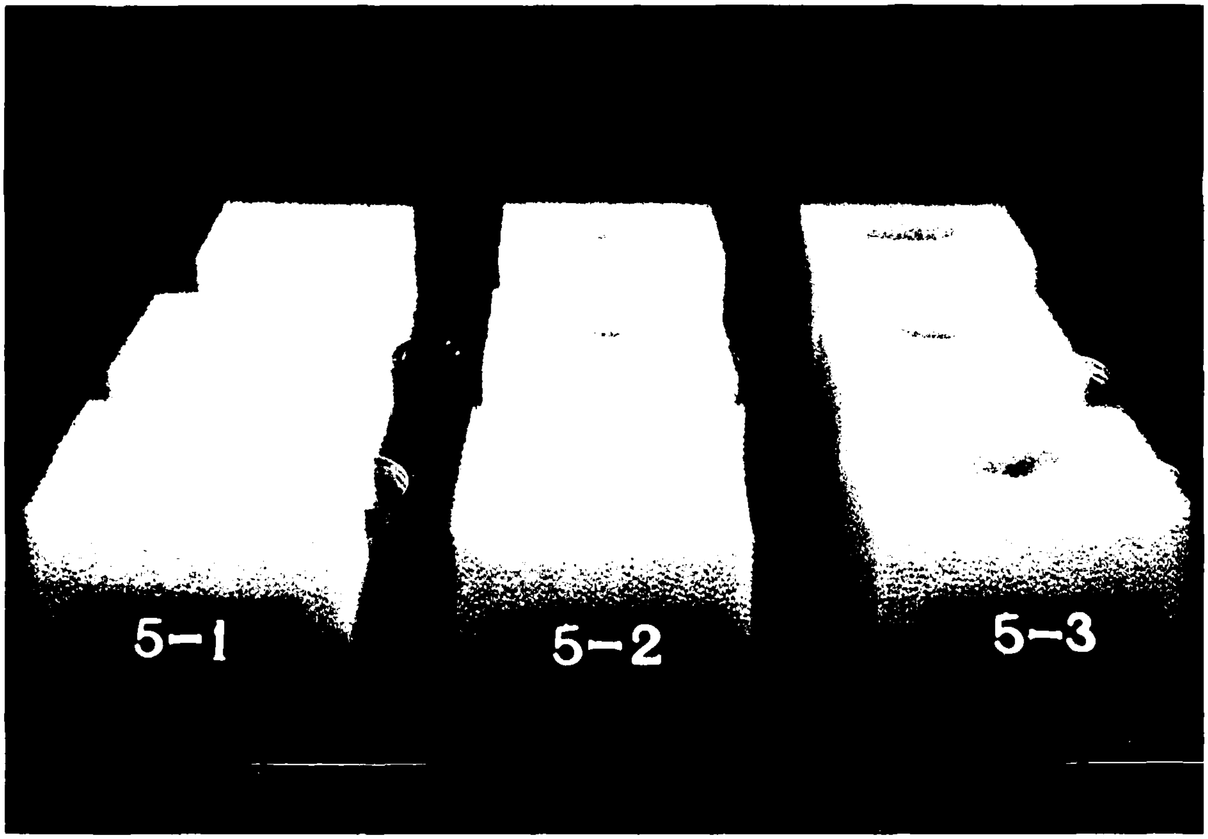


Figure A1-62. Perspective view of red foam specimens, subjected to hot air impingement for ~2, ~3.5, and ~5 seconds, respectively.

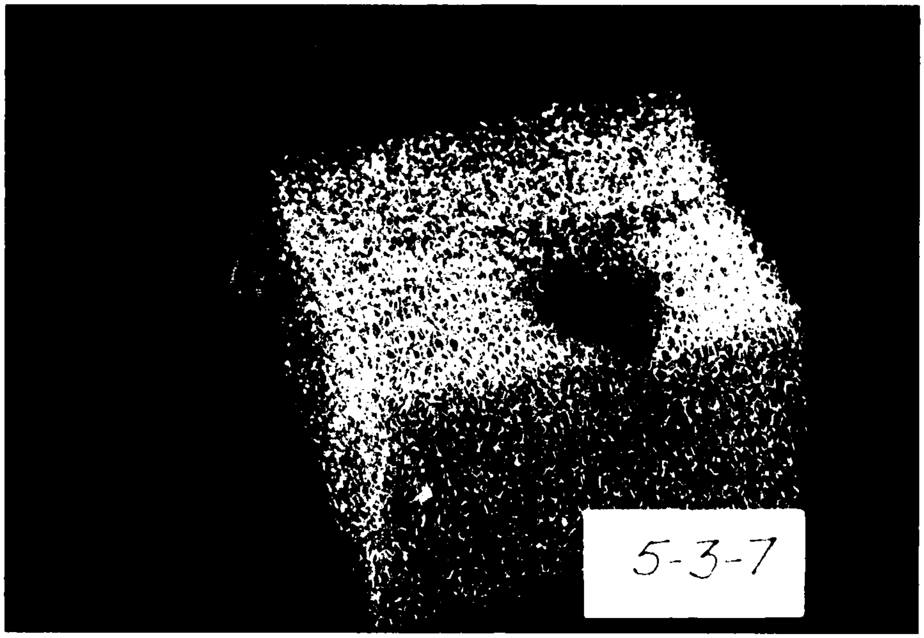


Figure A1-60. Sample 5-3-7 (aged foam), perspective view.

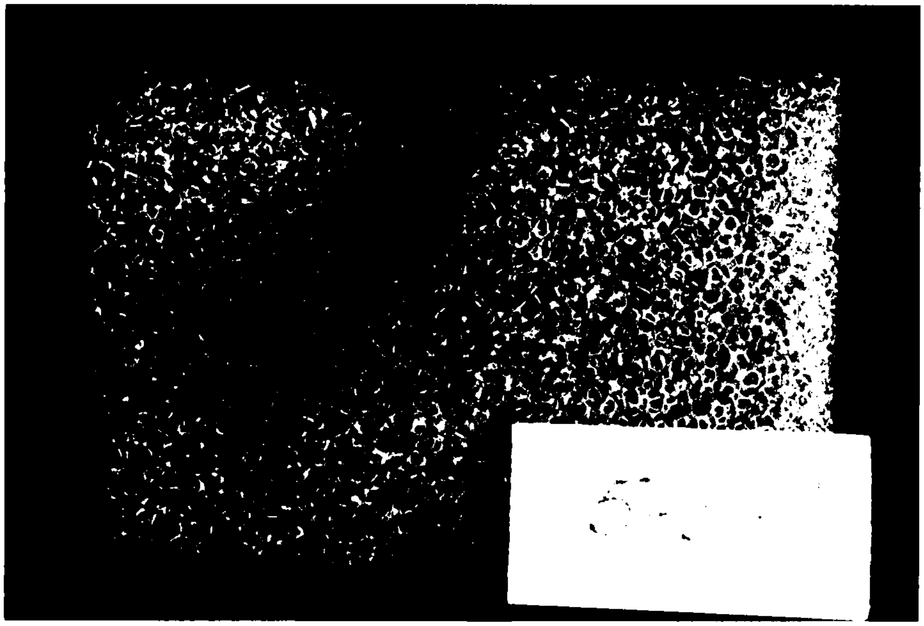


Figure A1-61. Sample 5-3-7 (aged foam), cross-sectional view.

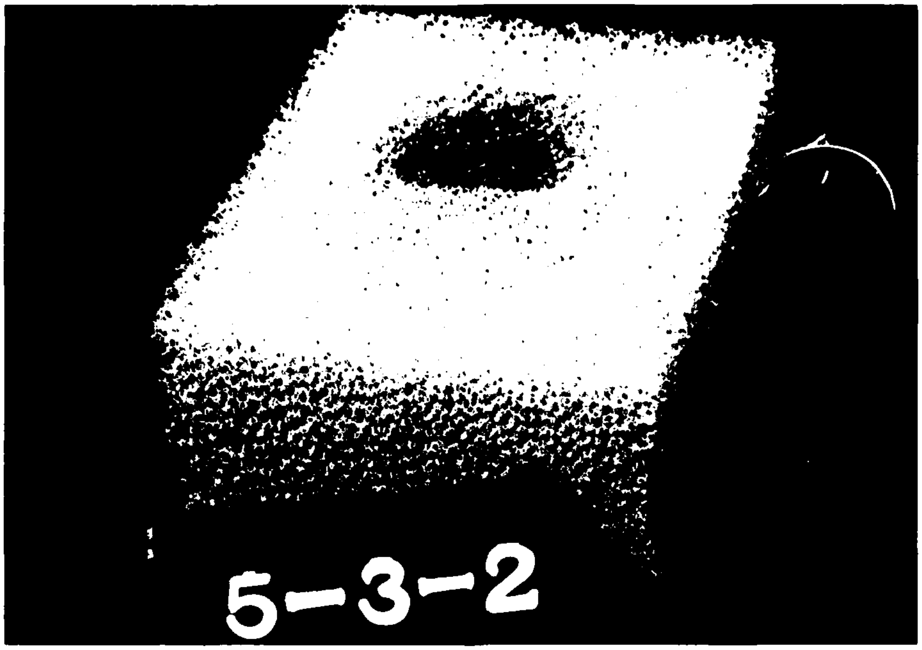


Figure A1-58. Sample 5-3-2, perspective view.

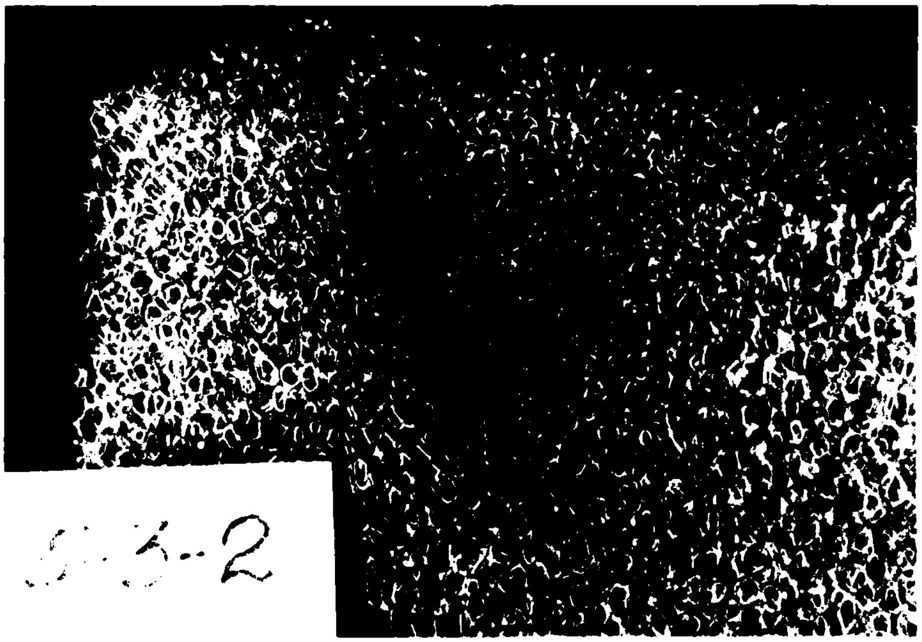


Figure A1-59. Sample 5-3-2, cross-sectional view.

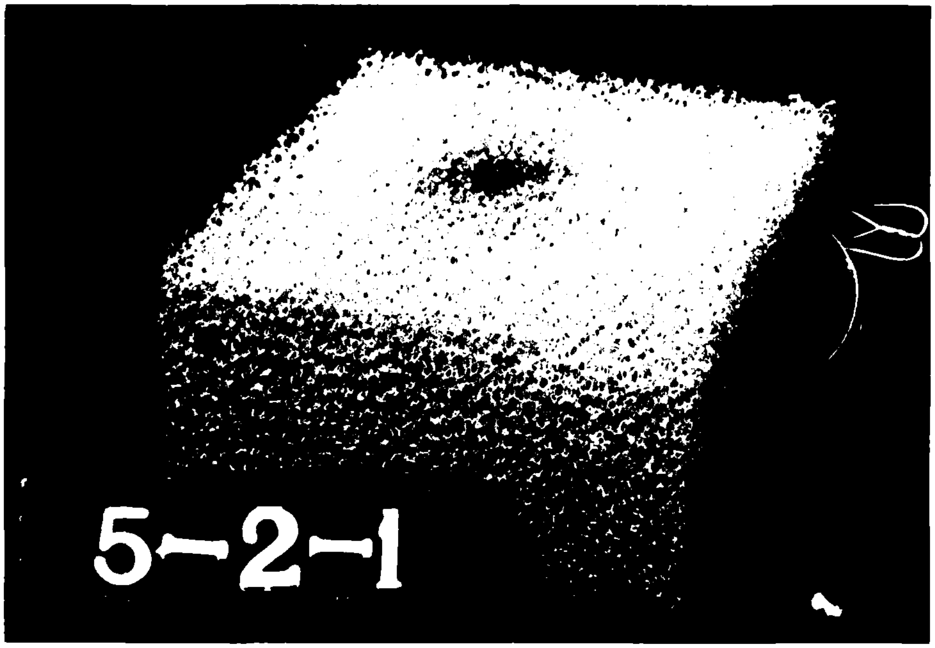


Figure A1-56. Sample 5-2-1, perspective view.

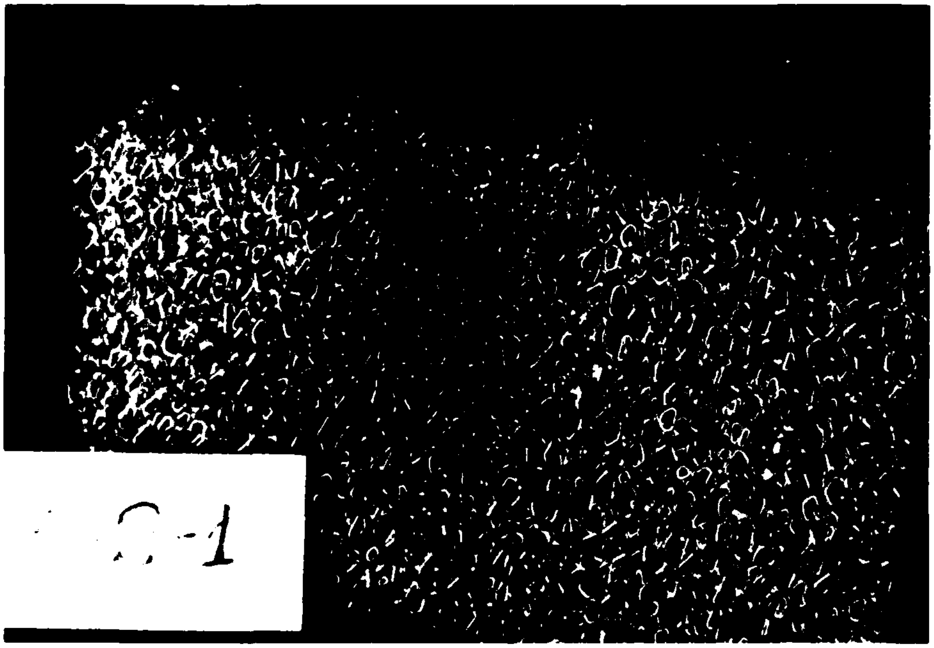


Figure A1-57. Sample 5-2-1, cross-sectional view.

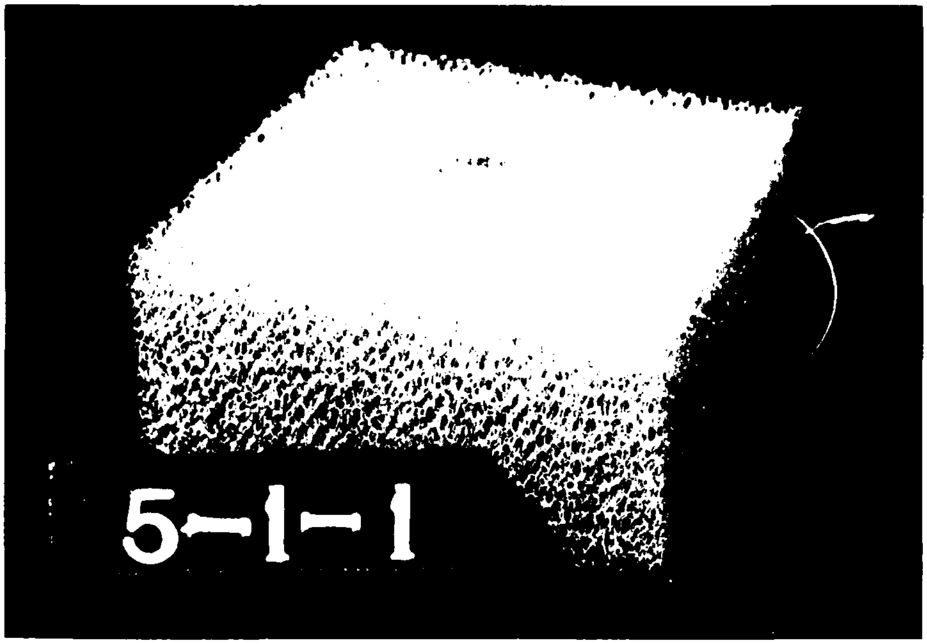


Figure A1-54. Sample 5-1-1, perspective view.

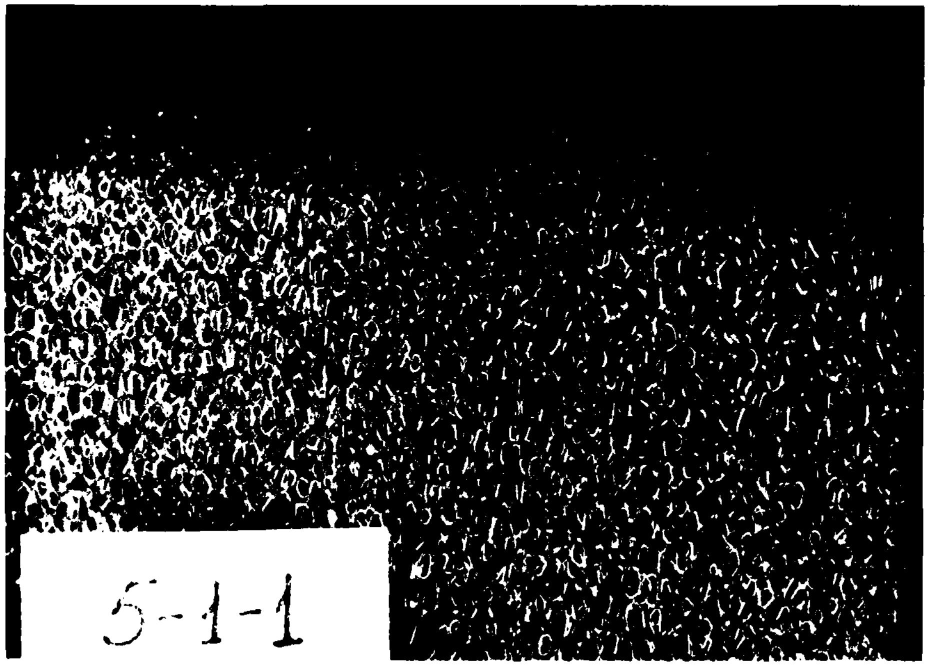


Figure A1-55. Sample 5-1-1, cross-sectional view.

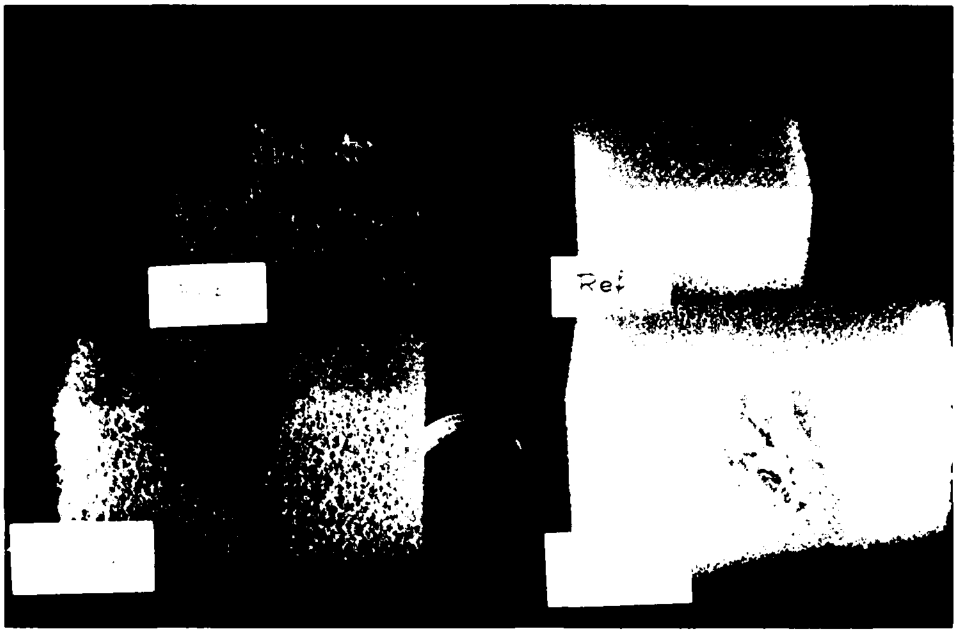


Figure A1-52. Cross-sectional view of blue and red foam specimens, subjected to hot air impingement for five seconds.

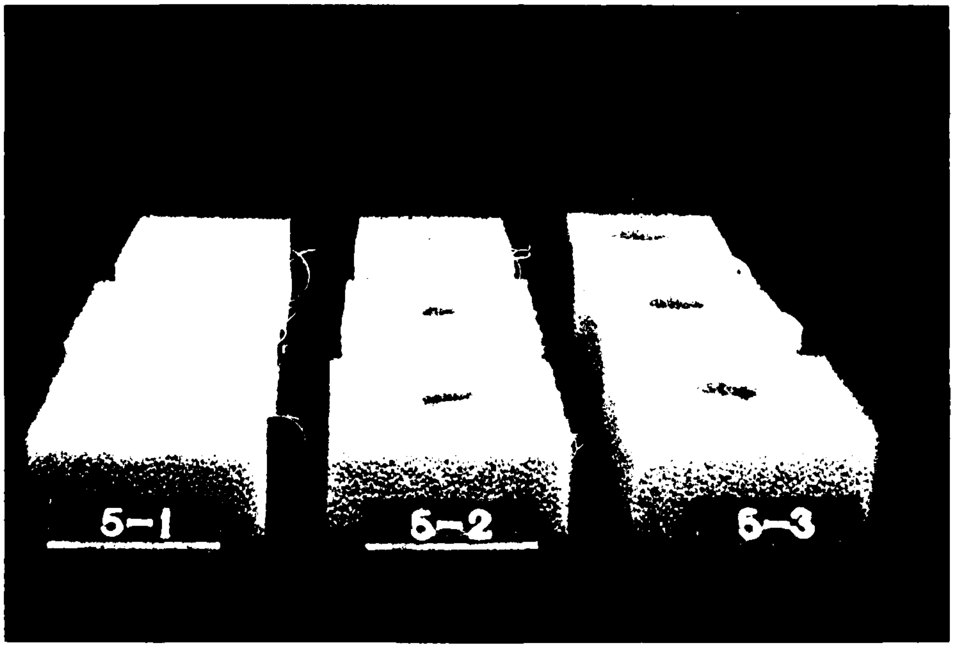


Figure A1-53. Perspective view of blue foam specimens, subjected to hot air impingement for ∿2, ∿3.5, and ∿5 seconds, respectively.

A1.6. FIGURES DEPICTING SAMPLES FROM HOT AIR IMPINGEMENT EXPERIMENTS

Specimens produced in hot air impingement experiments are identified in Table A1-5.

TABLE A1-5. CODE FOR FOAM SPECIMENS PRODUCED BY HOT AIR IMPINGEMENT

Foam	Sample size, in.	Exposure duration, sec ~2	~3.5	~5
Blue, dry, new	4x4x2	5-1-1	5-2-1	5-3-1
	4x4x2	5-1-2	5-2-2	5-3-2
	4x4x2	5-1-3	5-2-3	5-3-3
Blue, dry, aged	3x3x2			5-3-7[a]
Red, dry, new	4x4x2	5-1-10	5-2-10	5-3-10
	4x4x2	5-1-11	5-2-11	5-3-11
	4x4x2	5-1-12	5-2-12	5-3-12

---

[a] This sample had been subjected to accelerated aging in air at 200°F (93°C) for five weeks.

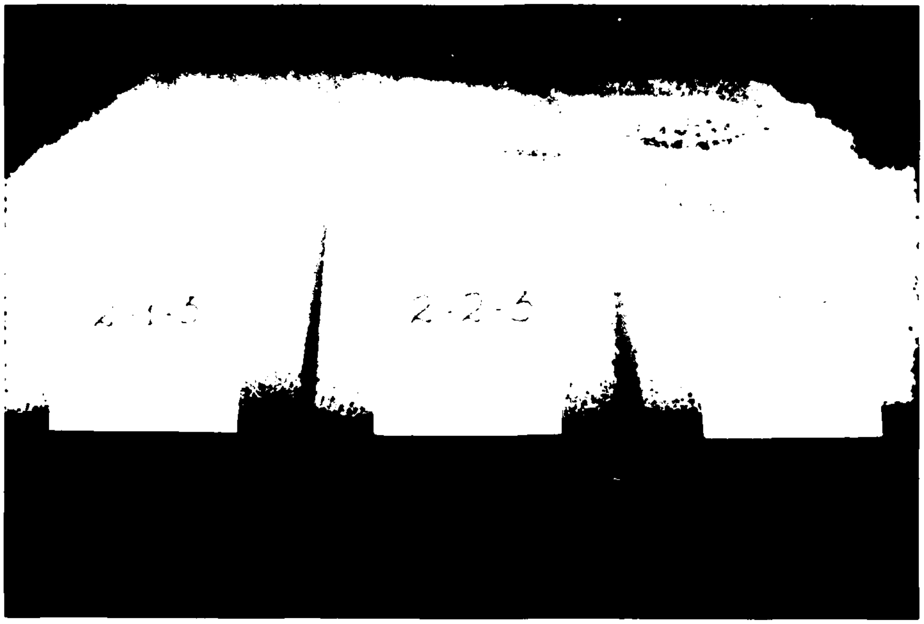


Figure A1-50. Specimens of yellow foam, cut along the upper surface at 10, 5, and 2.5 ft/min, respectively.

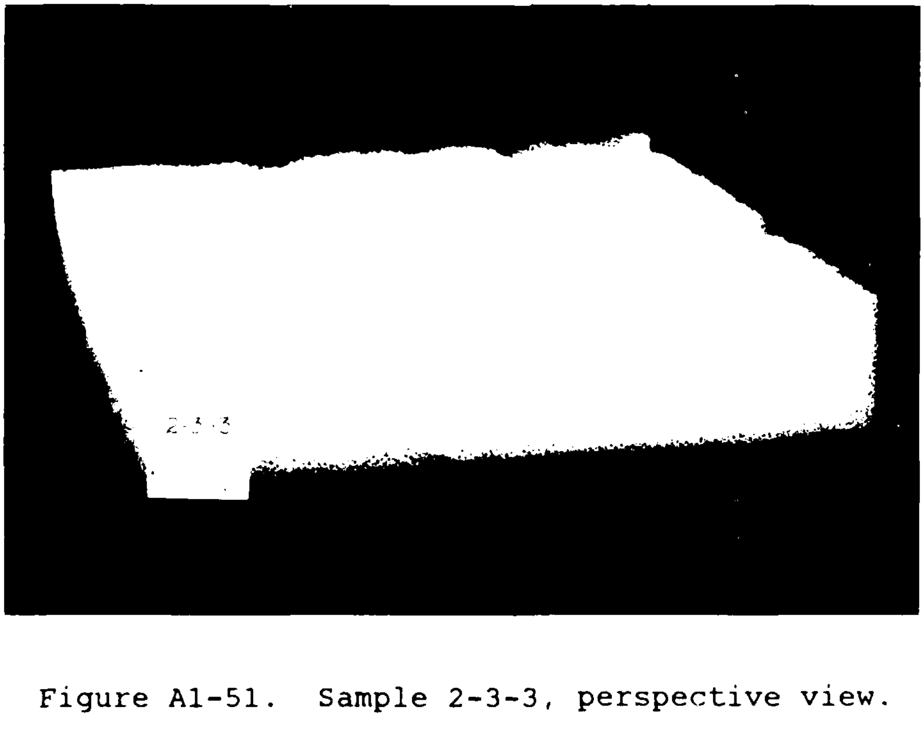


Figure A1-51. Sample 2-3-3, perspective view.

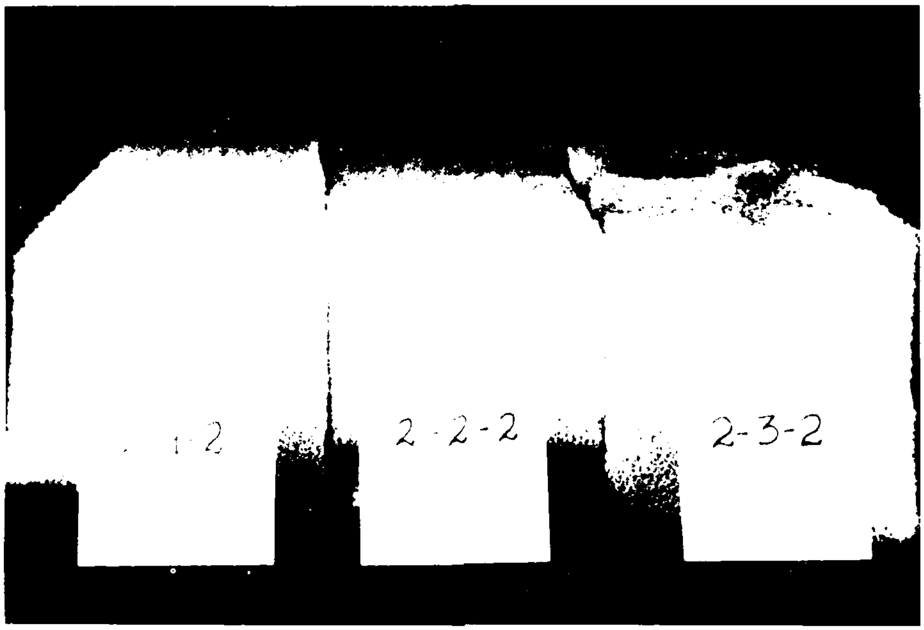


Figure A1-48. Specimens of red foam, cut along the upper surface at 10, 5, and 2.5 ft/min, respectively.

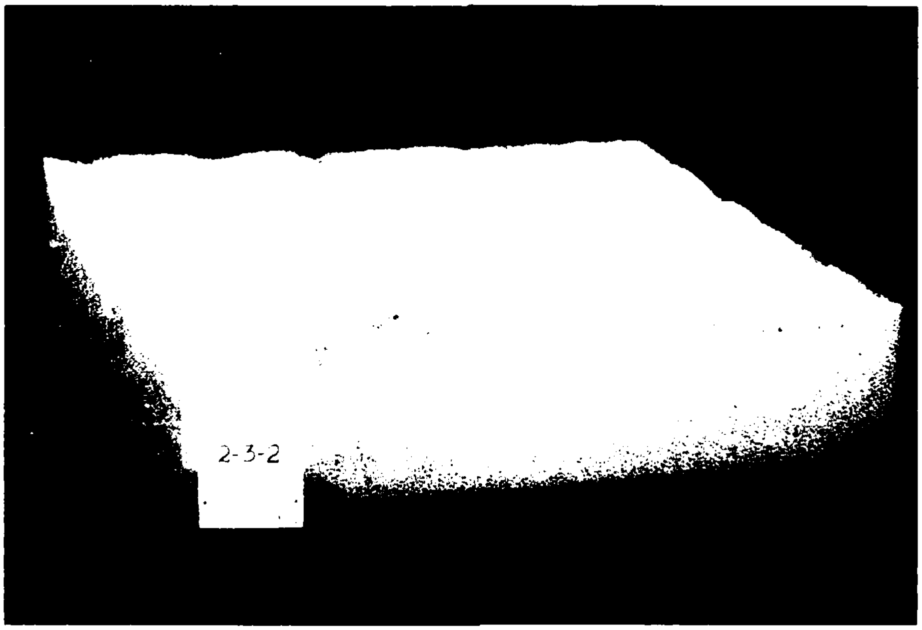


Figure A1-49. Sample 2-3-2, perspective view.

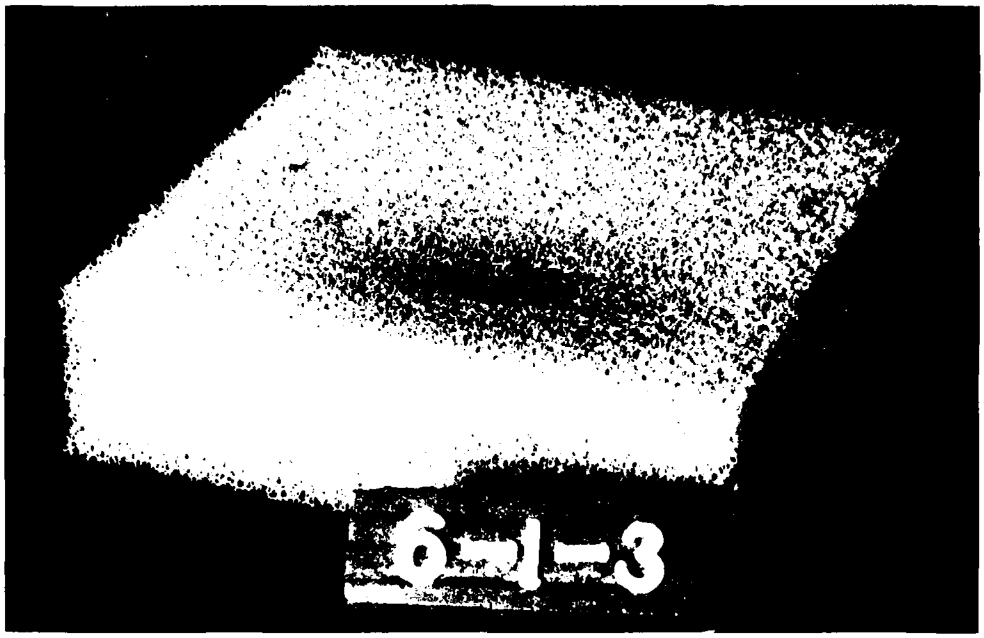


Figure A1-71. Sample 6-1-3, perspective view.

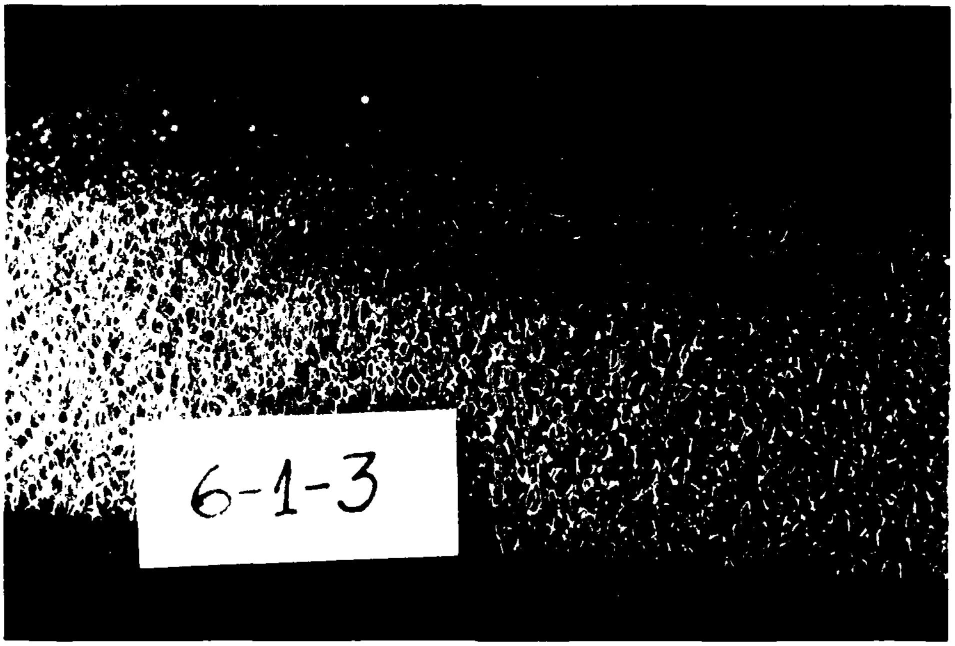


Figure A1-72. Sample 6-1-3, cross-sectional view.

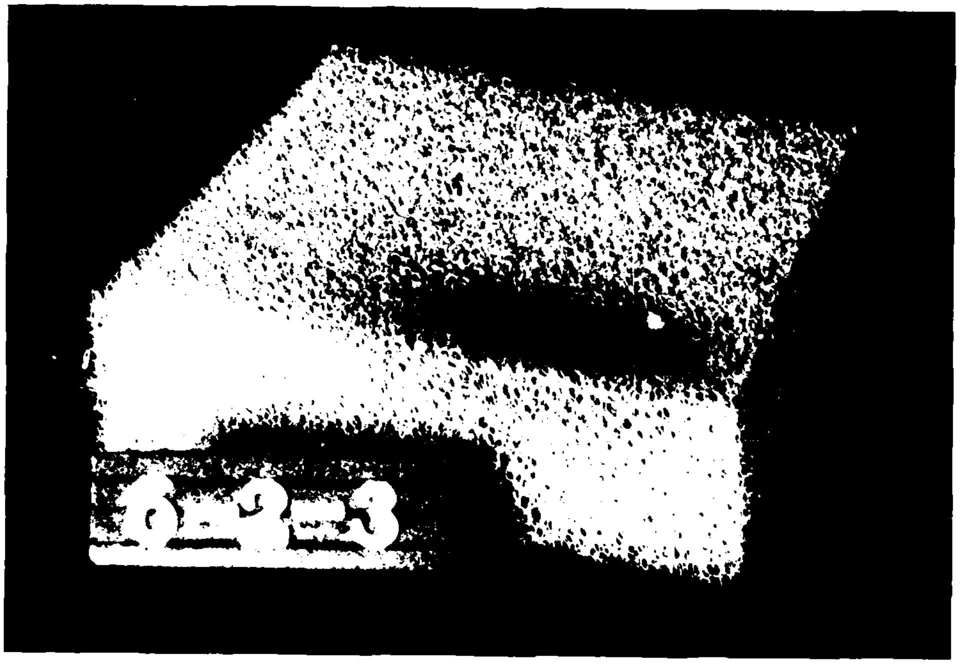


Figure A1-73. Sample 6-2-3, perspective view.

Figure A1-74. Sample 6-2-3, cross-sectional view.

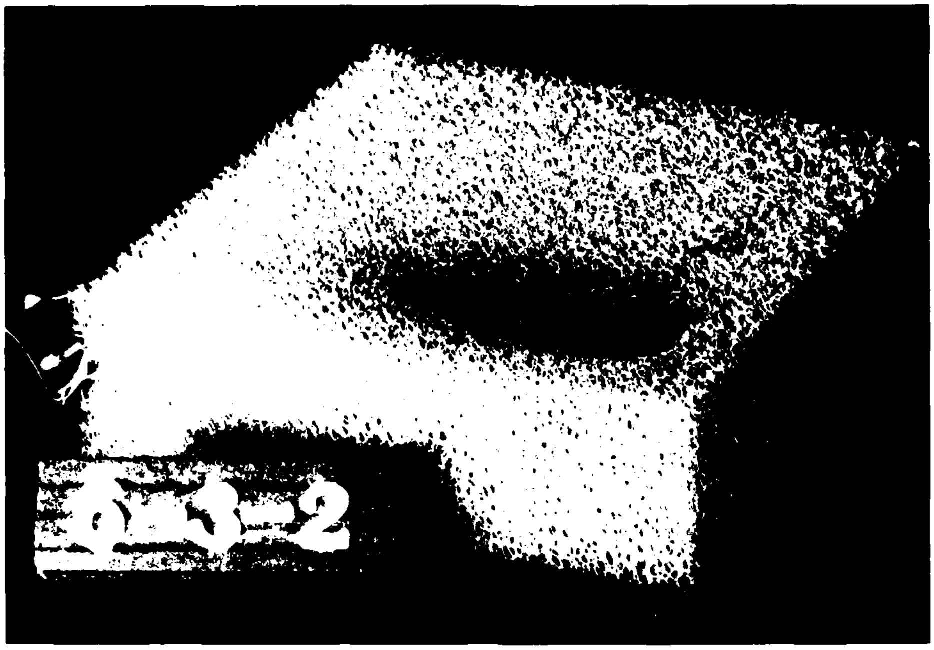


Figure A1-75. Sample 6-3-2, perspective view.

Figure A1-76. Sample 6-3-2, cross-sectional view.

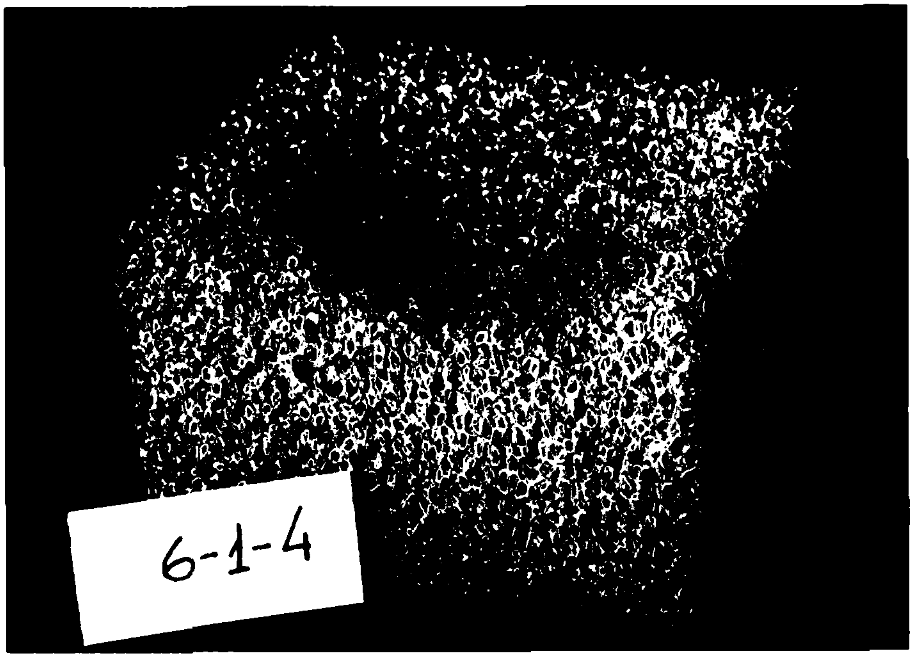


Figure A1-77. Sample 6-1-4 (aged foam), perspective view.

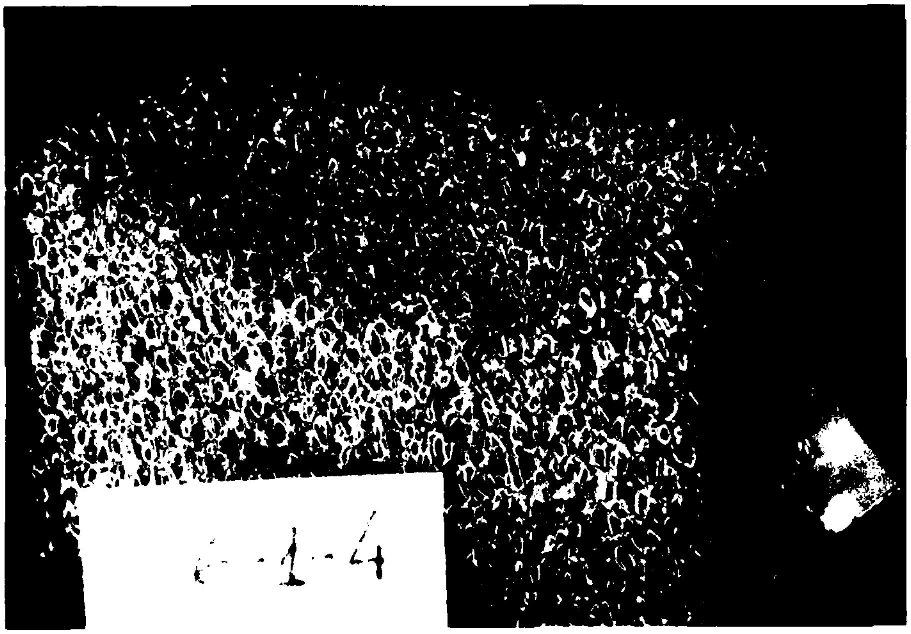


Figure A1-78. Sample 6-1-4 (aged foam), cross-sectional view.

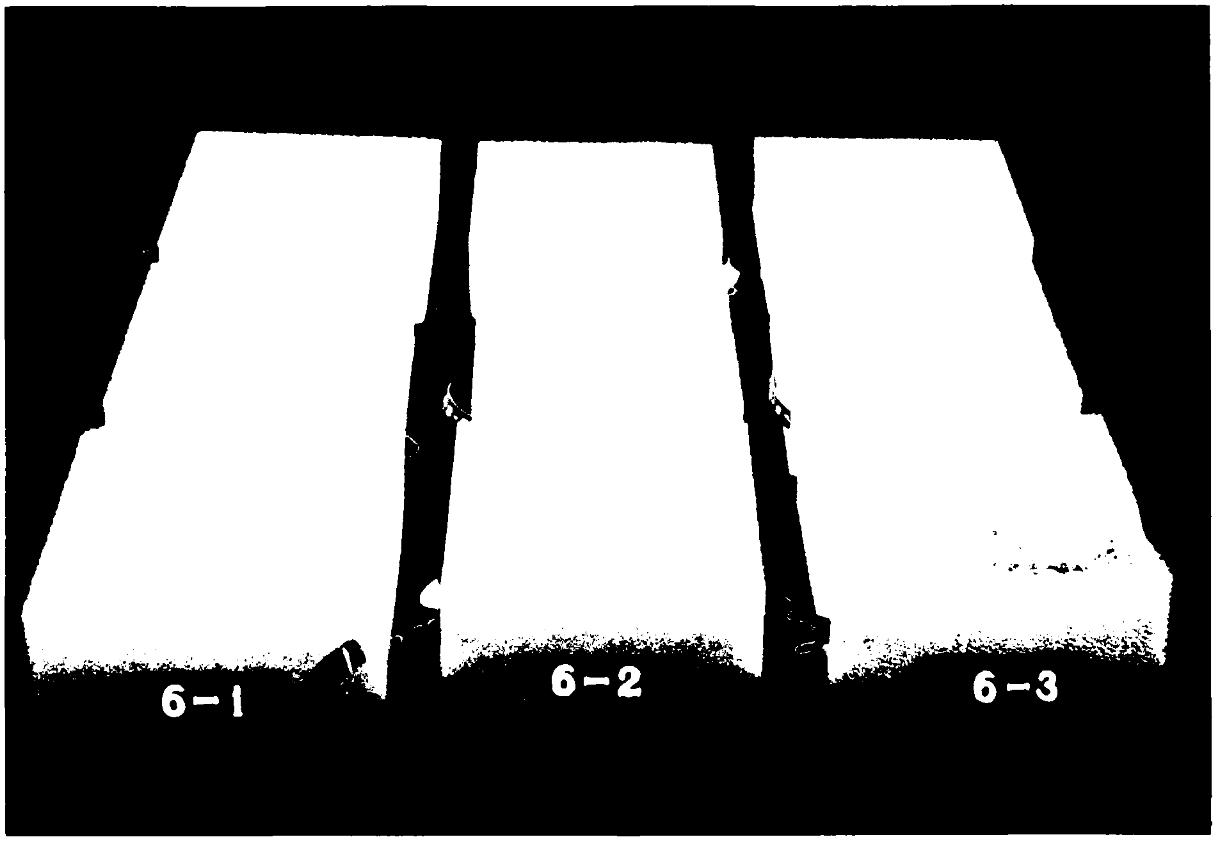


Figure A1-79. Perspective view of red foam specimens, subjected to radiant heat exposure for 10, 20, and 30 seconds, respectively.

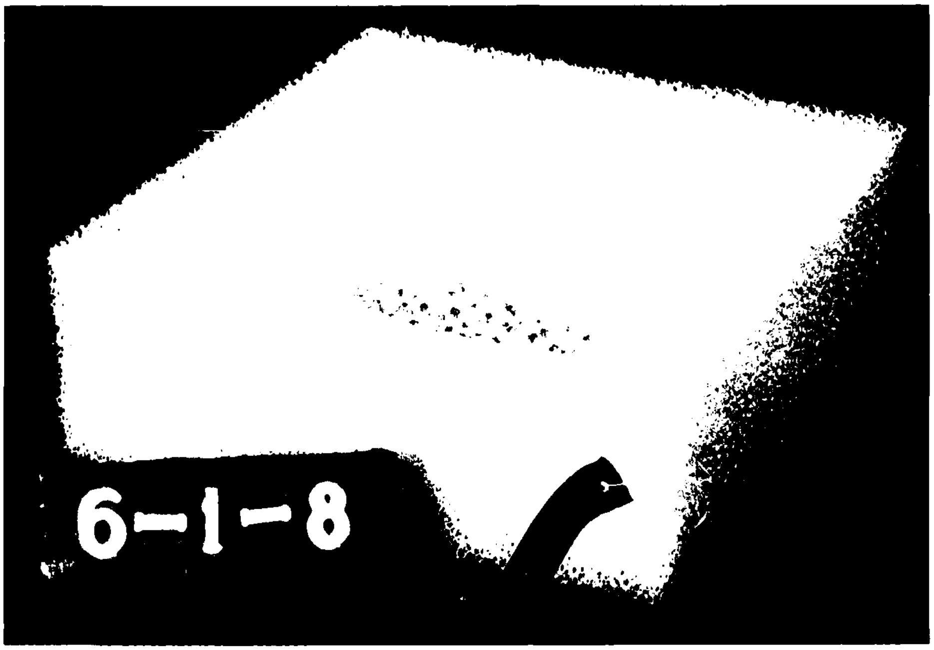


Figure A1-80. Sample 6-1-8, perspective view.

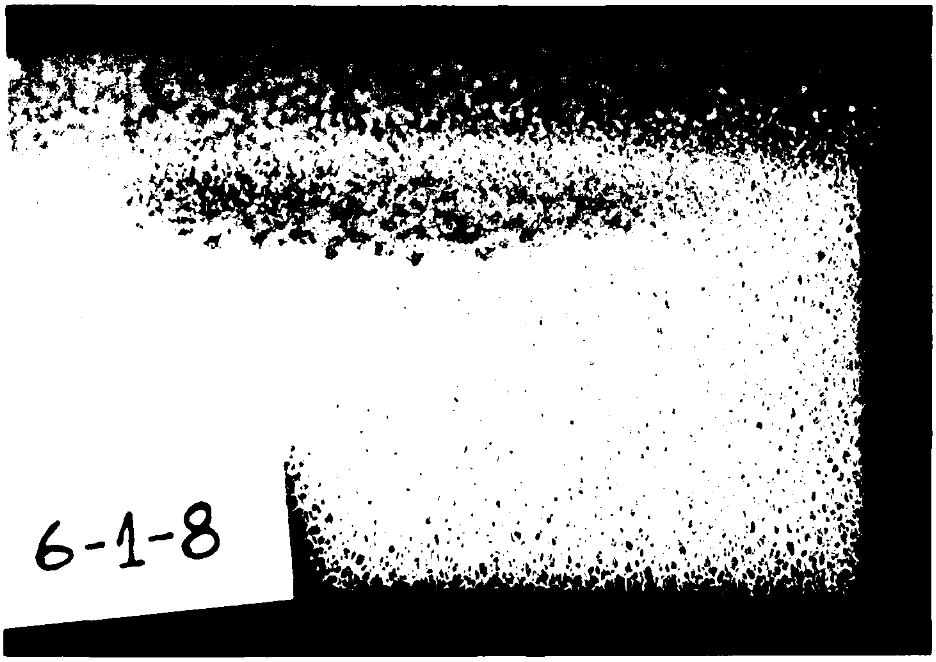


Figure A1-81. Sample 6-1-8, cross-sectional view.

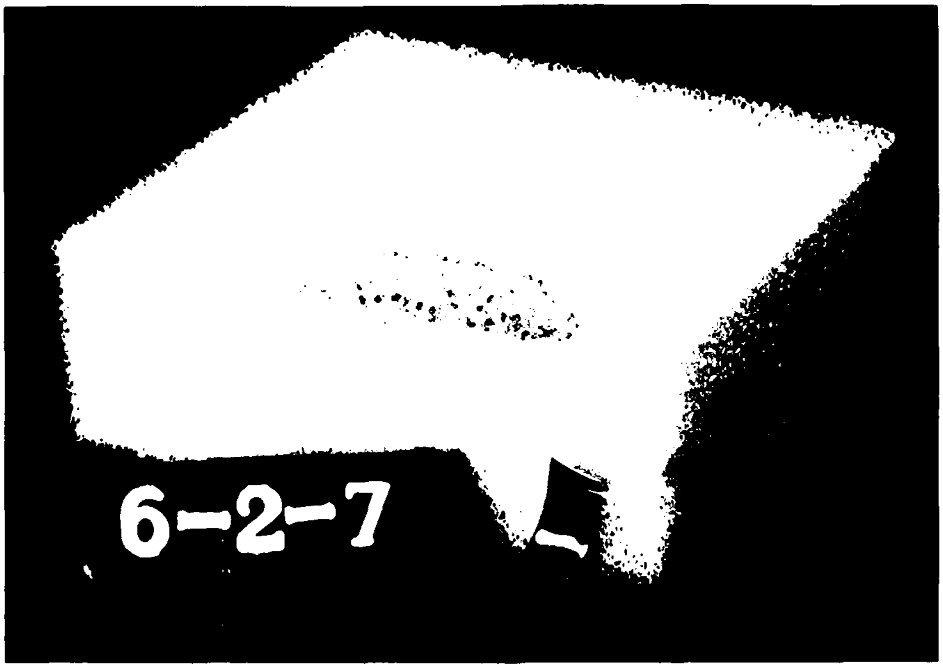


Figure A1-82. Sample 6-2-7, perspective view.

Figure A1-83. Sample 6-2-7, cross-sectional view.

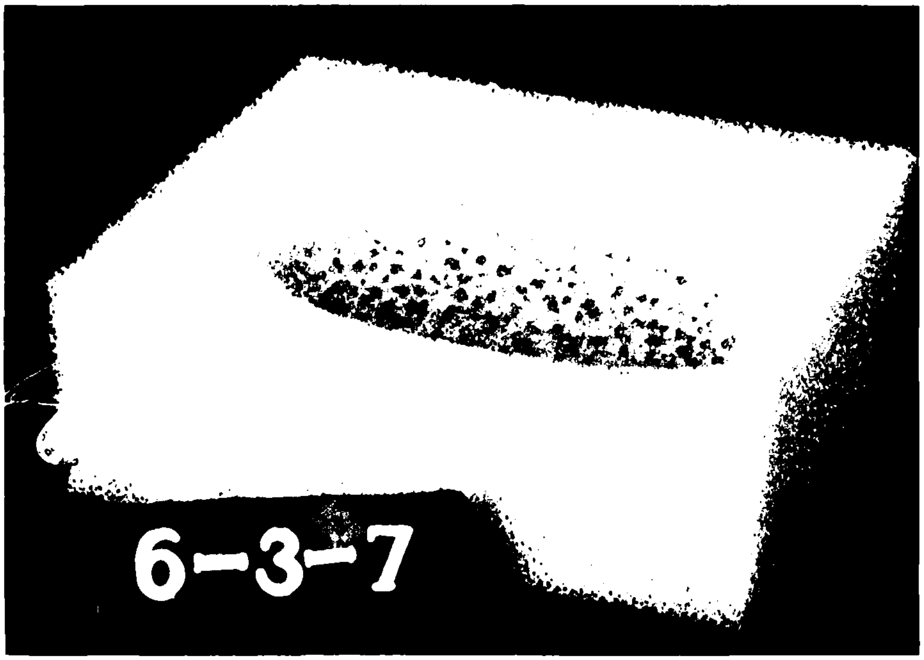


Figure A1-84. Sample 6-3-7, perspective view.

Figure A1-85. Sample 6-3-7, cross-sectional view.

A1.8. FIGURES DEPICTING FOAM SAMPLES FROM BRIEF FLAME IMPINGEMENT EXPERIMENTS

Designation of samples produced in brief flame impingement experiments is shown in Table A1-7.

TABLE A1-7. CODE FOR FOAM SPECIMENS PRODUCED BY BRIEF FLAME IMPINGEMENT

Foam	Sample size, in.	Horizontal, top ignition	Vertical, bottom ignition	Horizontal, bottom ignition
Blue, dry, new	6x6x2	3-1-1	3-2-1	3-3-1
	6x6x2	3-1-2	3-2-2	3-3-2
	6x6x2	3-1-3	3-2-3	3-3-3
Blue, wet, new	6x6x2	3-1-4	3-2-4	
	6x6x2	3-1-5	3-2-5	
Blue, dry, aged	3x3x2	3-1-9		
Red, dry, new	6x6x2	3-1-10	3-2-10	3-3-10
	6x6x2	3-1-11	3-2-11	3-3-11
	6x6x2	3-1-12	3-2-12	3-3-12
Yellow, dry, new	6x6x2	3-1-13	3-2-13	3-3-13
	6x6x2	3-1-14	3-2-14	3-3-14
	6x6x2	3-1-15	3-2-15	3-3-15

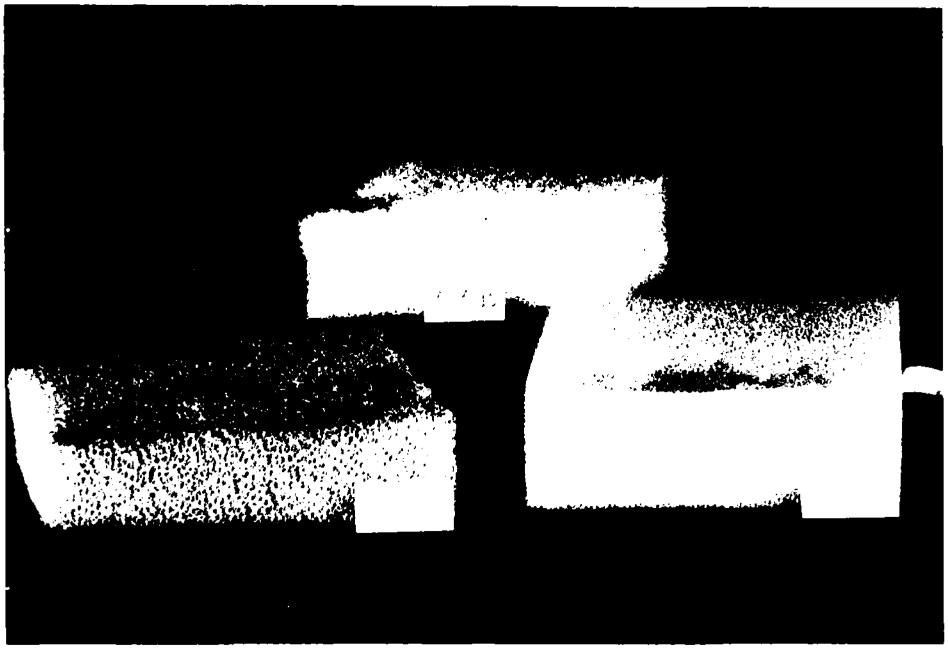


Figure A1-86. Cross-sectional view of blue, red, and yellow foam specimens, subjected to brief flame impingement at the bottom while in horizontal position.

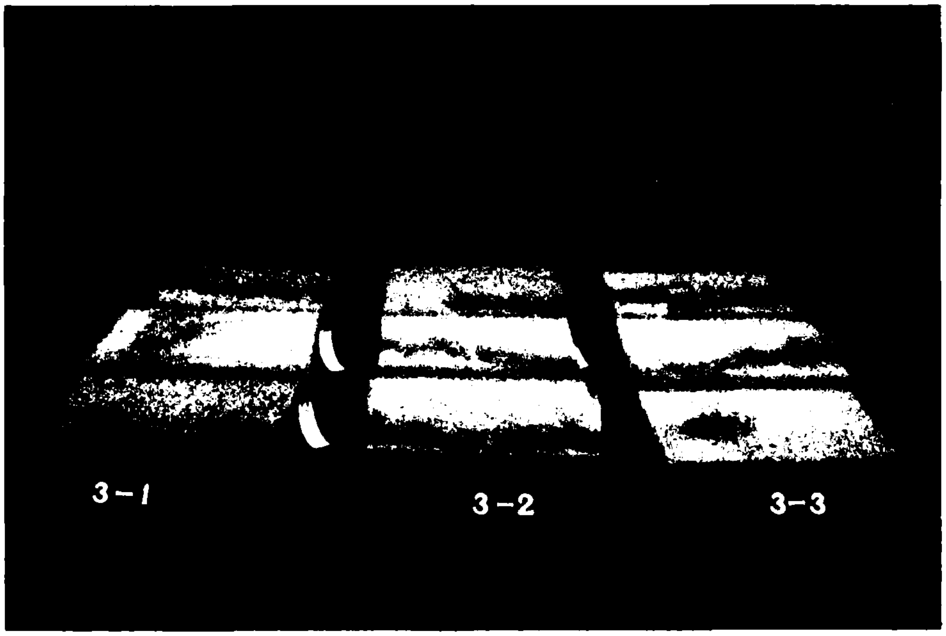


Figure A1-87. Perspective view of blue foam specimens, subjected to brief flame impingement from top while in horizontal position, and from bottom while in vertical and horizontal positions, respectively.

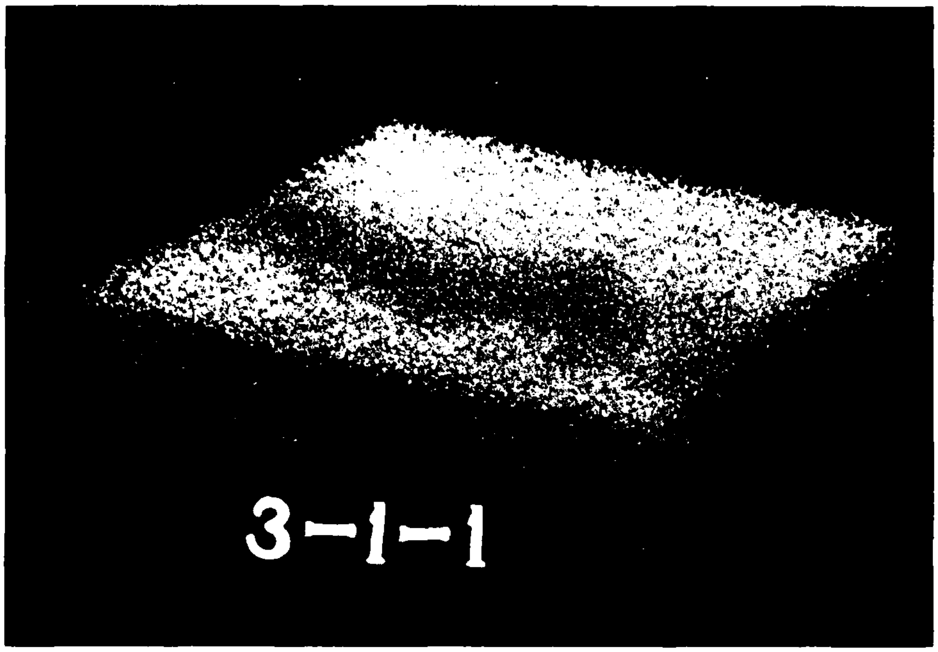


Figure A1-88. Sample 3-1-1, perspective view.

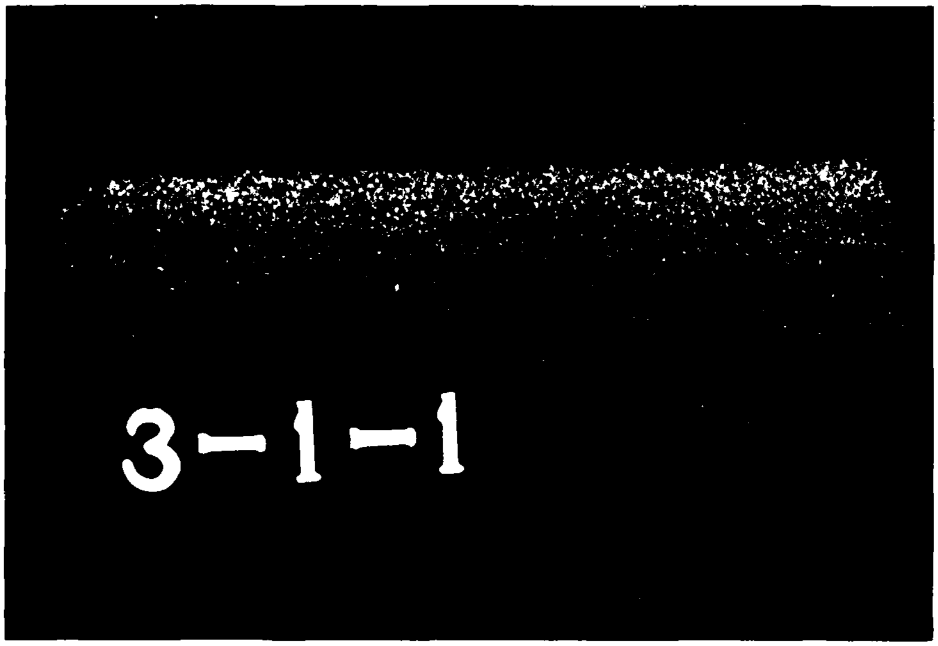


Figure A1-89. Sample 3-1-1, cross-sectional view.

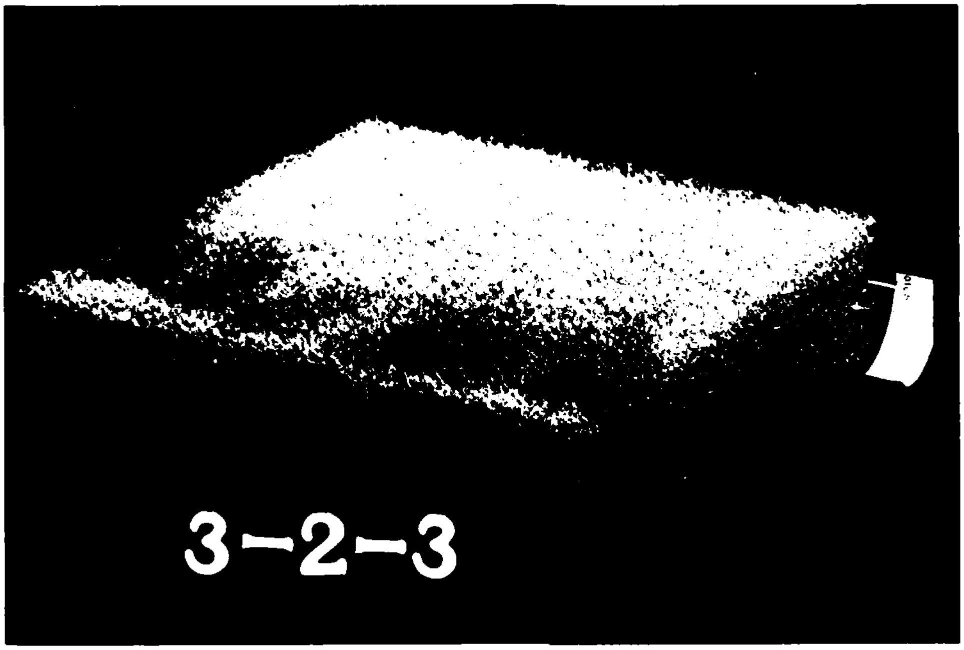


Figure A1-90. Sample 3-2-3, perspective view.

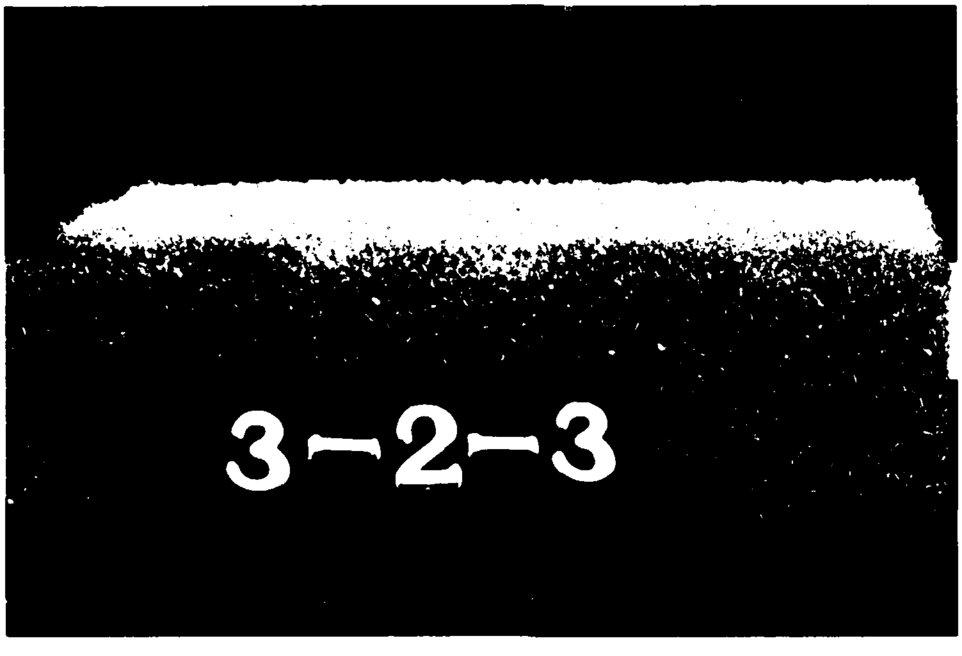


Figure A1-91. Sample 3-2-3, cross-sectional view.

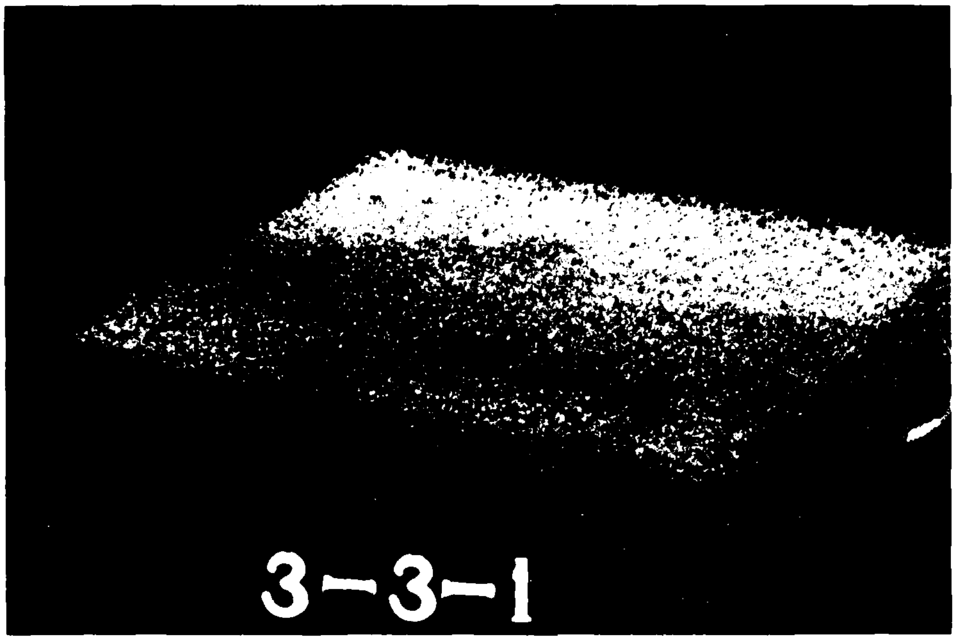


Figure A1-92. Sample 3-3-1, perspective view.

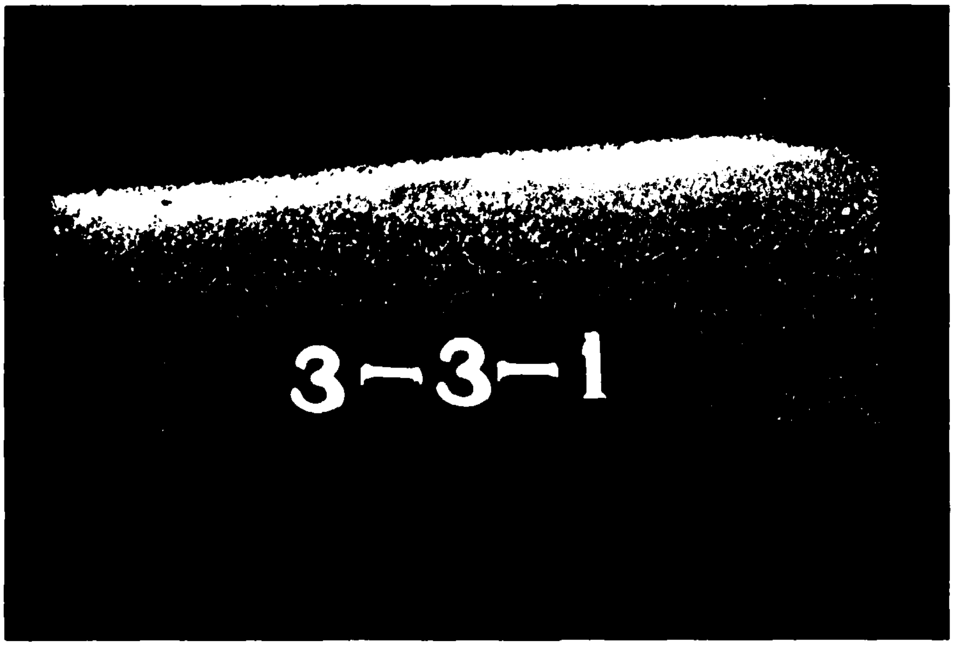


Figure A1-93. Sample 3-3-1, cross-sectional view.

Figure A1-94. Sample 3-1-4 (wet, new foam), perspective view.

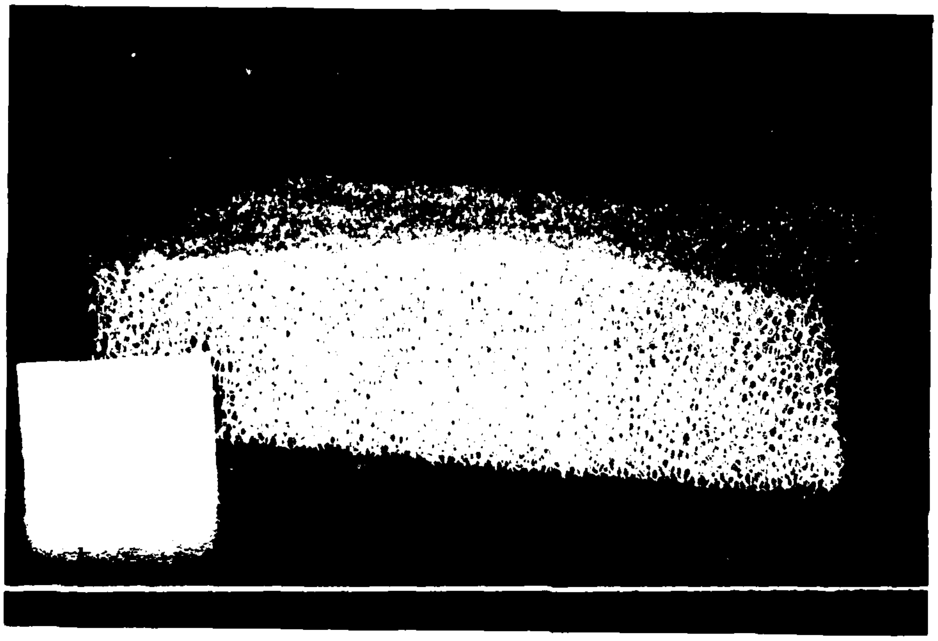


Figure A1-95. Sample 3-1-4 (wet, new foam), cross-sectional view.

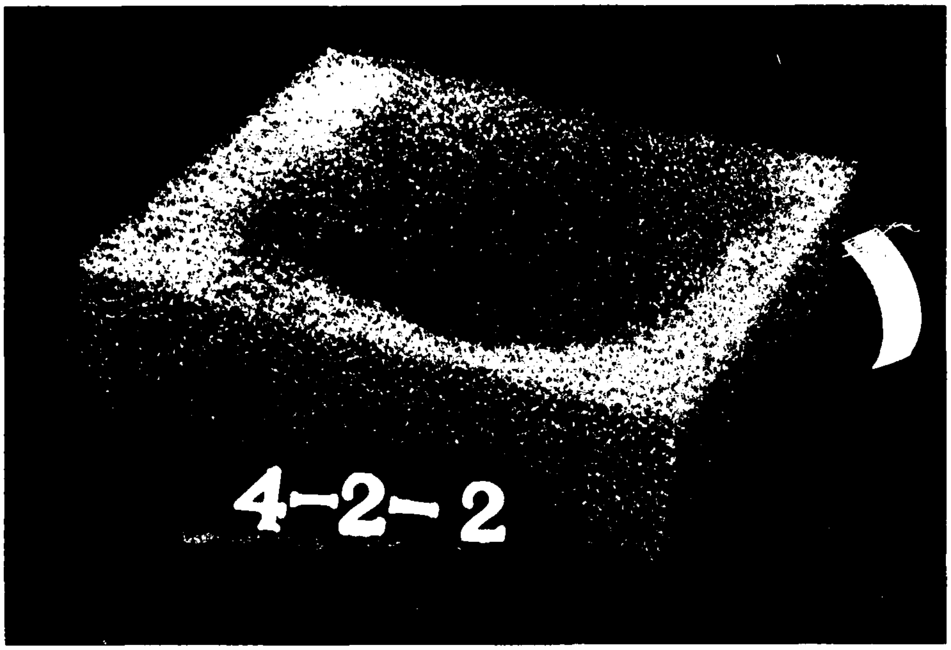


Figure A1-118. Sample 4-2-2, perspective view.

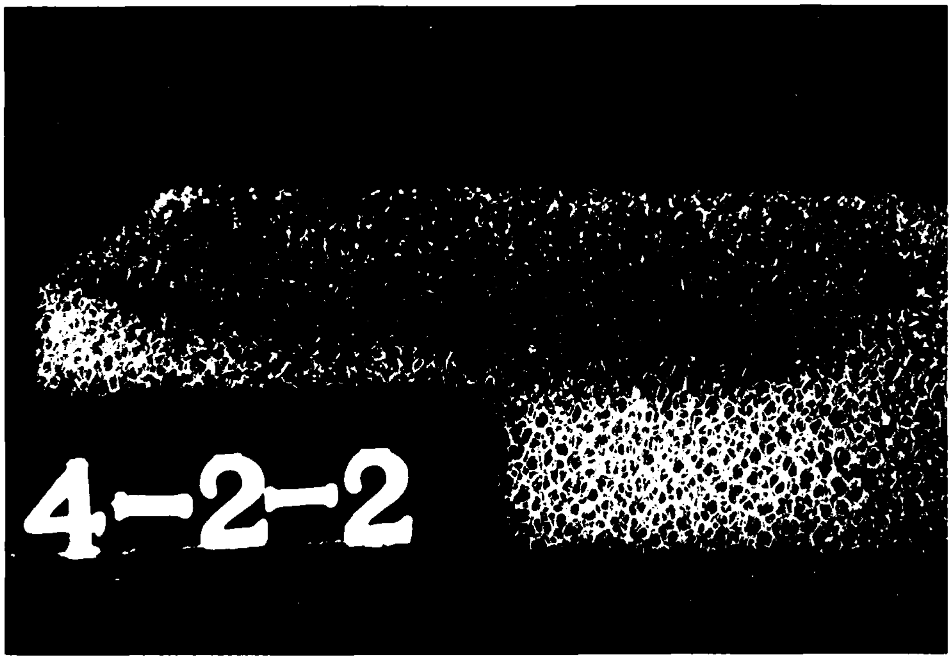


Figure A1-119. Sample 4-2-2, cross-sectional view.

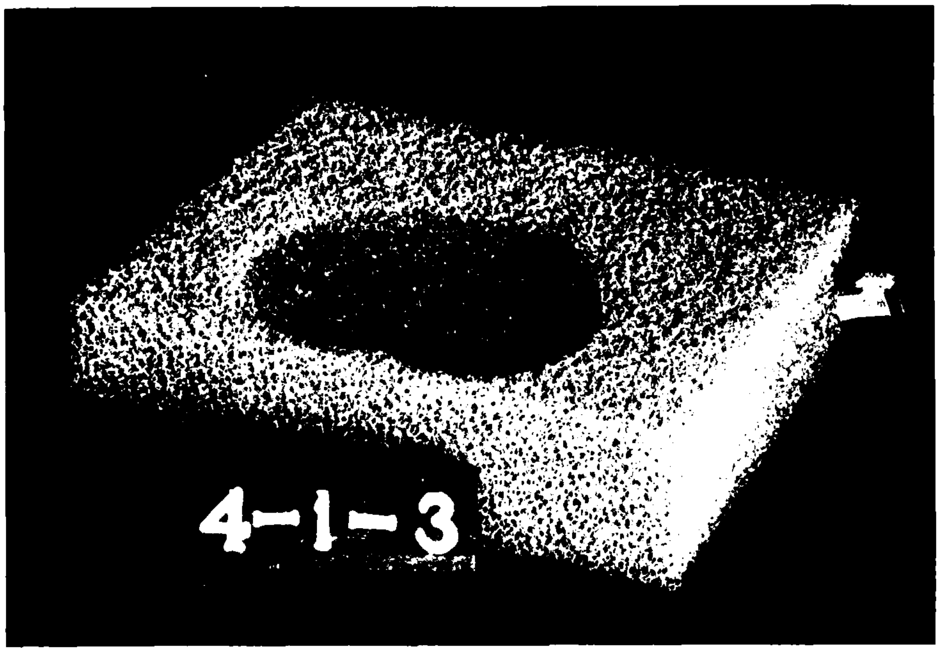


Figure A1-116. Sample 4-1-3, perspective view.

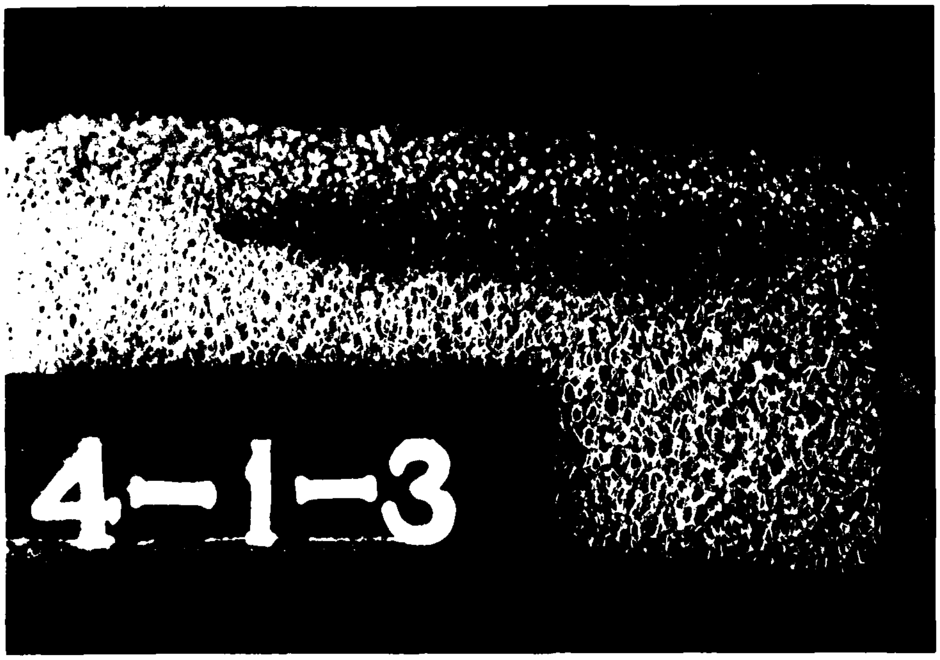


Figure A1-117. Sample 4-1-3, cross-sectional view.

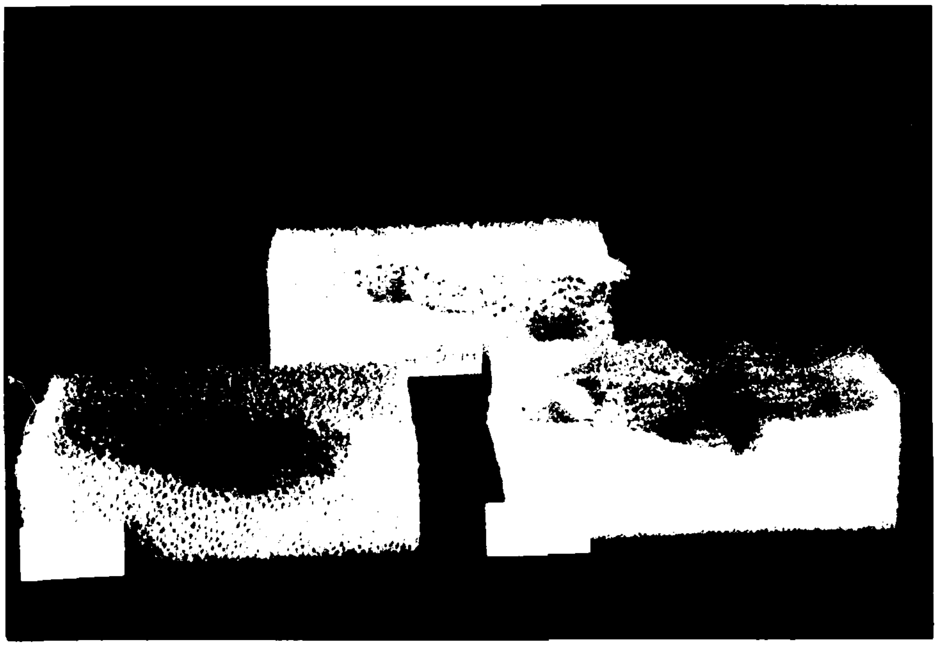


Figure A1-114. Cross-sectional view of blue, red, and yellow foam specimens, subjected to sustained burning by bottom ignition while in horizontal position.

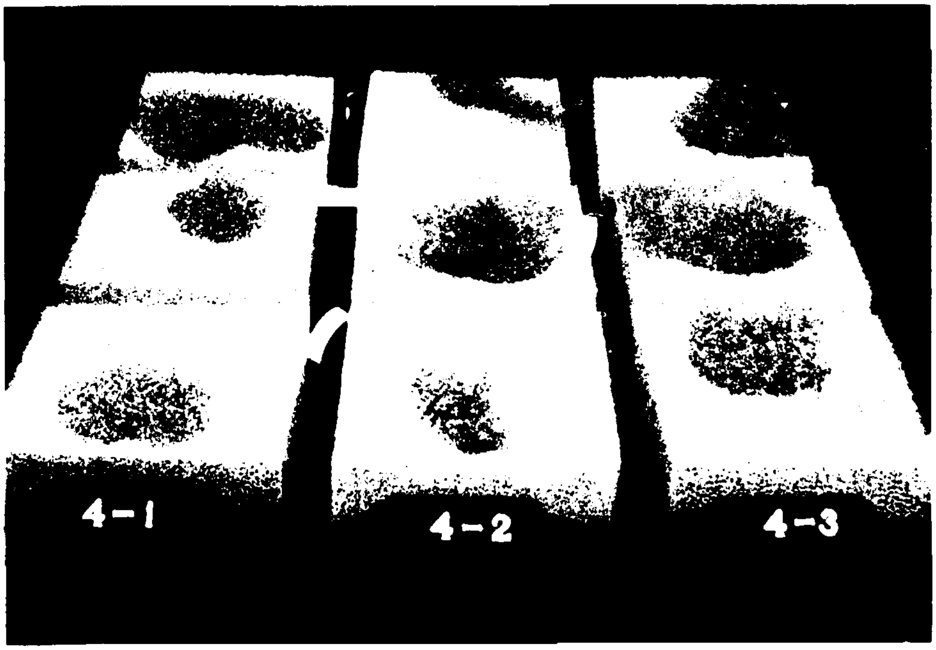


Figure A1-115. Perspective view of blue foam specimens, subjected to sustained burning. Samples ignited by flame from top while in horizontal position, and from bottom while in vertical and horizontal positions, respectively.

A1.9. FIGURES DEPICTING FOAM SAMPLES FROM SUSTAINED BURNING EXPERIMENTS

Samples produced in sustained burning experiments, designated by code in figures, are identified in the following table.

TABLE A1-8. CODE FOR FOAM SPECIMENS PRODUCED BY SUSTAINED BURNING

Foam	Sample size, in.	Horizontal, top ignition	Vertical, bottom ignition	Horizontal, bottom ignition
Blue, dry, new	6x6x2	4-1-1	4-2-1	4-3-1
	6x6x2	4-1-2	4-2-2	4-3-2
	6x6x2	4-1-3	4-2-3	4-3-3
Blue, wet, new	6x6x2	4-1-4	4-2-4	
	6x6x2	4-1-5	4-2-5	
Blue, dry, aged	3x3x2	4-1-9		
Red, dry, new	6x6x2	4-1-10	4-2-10	4-3-10
	6x6x2	4-1-11	4-2-11	4-3-11
	6x6x2	4-1-12	4-2-12	4-3-12
Yellow, dry, new	6x6x2	4-1-13	4-2-13	4-3-13
	6x6x2	4-1-14	4-2-14	4-3-14
	6x6x2	4-1-15	4-2-15	4-3-15

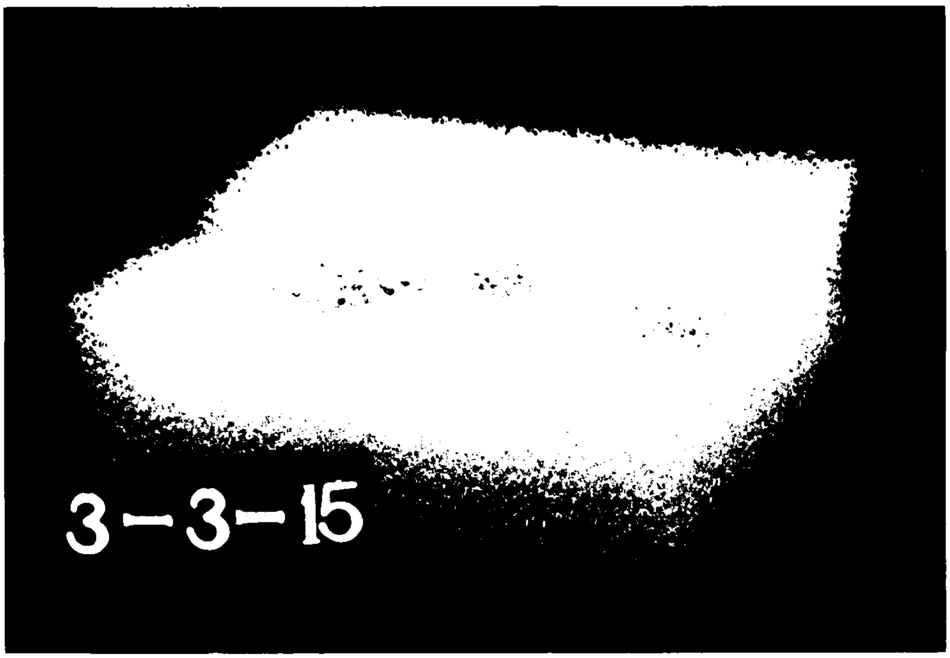


Figure A1-112. Sample 3-3-15, perspective view.

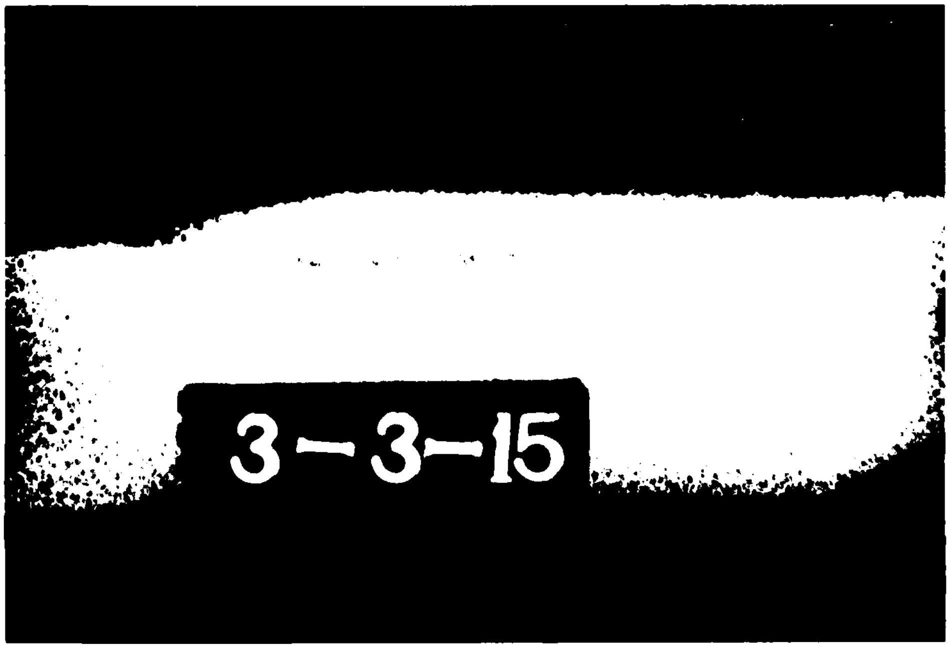


Figure A1-113. Sample 3-3-15, cross-sectional view.

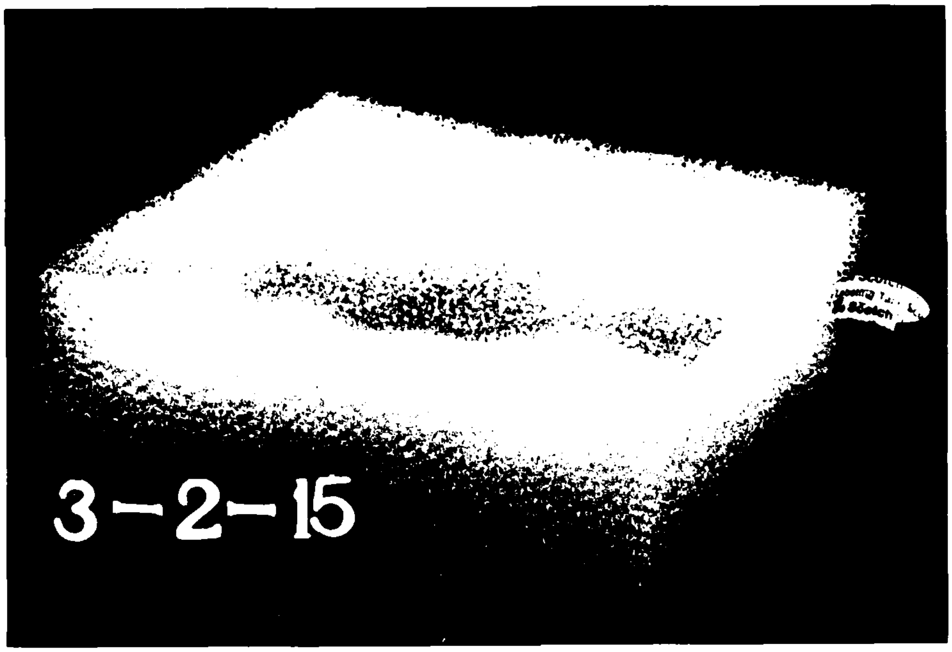


Figure A1-110. Sample 3-2-15, perspective view.

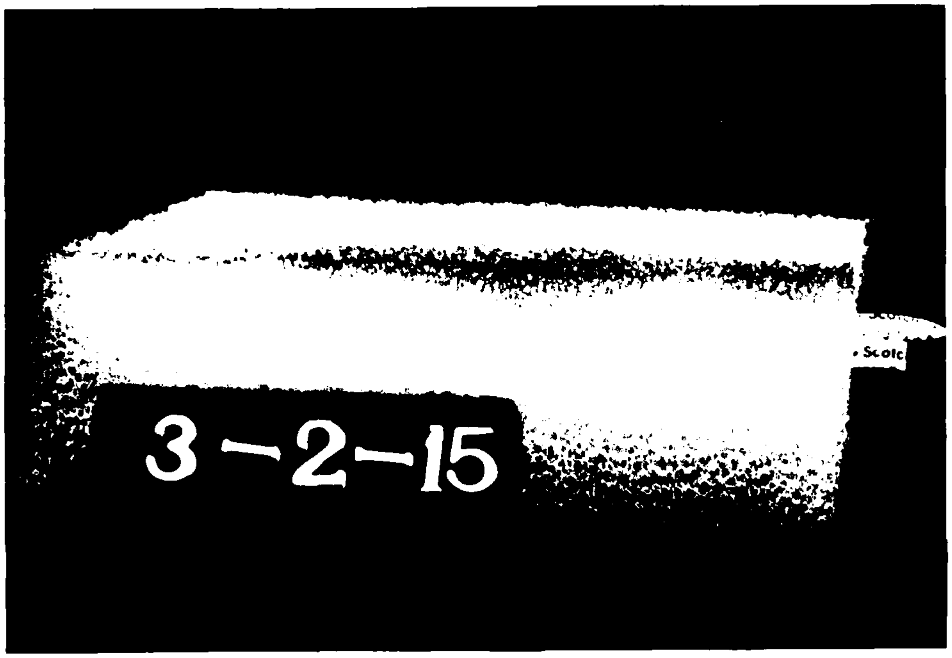


Figure A1-111. Sample 3-2-15, cross-sectional view.

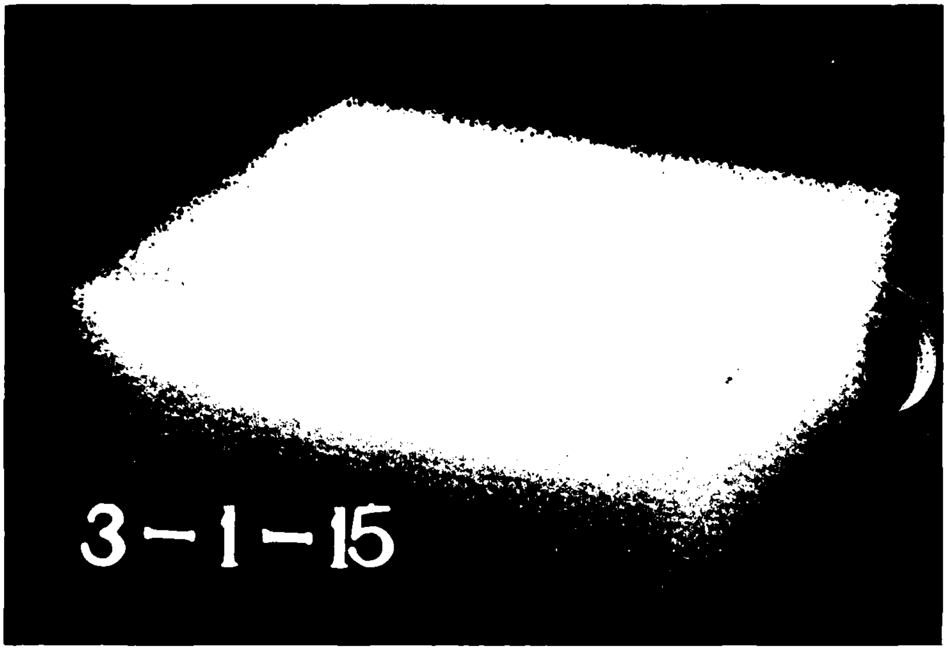


Figure A1-108. Sample 3-1-15, perspective view.

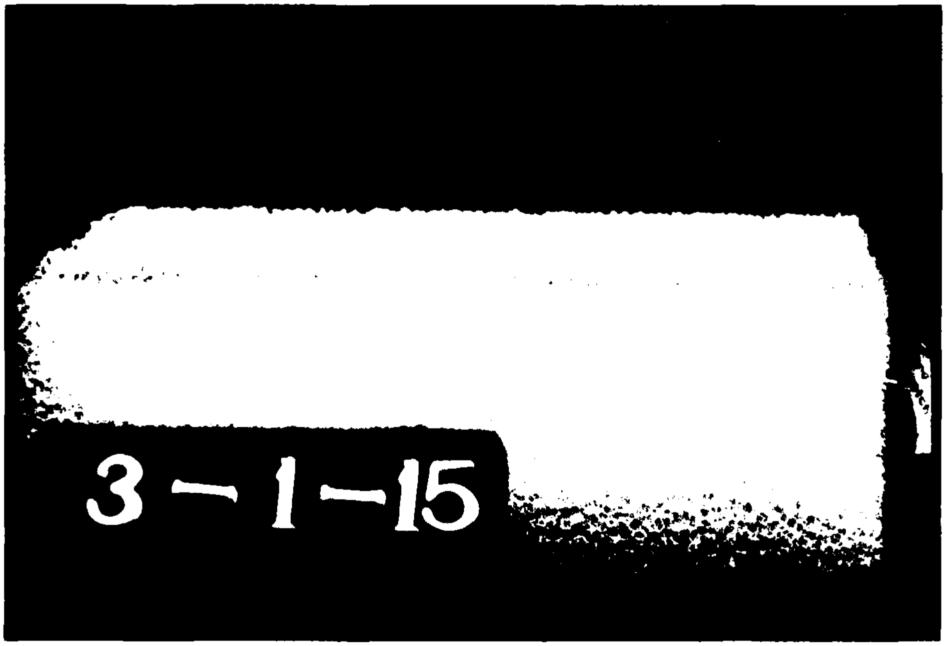


Figure A1-109. Sample 3-1-15, cross-sectional view.

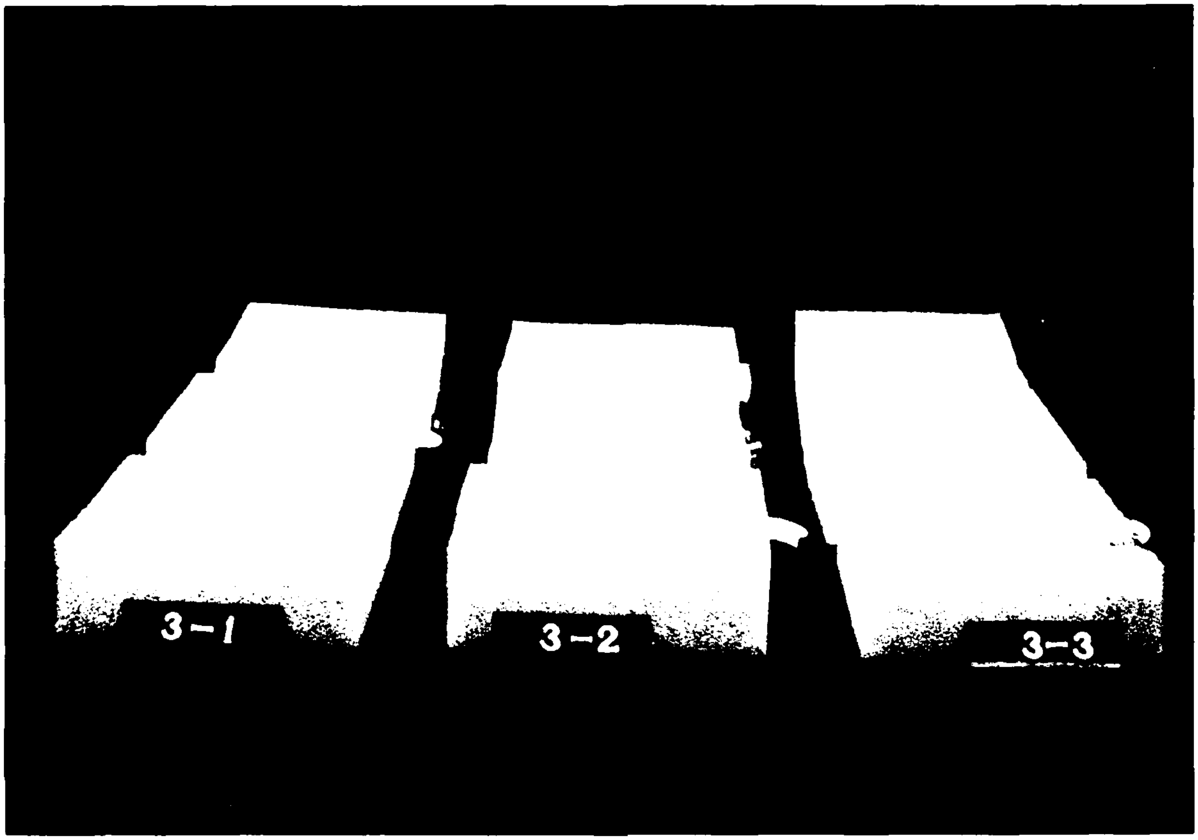


Figure A1-107. Perspective view of yellow foam specimens, subjected to brief flame impingement from top while in horizontal position, and from bottom while in vertical and horizontal positions, respectively.

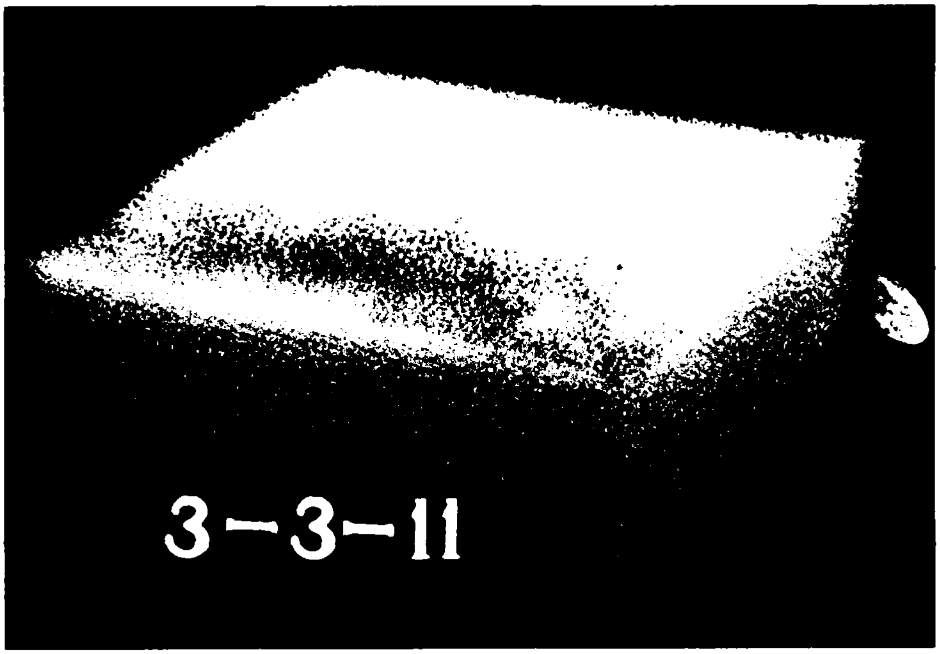


Figure A1-105. Sample 3-3-11, perspective view.

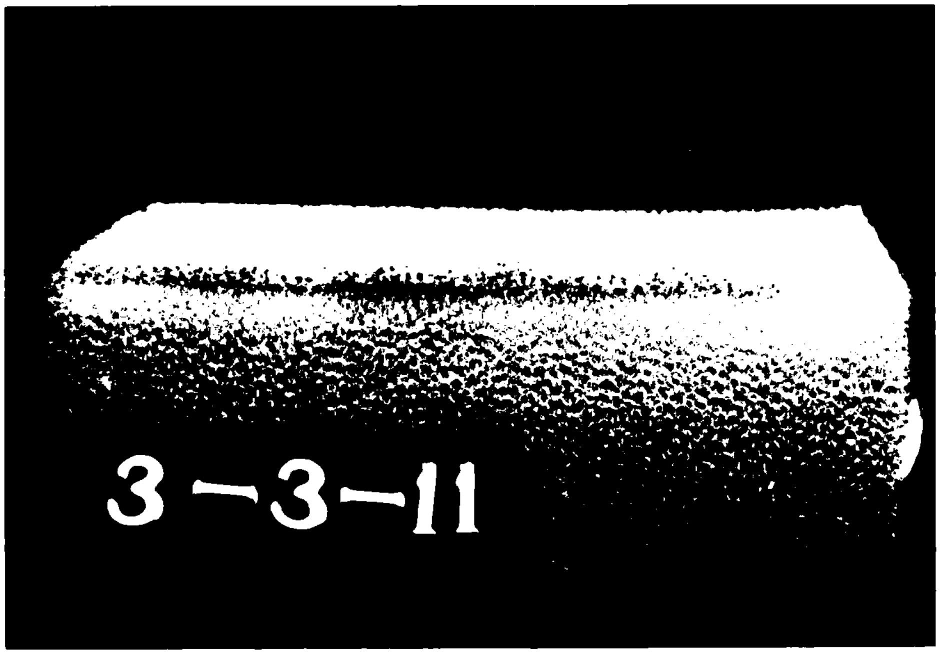


Figure A1-106. Sample 3-3-11, cross-sectional view.

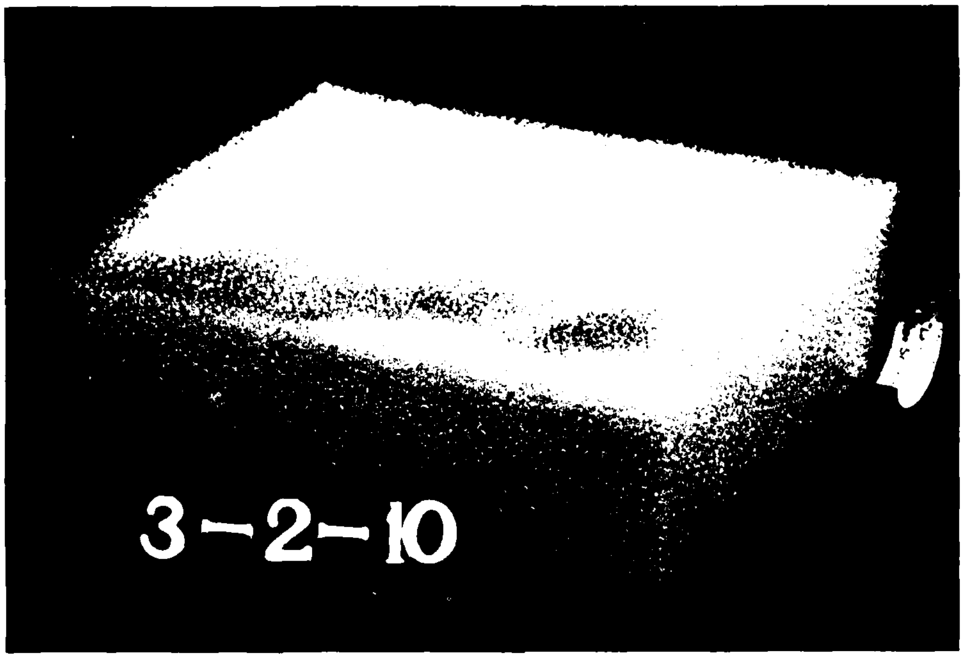


Figure A1-103. Sample 3-2-10, perspective view.

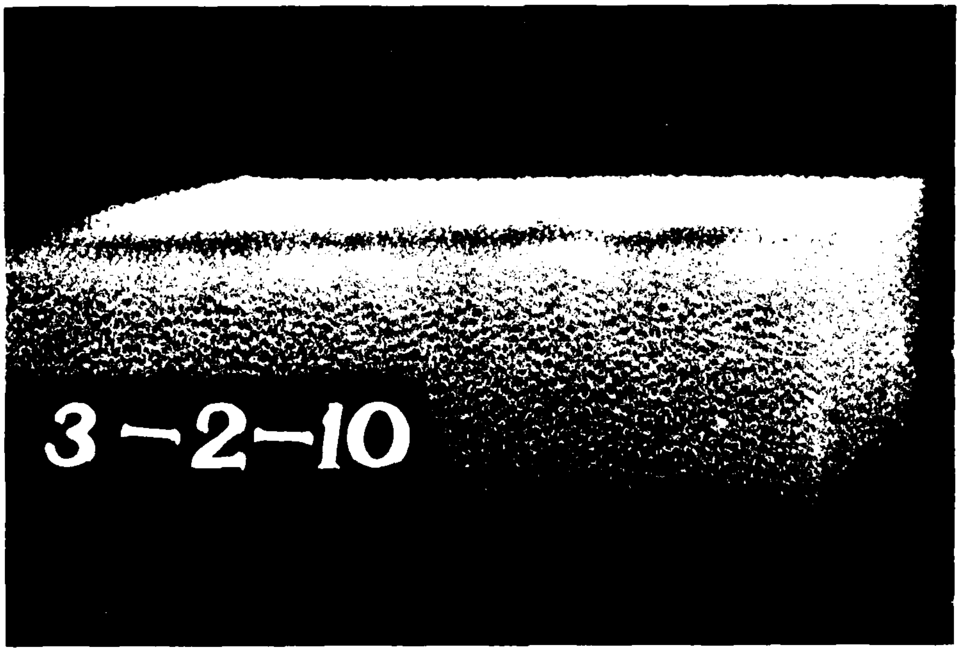


Figure A1-104. Sample 3-2-10, cross-sectional view.

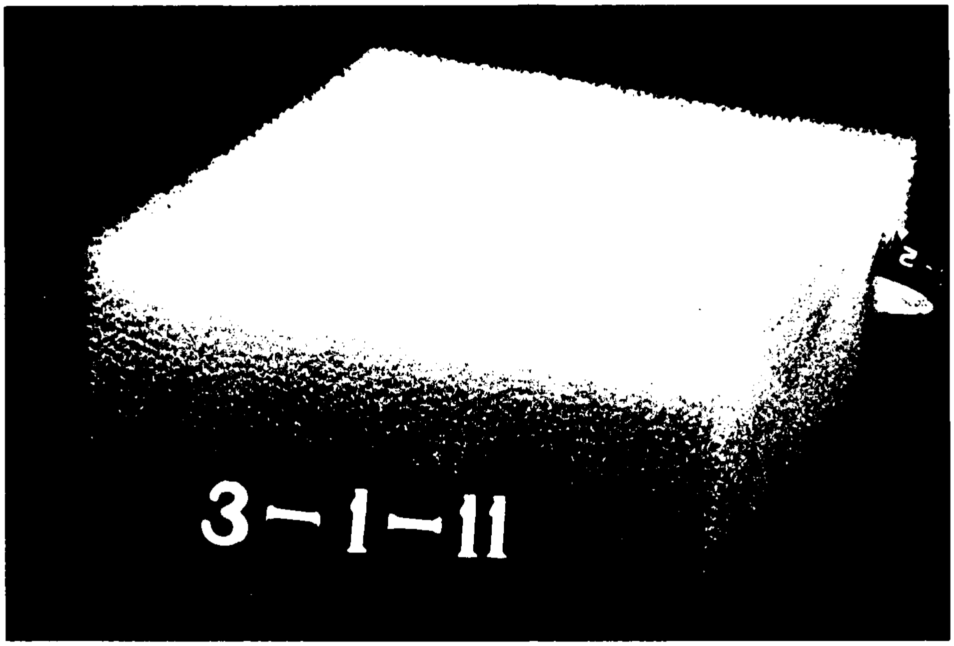


Figure A1-101. Sample 3-1-11, perspective view.

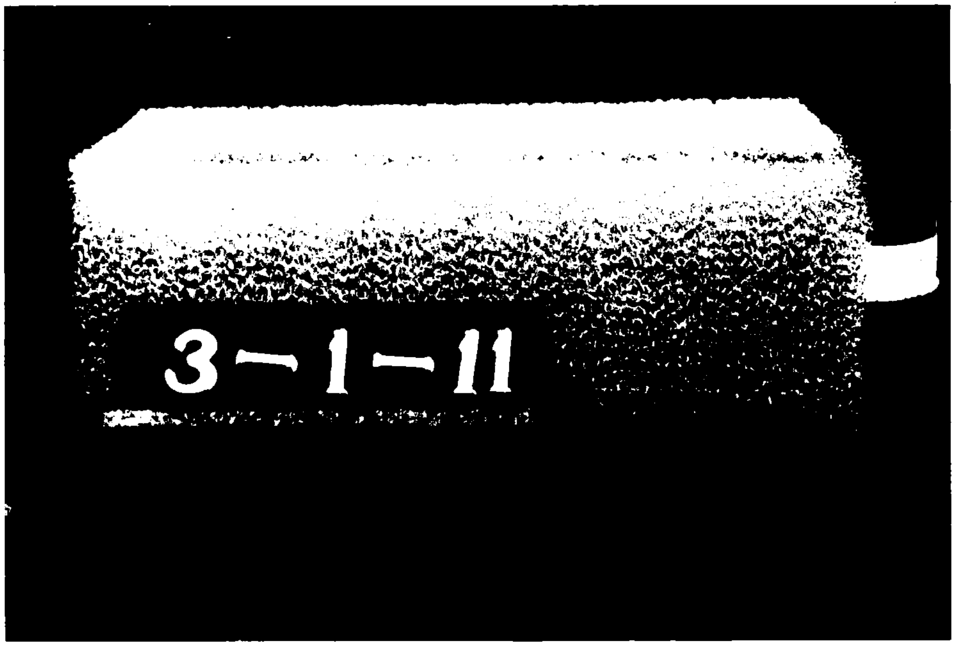


Figure A1-102. Sample 3-1-11, cross-sectional view.

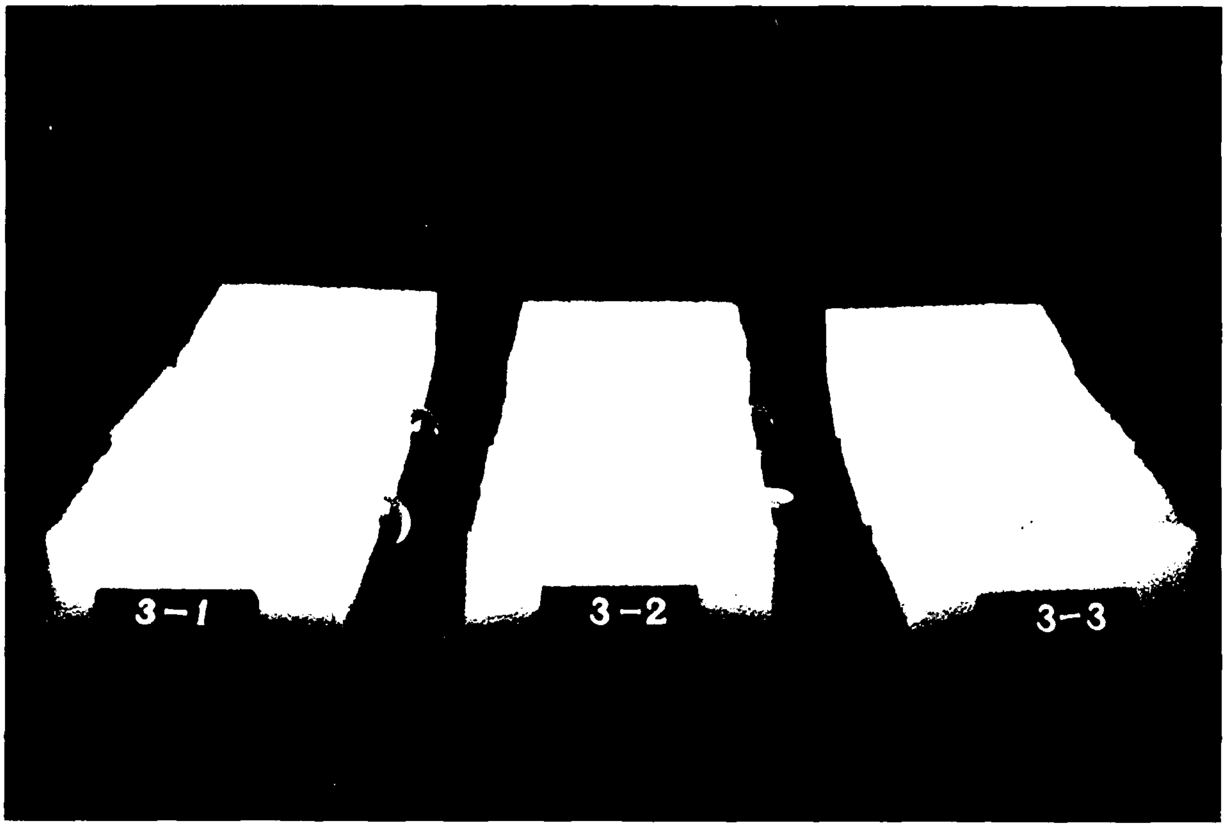


Figure A1-100. Perspective view of red foam specimens, subjected to brief flame impingement from top while in horizontal position, and from bottom while in vertical and horizontal positions, respectively.

Figure A1-98. Sample 3-1-9 (dry, aged foam), perspective view.

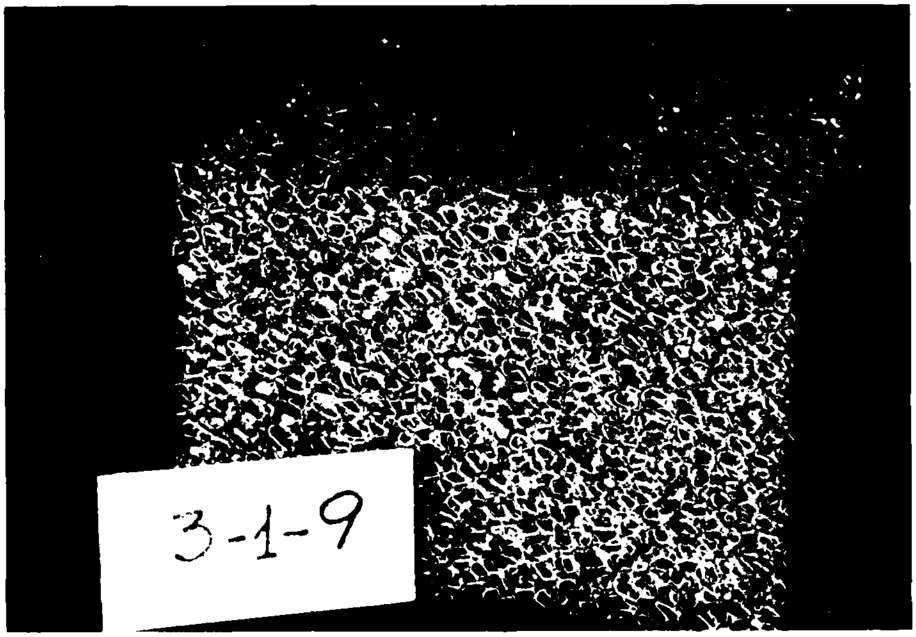


Figure A1-99. Sample 3-1-9 (dry, aged foam), cross-sectional view.

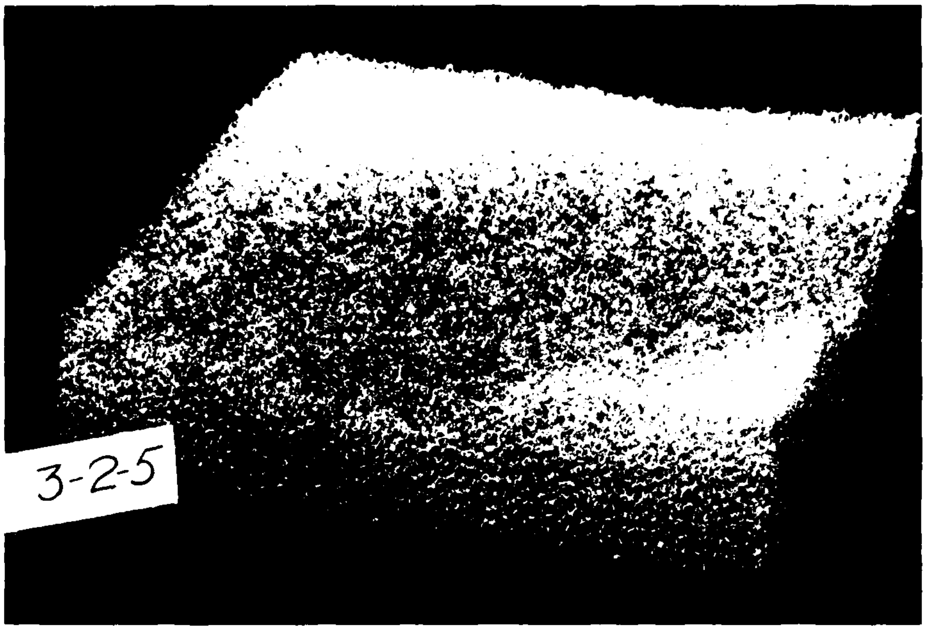


Figure A1-96. Sample 3-2-5 (wet, new foam), perspective view.

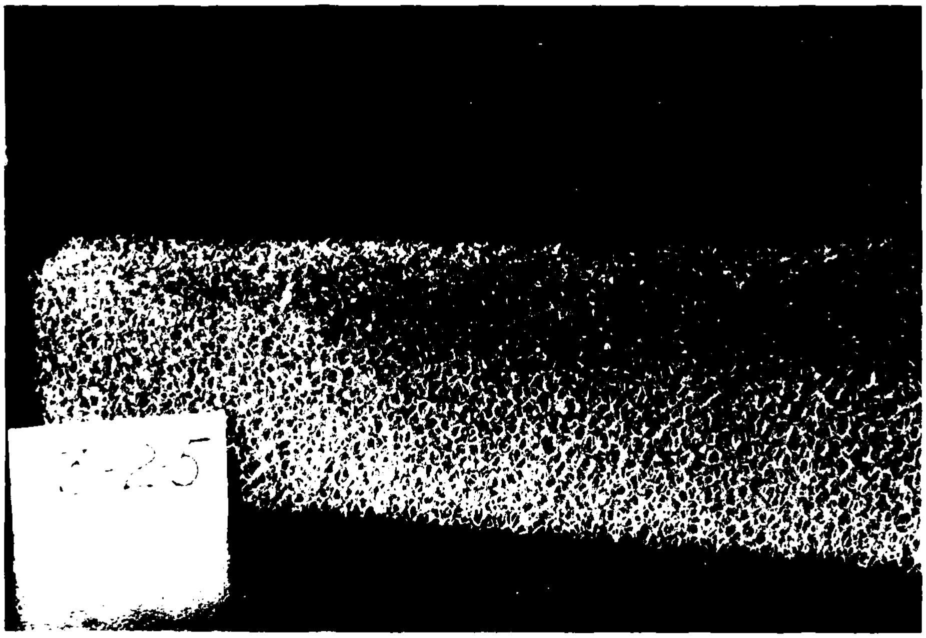


Figure A1-97. Sample 3-2-5 (wet, new foam), cross-sectional view.

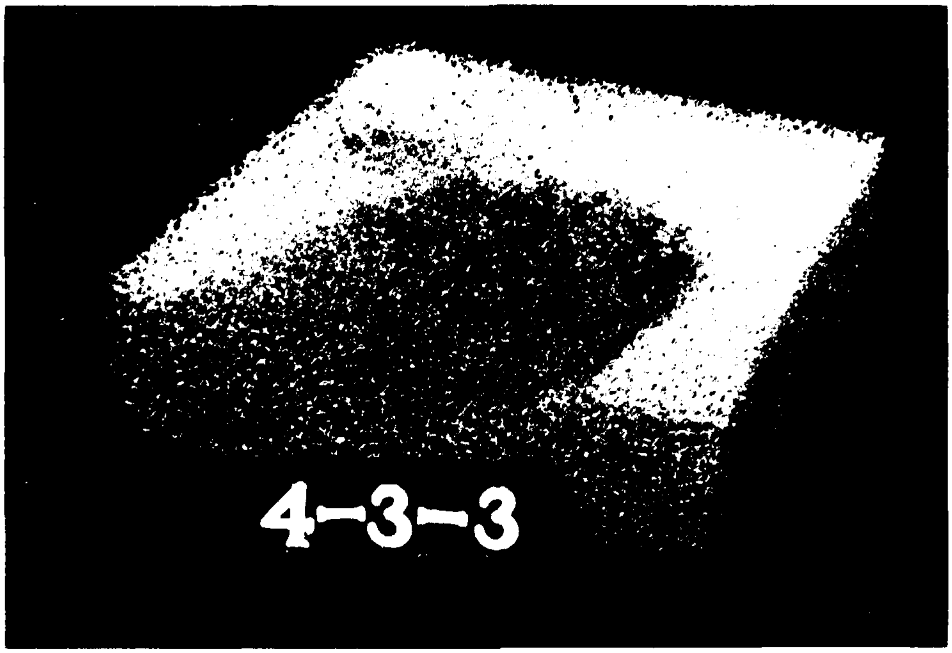


Figure A1-120. Sample 4-3-3, perspective view.

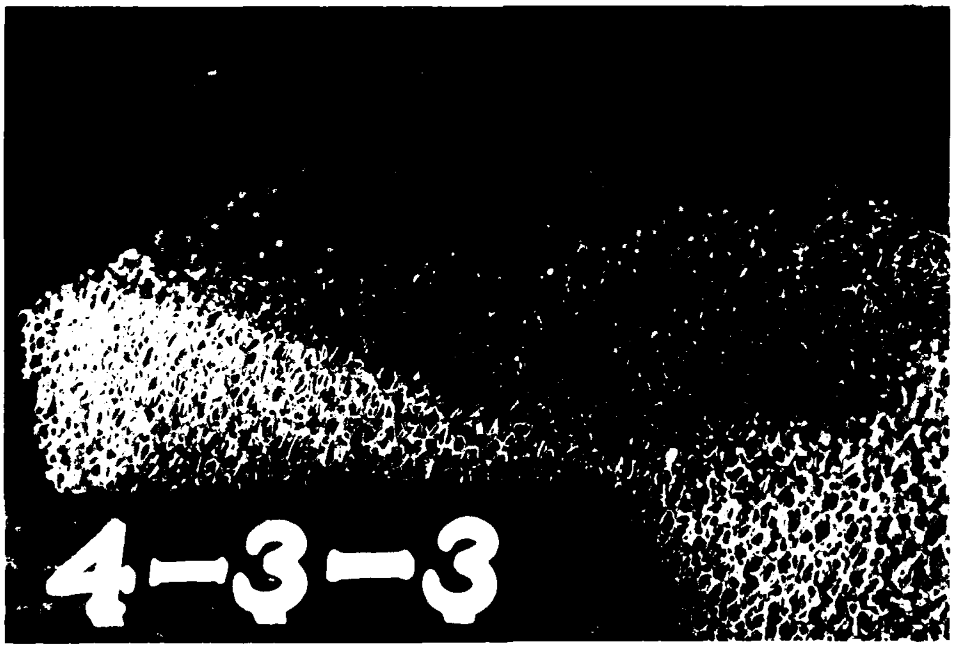


Figure A1-121. Sample 4-3-3, cross-sectional view.

Figure A1-122. Sample 4-1-4 (wet, new foam), perspective view.

Figure A1-123. Sample 4-1-4 (wet, new foam), cross-sectional view.

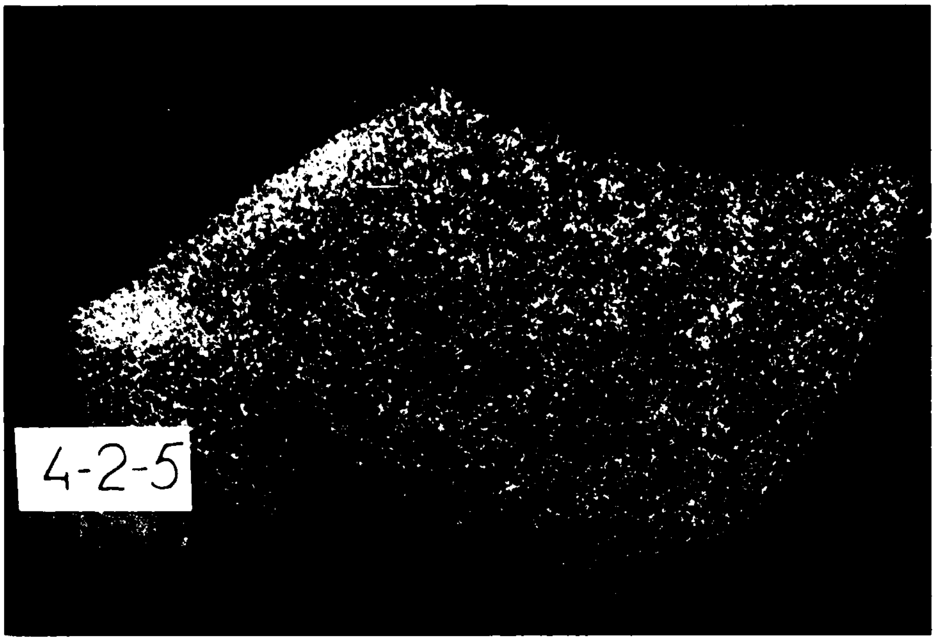


Figure A1-124. Sample 4-2-5 (wet, new foam), perspective view.

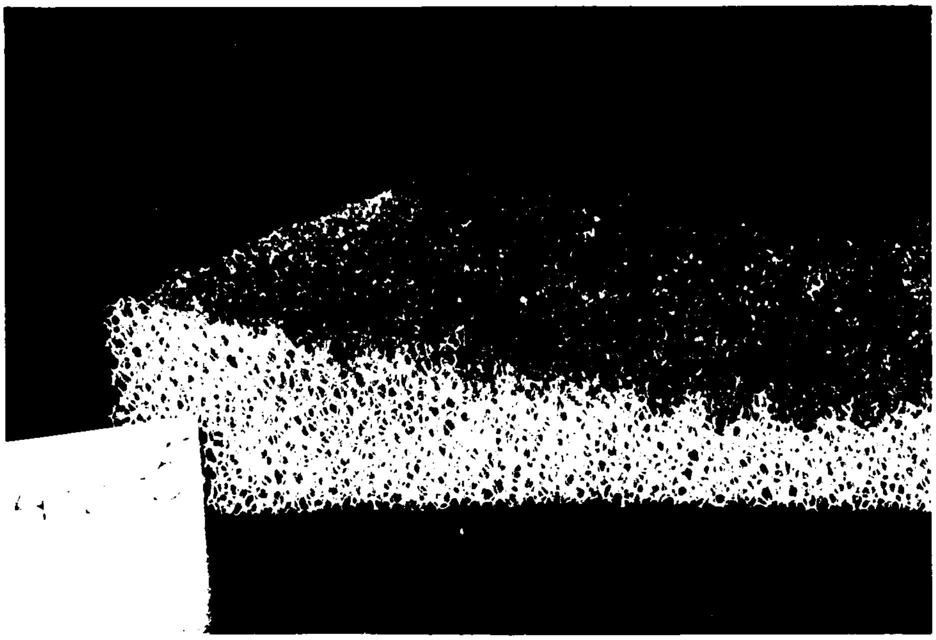


Figure A1-125. Sample 4-2-5 (wet, new foam), cross-sectional view.

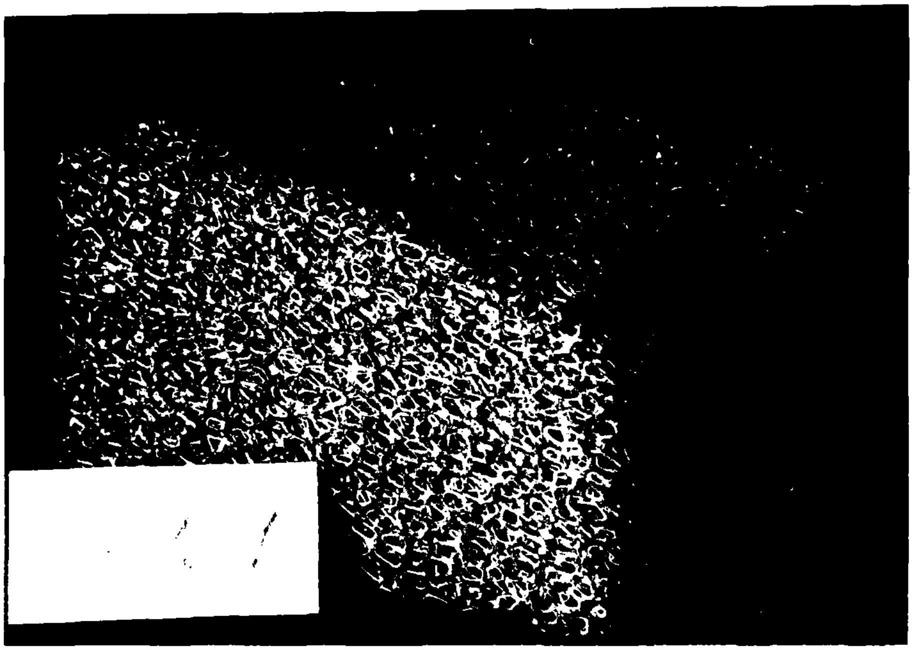


Figure A1-126. Sample 4-1-9 (aged, dry foam), perspective view.

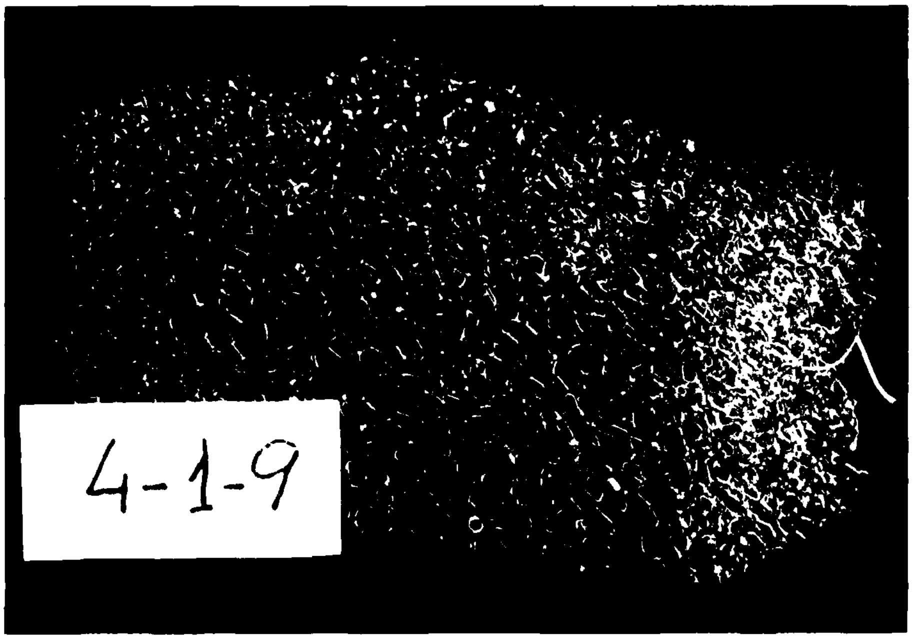


Figure A1-127. Sample 4-1-9 (aged, dry foam), cross-sectional view.

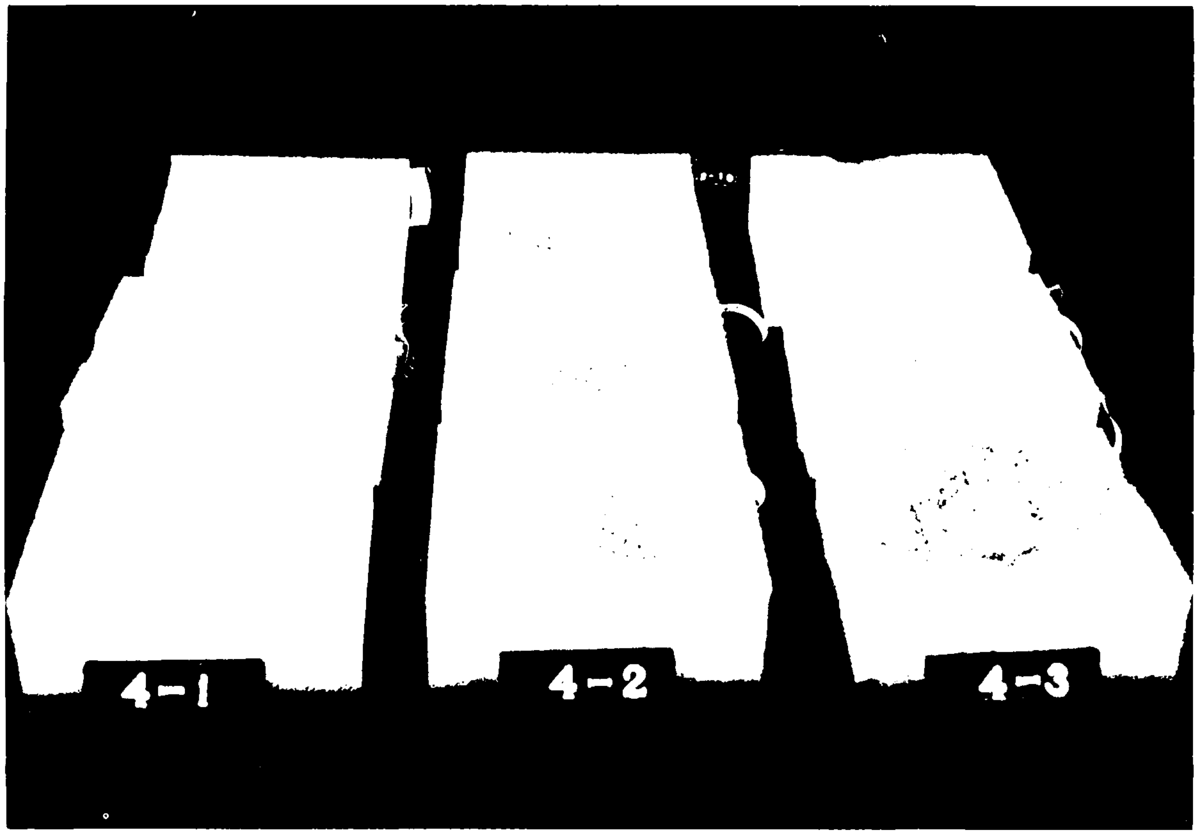


Figure A1-128. Perspective view of red foam specimens, subjected to sustained burning. Samples ignited by flame from top while in horizontal position, and from bottom while in vertical and horizontal positions, respectively.

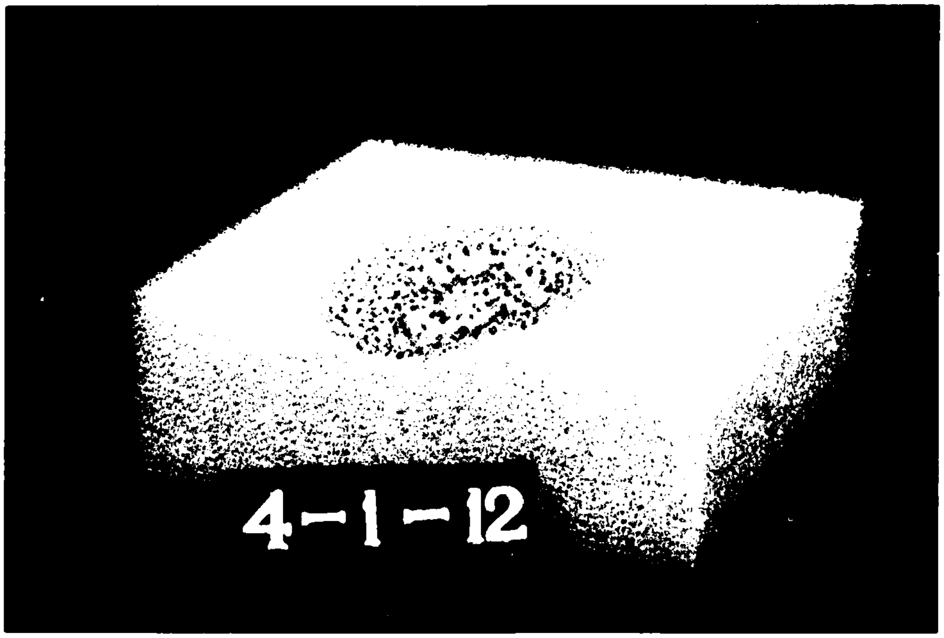


Figure A1-129. Sample 4-1-12, perspective view.

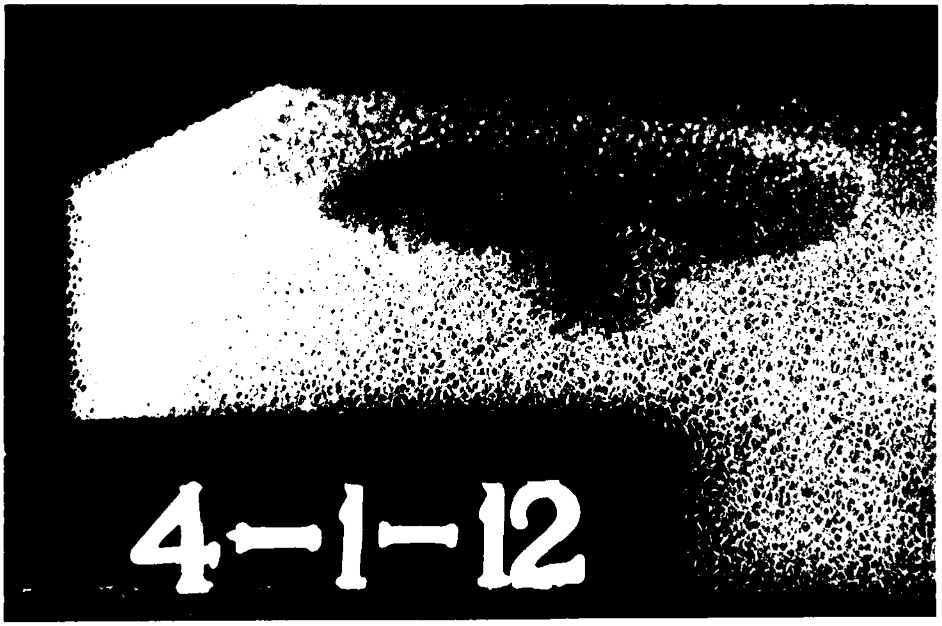


Figure A1-130. Sample 4-1-12, cross-sectional view.

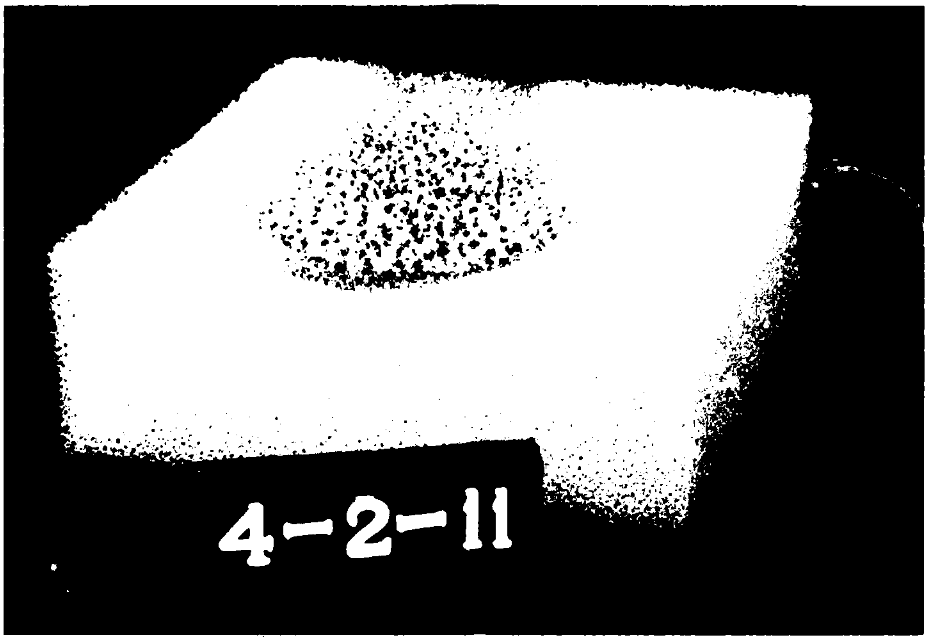


Figure A1-131. Sample 4-2-11, perspective view.

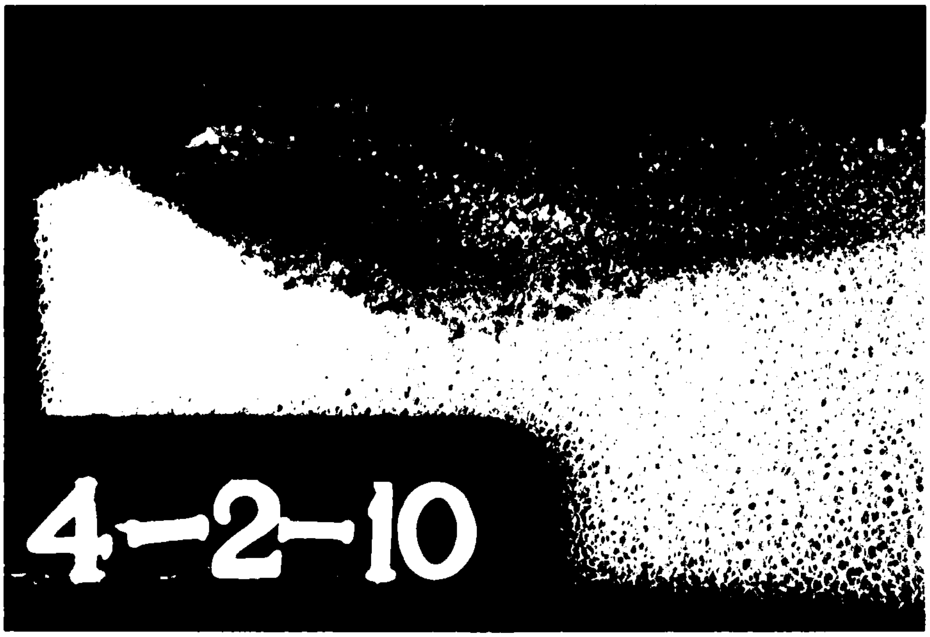


Figure A1-132. Sample 4-2-10, cross-sectional view.

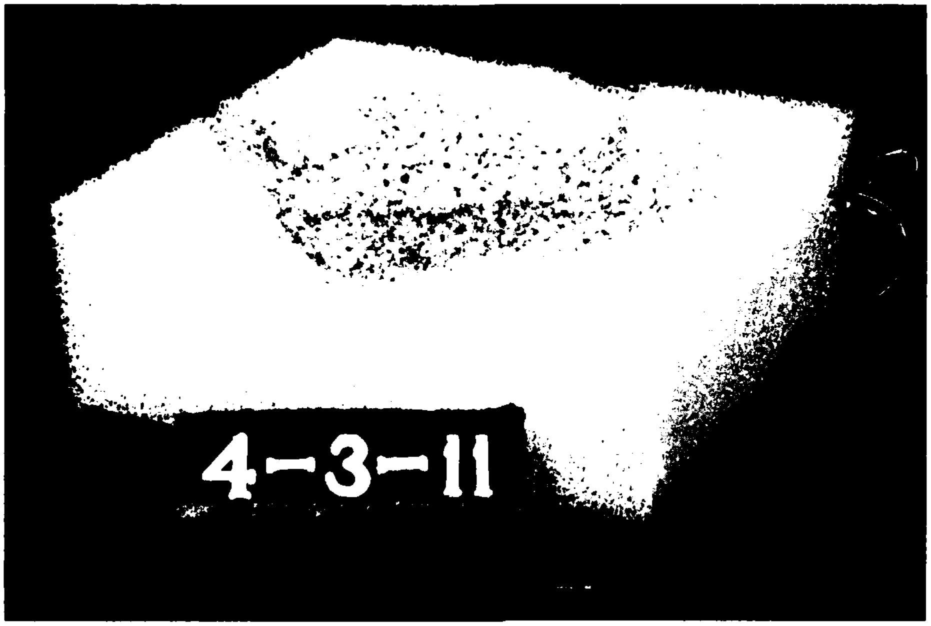


Figure A1-133. Sample 4-3-11, perspective view.

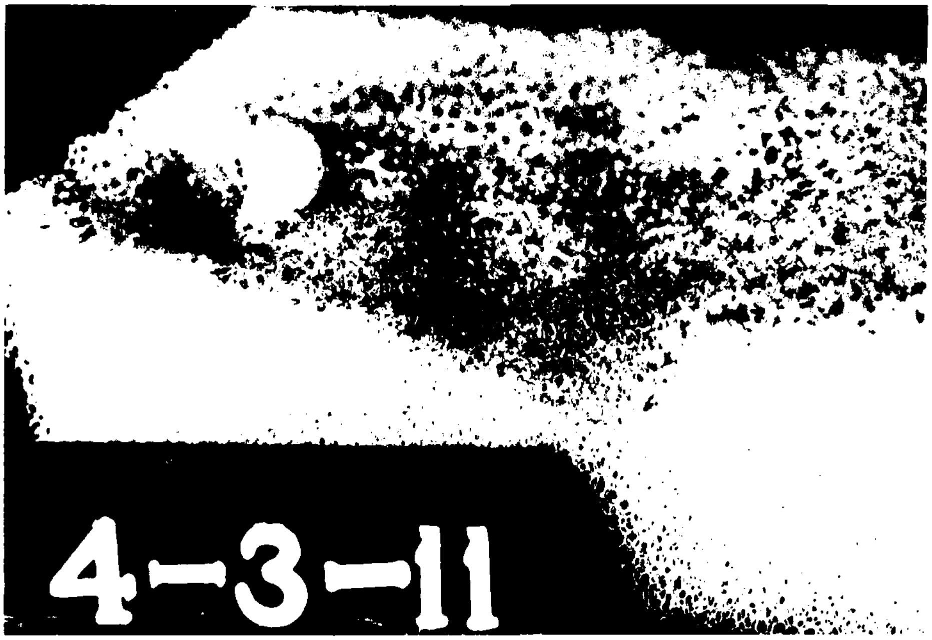


Figure A1-134. Sample 4-3-11, cross-sectional view.

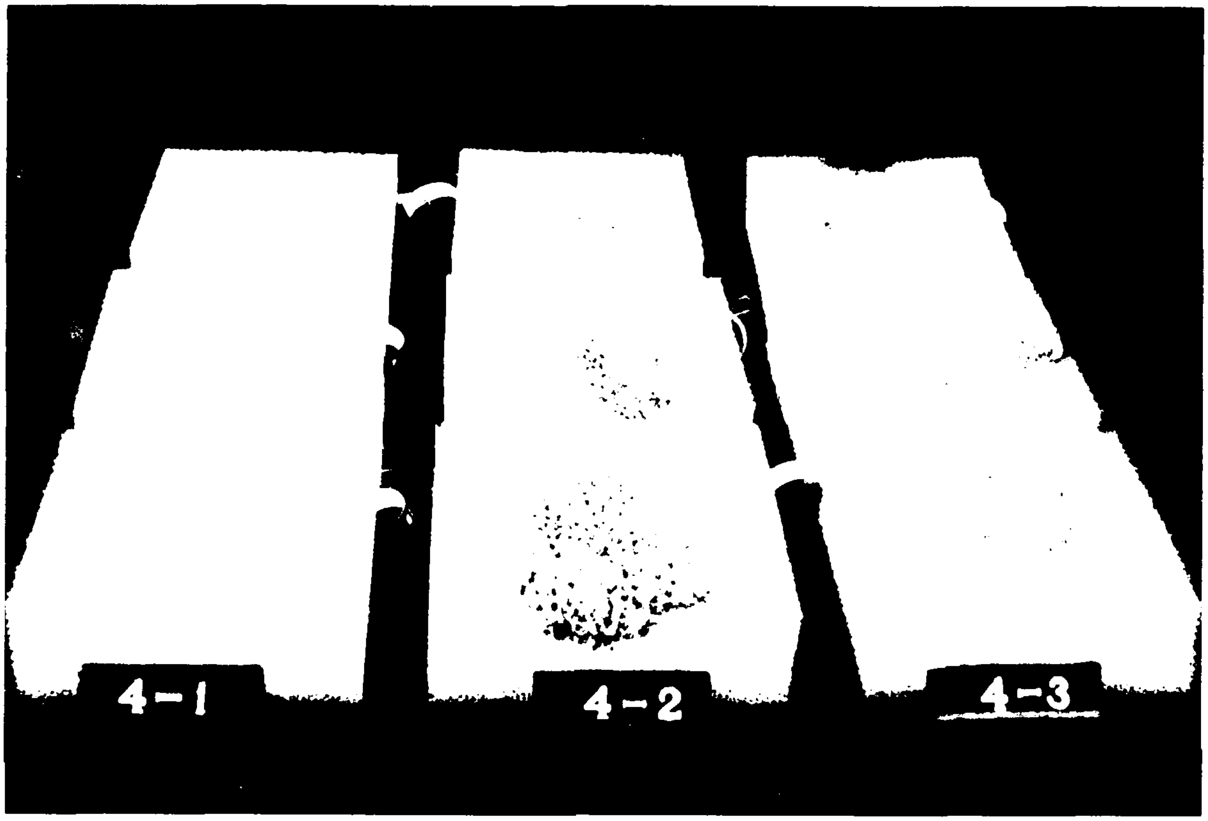


Figure A1-135. Perspective view of yellow foam specimens, subjected to sustained burning. Samples ignited by flame from top while in horizontal position, and from botton while in vertical and horizontal positions, respectively.

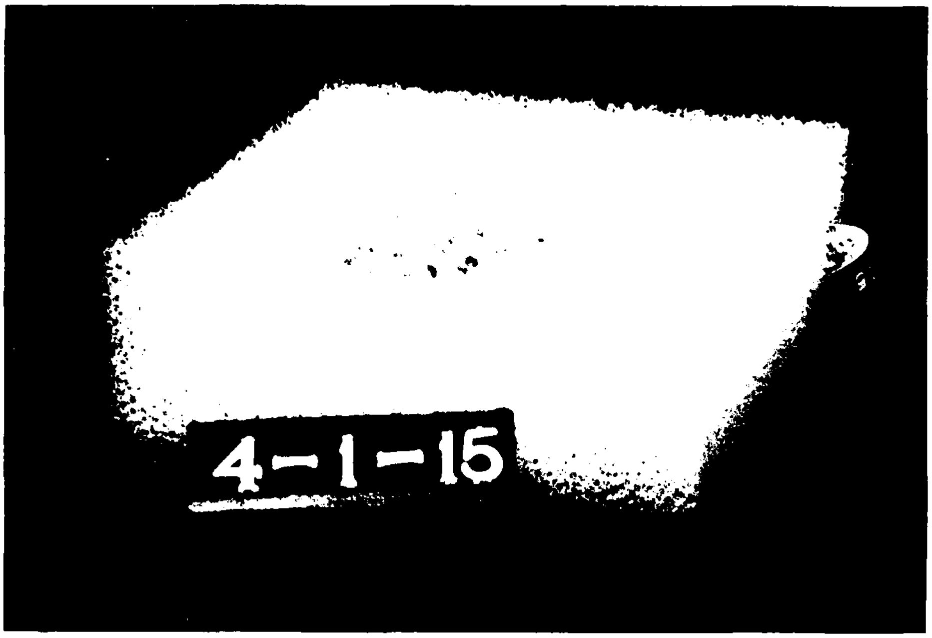


Figure A1-136. Sample 4-1-15, perspective view.

Figure A1-137. Sample 4-1-15, cross-sectional view.

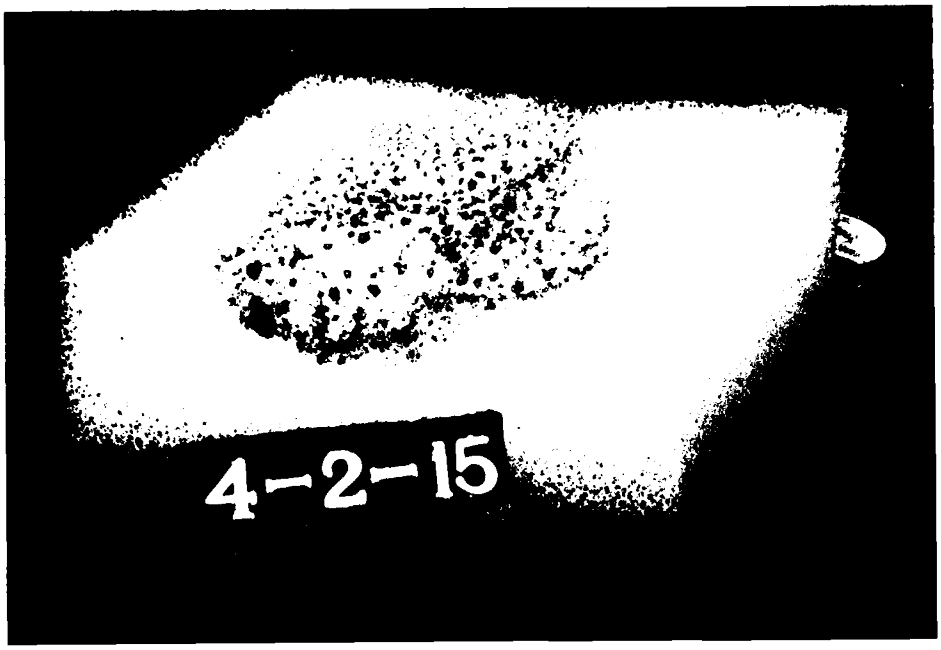


Figure A1-138. Sample 4-2-15, perspective view.

Figure A1-139. Sample 4-2-15, cross-sectional view.

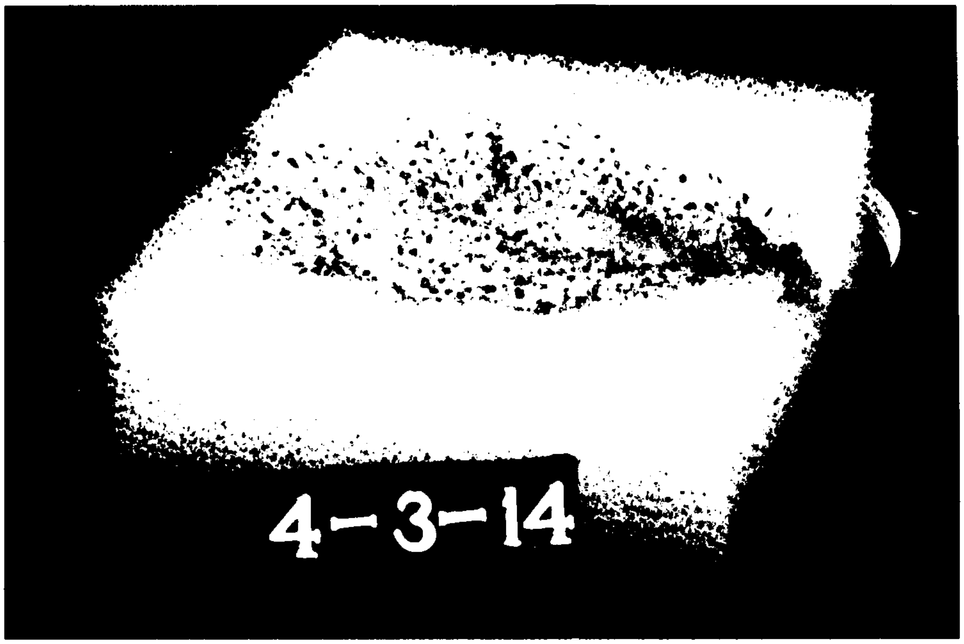


Figure A1-140. Sample 4-3-14, cross-sectional view.

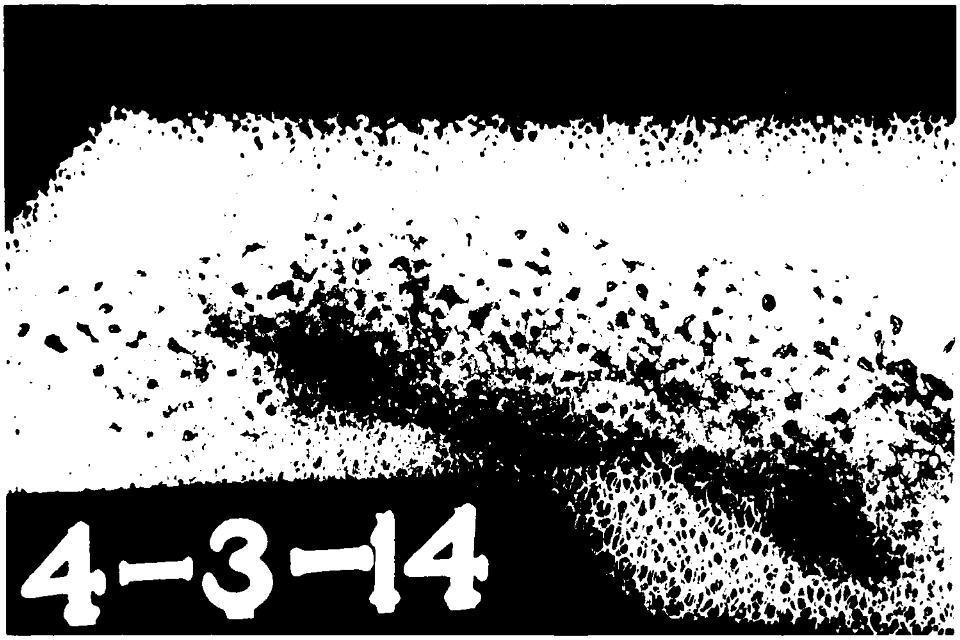


Figure A1-141. Sample 4-3-14, perspective view.

A1.10. FIGURES DEPICTING FOAM SAMPLES FROM FLASH FIRE EXPERIMENTS

Simulated flash fire exposure specimens are identified in Table A1-9. The positions which the samples occupied in the flame tube are shown in Figures A1-142 and A1-143.

TABLE A1-9. FLASH FIRE TESTS WITH FLAME TUBE[a]

Experiment number	Sample designation	Foam specimen	Propane conc., vol.-%	Initial pressure, psia
1	1-1-1	Blue, coarse, dry	3.5	14.4
1	1-A-1	Blue, coarse, dry	3.5	14.4
5	1-1-5	Blue, coarse, dry	5.0	17.7
5	1-2-5	Blue, coarse, dry	5.0	17.7
7	1-D-7	Blue, coarse, dry	6.5	17.7
10	1-D-10	Blue, coarse, dry	6.5	14.4
11	1-1-11	Yellow, dry	3.5	14.4
12	1-1-12	Yellow, dry	5.0	14.4
14	1-1-14	Red, dry	3.5	14.4
16	1-1-16	Red, dry	6.5	14.4
17	1-1-17	Blue, coarse, dry, aged 80 hours in sunlight	3.5	14.4
20	1-1-20	Blue, coarse, wetted with JP-5	3.5	14.4
22	1-1-22	Blue, coarse, wetted with JP-5	2.0	14.2
23	1-1-23	Yellow, wetted with JP-5	3.5	14.3
25	1-1-25	Yellow, wetted with JP-5	2.0	14.3
26	1-A-26	Blue, coarse, dry	3.5	14.3
28	1-3-28	Blue, coarse, dry	6.5	14.3
31	1-3-31	Red, dry	6.5	14.4
34	1-3-34	Yellow, dry	6.5	14.4
37	1-3-37	Blue, coarse,	6.5	14.3
39	1-E-39	Yellow, wetted with JP-5	5.0	14.4
40	1-3-40	Yellow, wetted with JP-5	6.5	14.4
43	1-3-43	Red, wetted with JP-5	6.5	14.3

---

[a] Tests 1-25 were unvented; tests 26-43 were vented. The total void volume in unvented tests was 20% (10% for each void). The vent tube increased the void volume to 22% in vented tests.

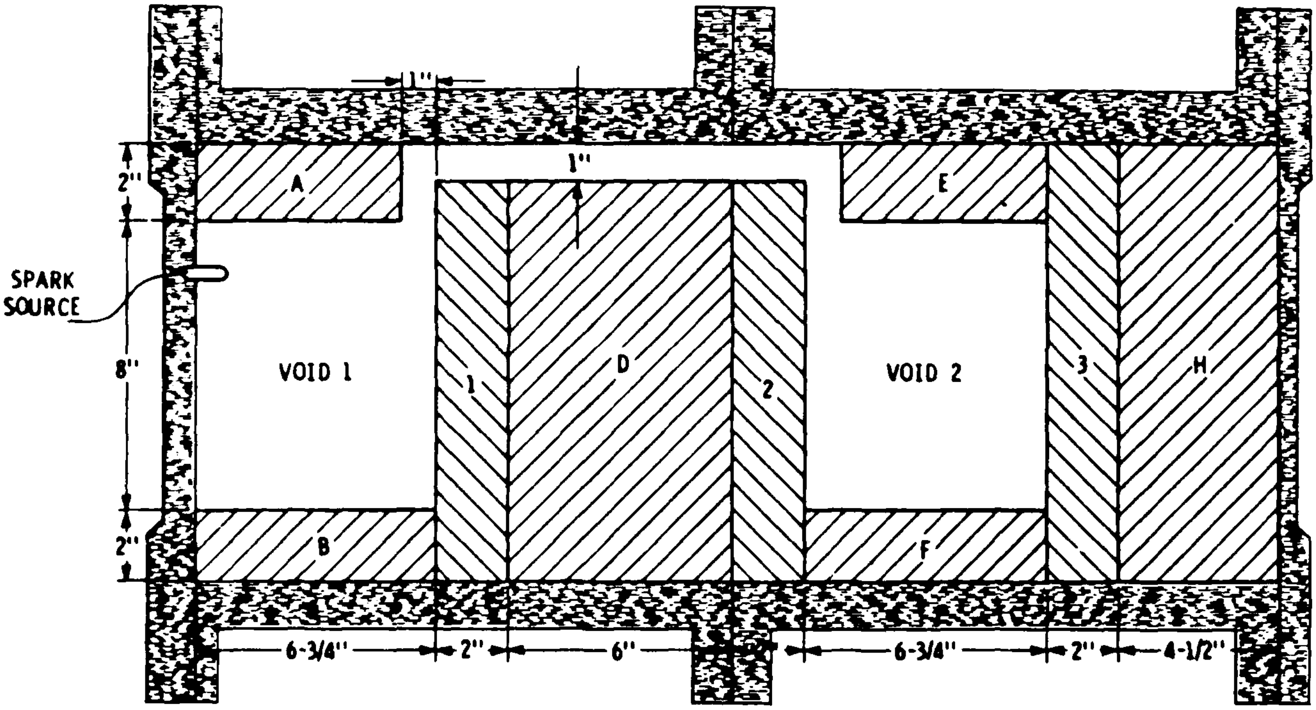


Figure A1-142. Cross-sectional view of flame tube in unvented configuration. (Dashed areas represent polyurethane foam. The opening between Voids 1 and 2 was 1 in. wide.)

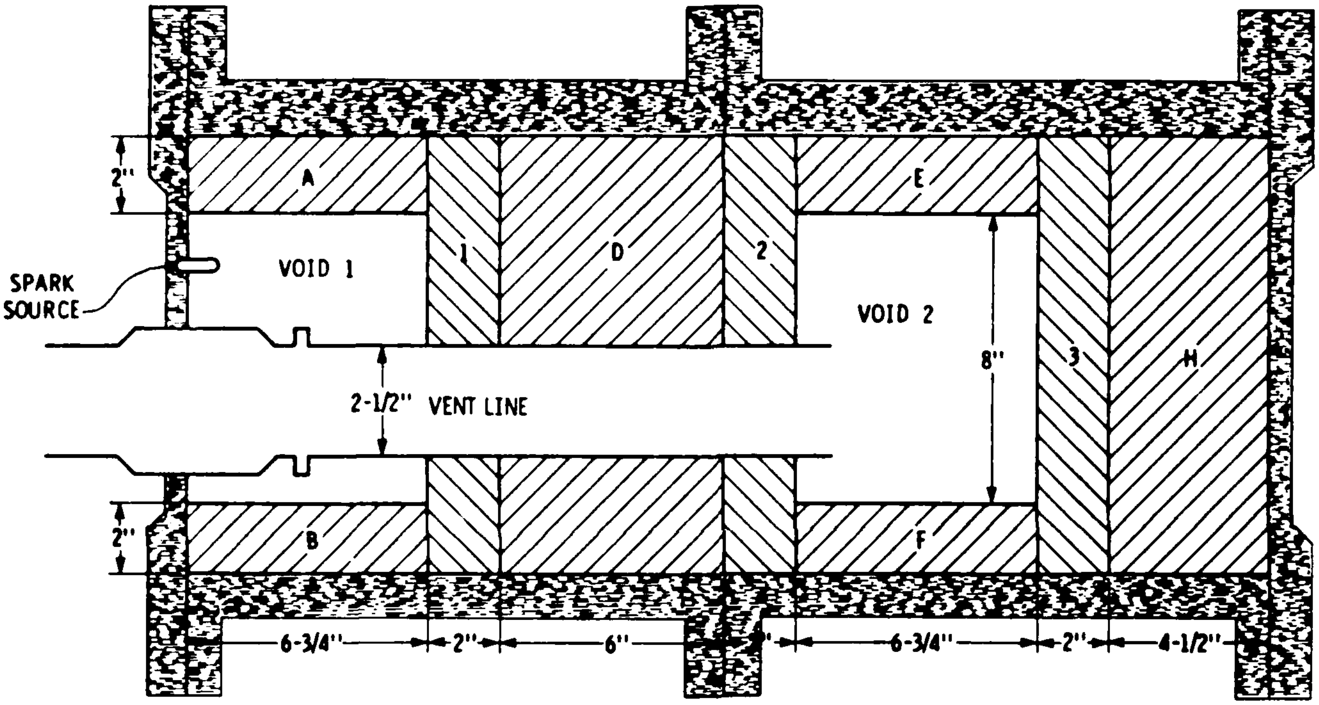


Figure A1-143. Cross-sectional view of flame tube in vented configuration. (Dashed areas represent polyurethane foam.)

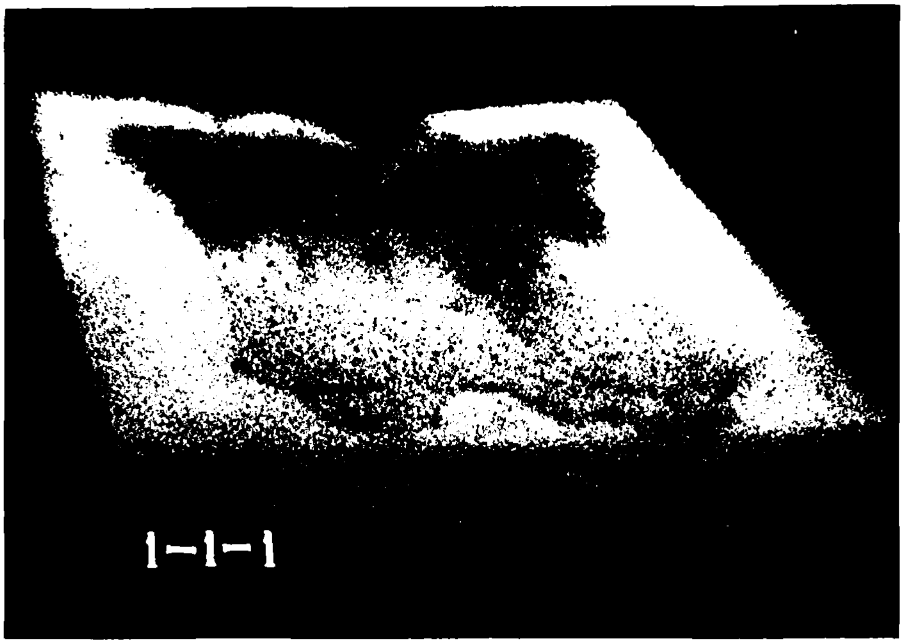


Figure A1-144. Sample 1-1-1, perspective front view.

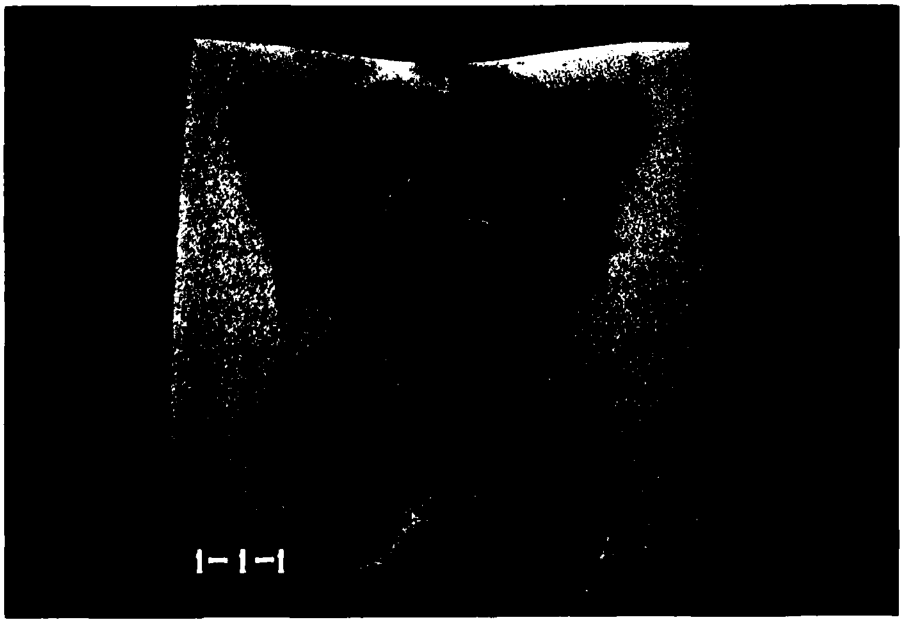


Figure A1-145. Sample 1-1-1, direct front view.

Figure A1-146. Sample 1-1-1, close-up front view.

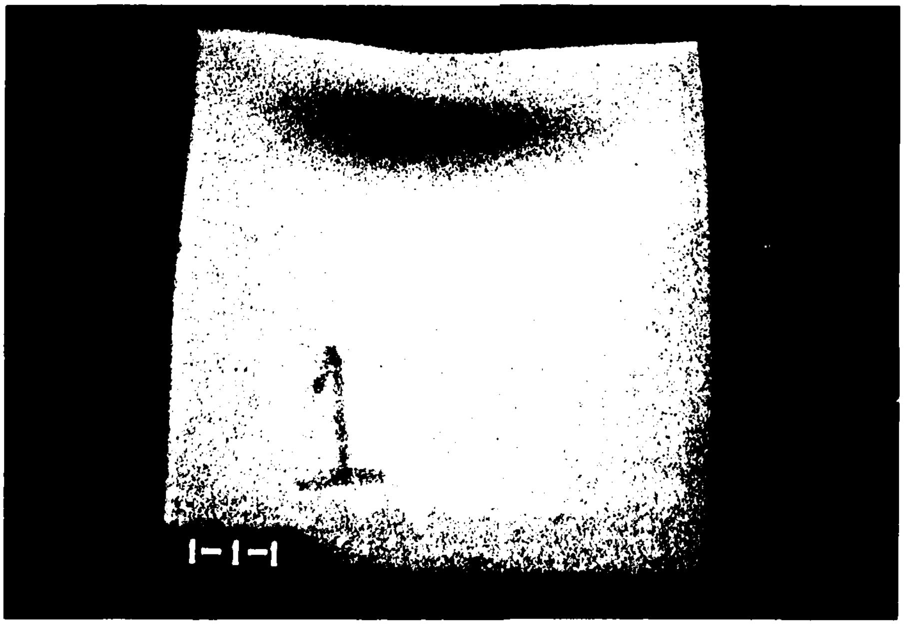


Figure A1-147. Sample 1-1-1, direct rear view.

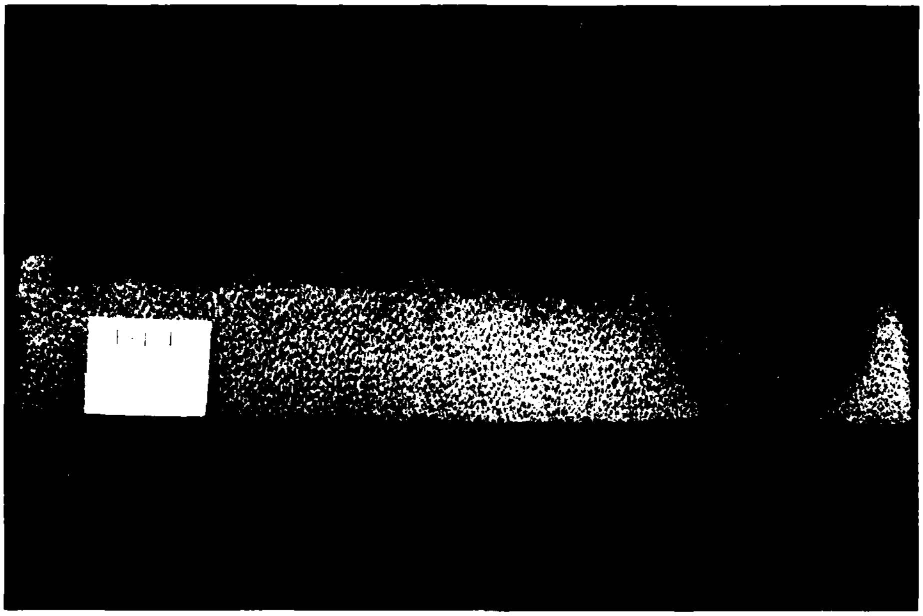


Figure A1-148. Sample 1-1-1, cross-sectional view.

Figure A1-149. Sample 1-A-1, perspective front view.

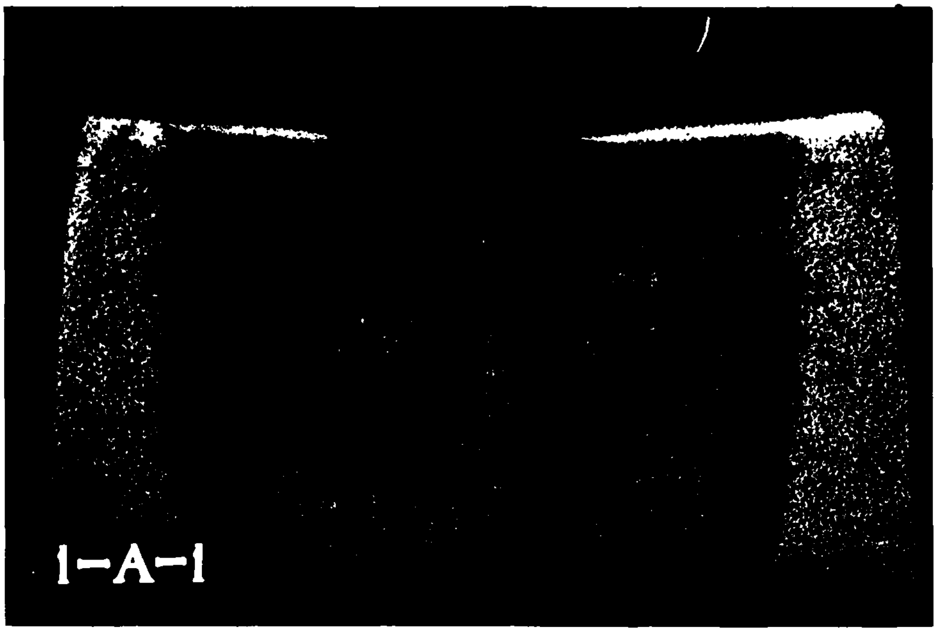


Figure A1-150. Sample 1-A-1, direct front view.

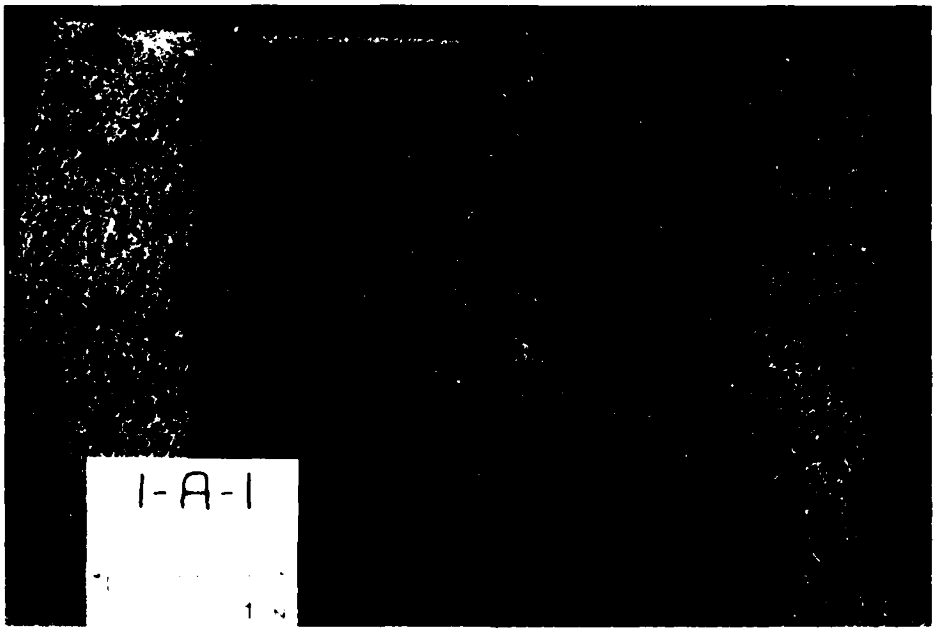


Figure A1-151. Sample 1-A-1, close-up front view, upper left corner.

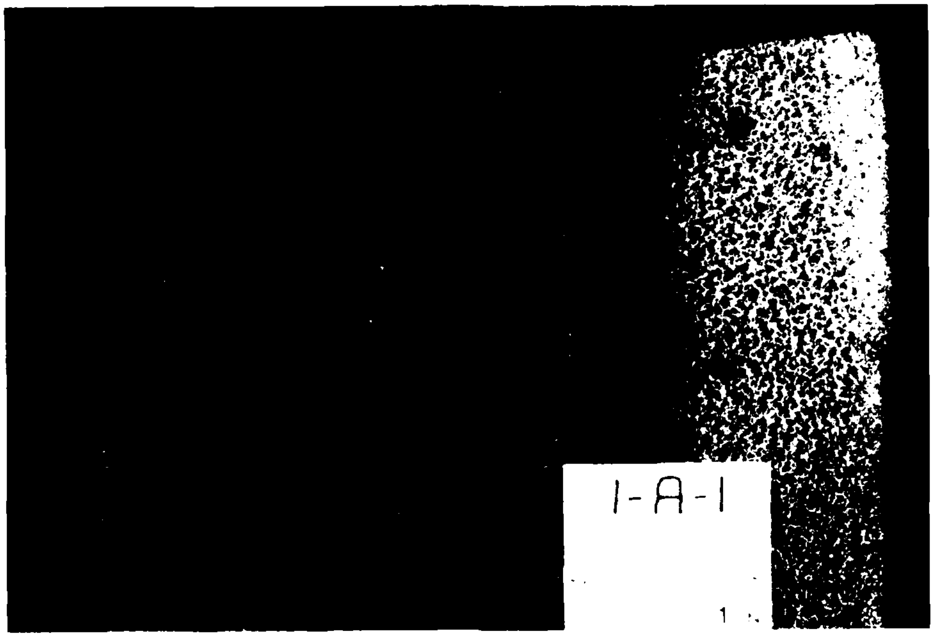


Figure A1-152. Sample 1-A-1, close-up front view, upper right corner.

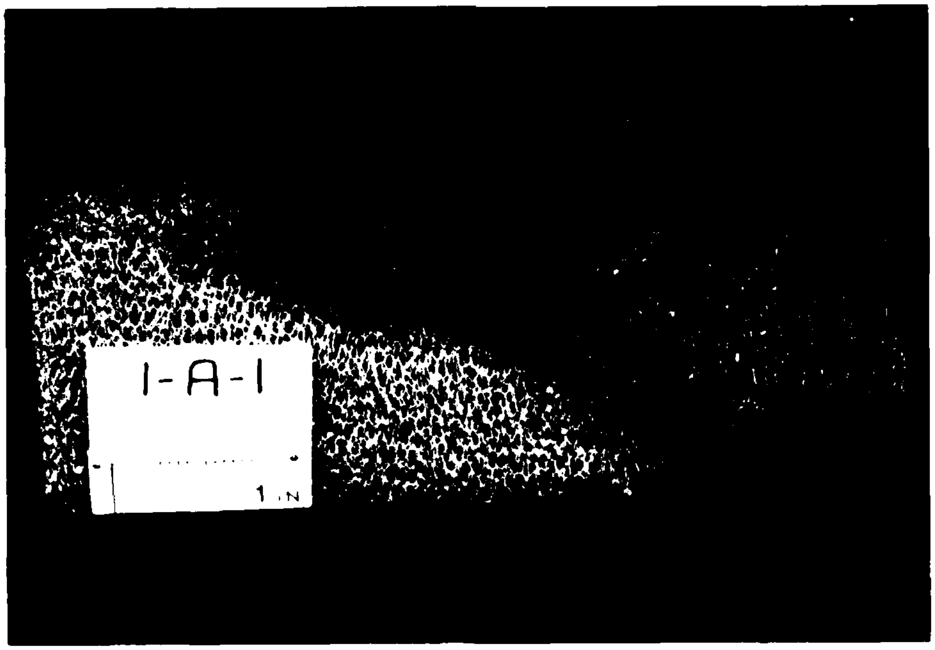


Figure A1-153. Sample 1-A-1, cross-sectional view, upper left corner.

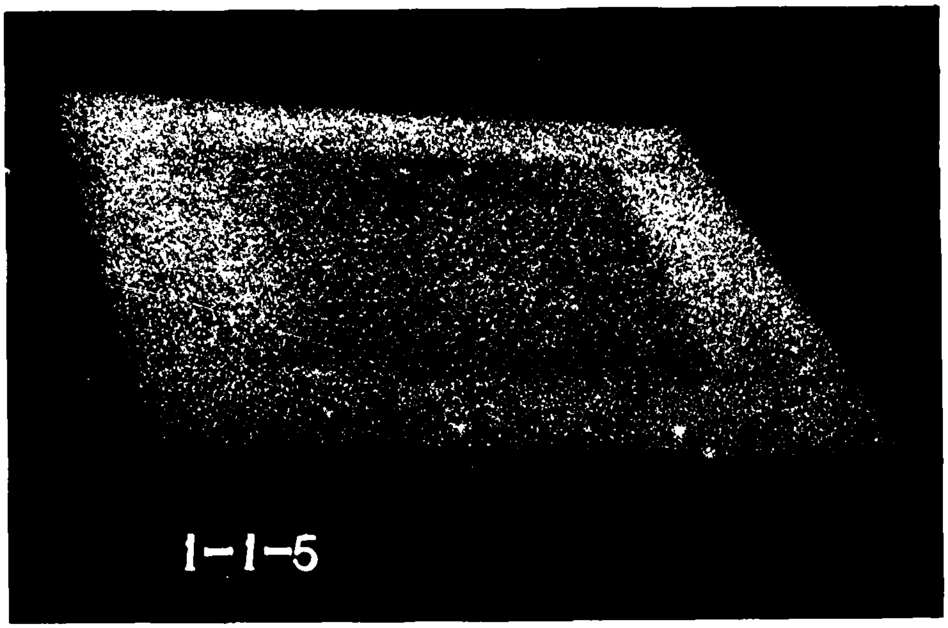


Figure A1-154. Sample 1-1-5, perpective front view.

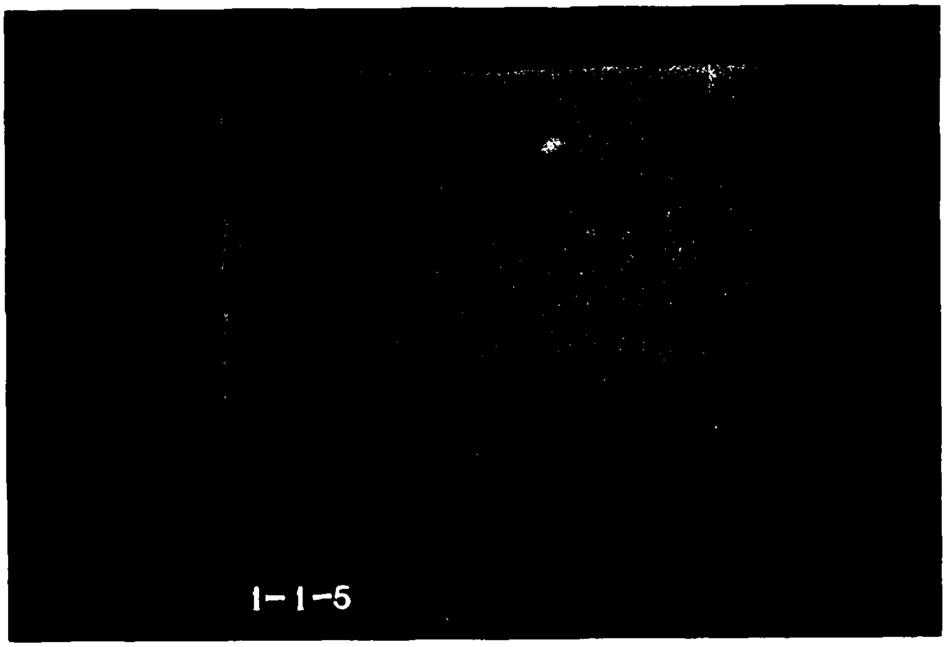


Figure A1-155. Sample 1-1-5, direct front view.

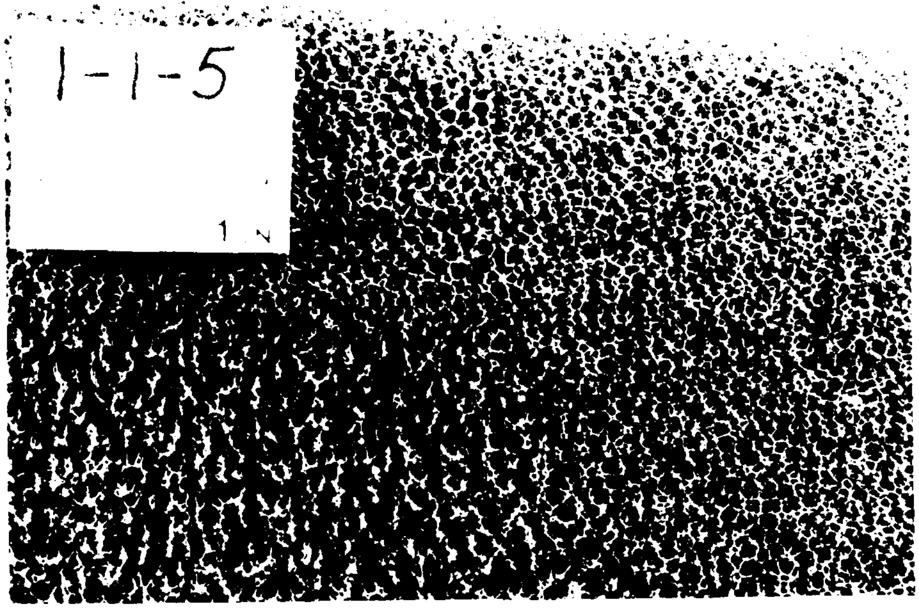


Figure A1-156. Sample 1-1-5, close-up view of front surface.

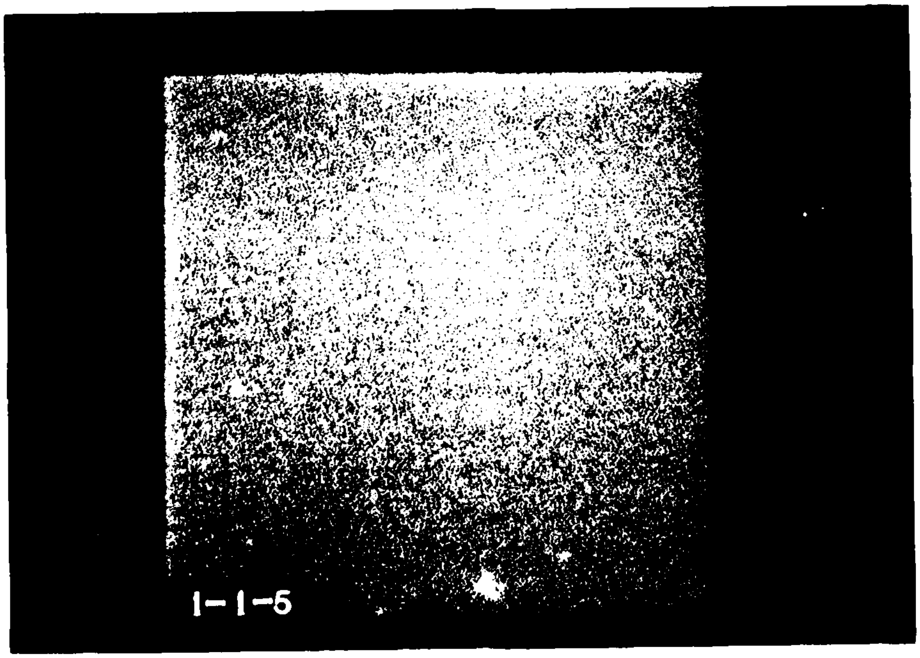


Figure A1-157. Sample 1-1-5, direct rear view.

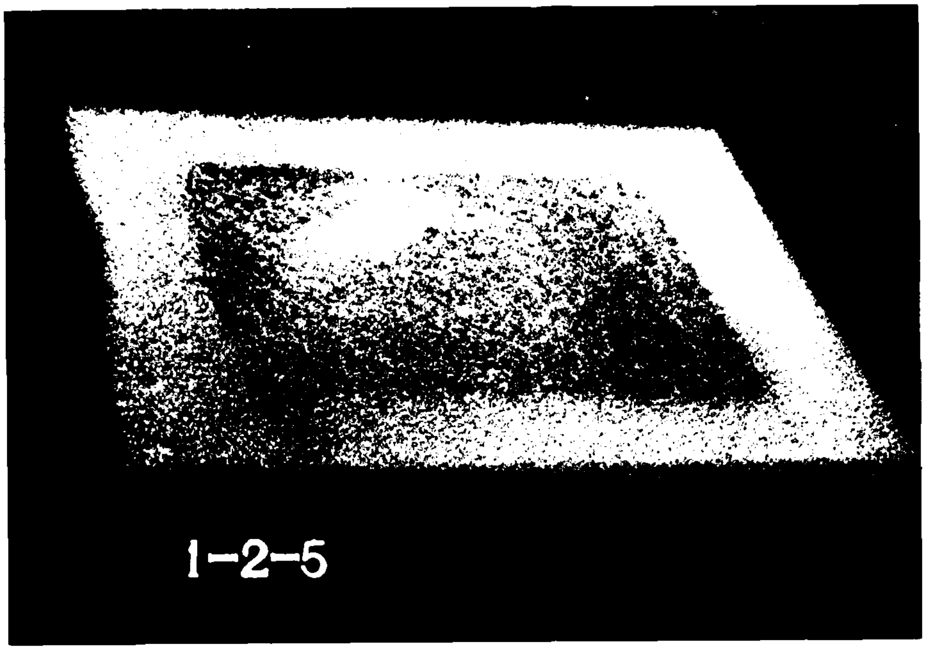


Figure A1-158. Sample 1-2-5, perspective front view.

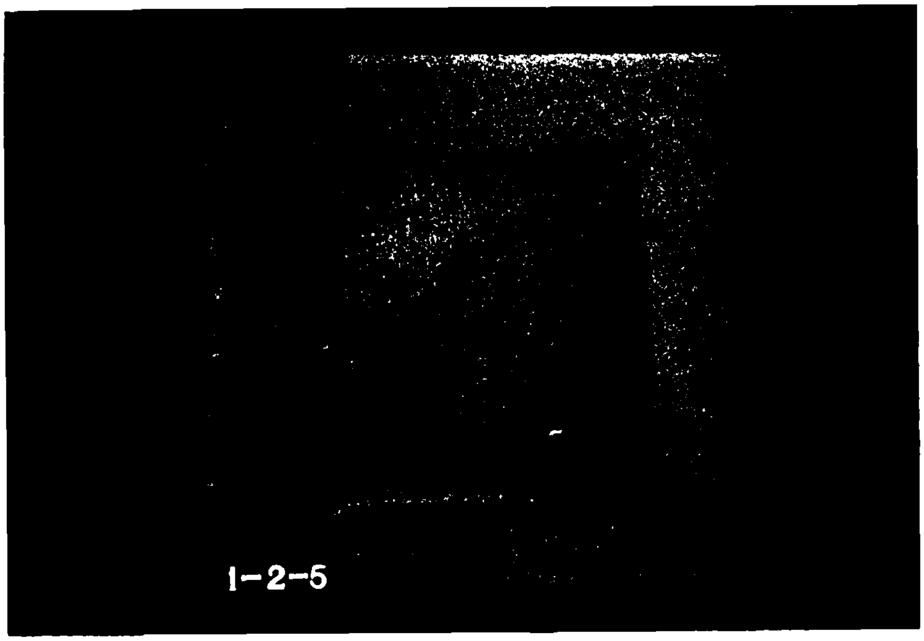


Figure A1-159. Sample 1-2-5, direct front view.

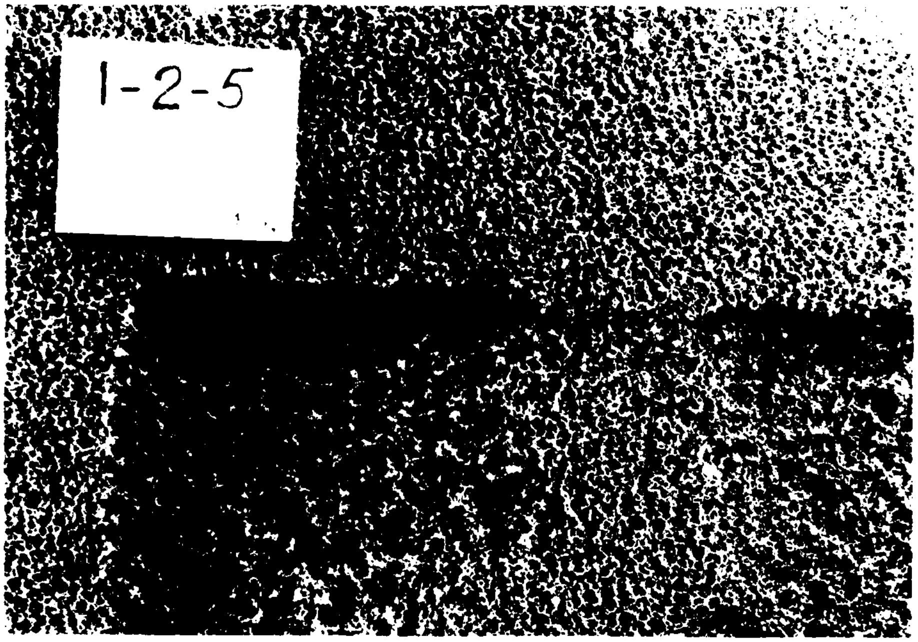


Figure A1-160. Sample 1-2-5, close-up view of front surface.

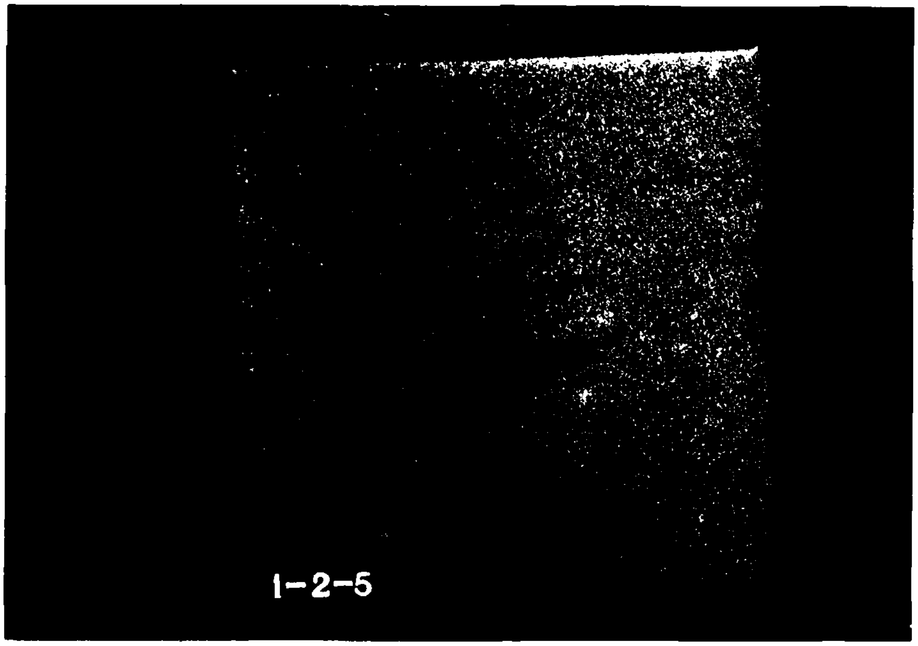


Figure A1-161. Sample 1-2-5, direct rear view.

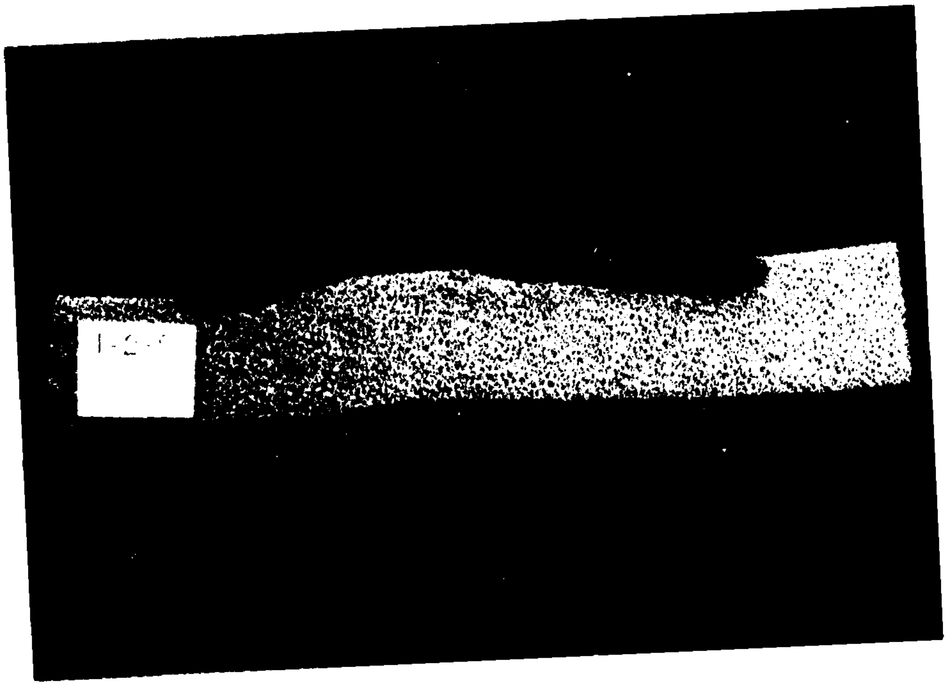


Figure A1-162. Sample 1-2-5, cross-sectional view.

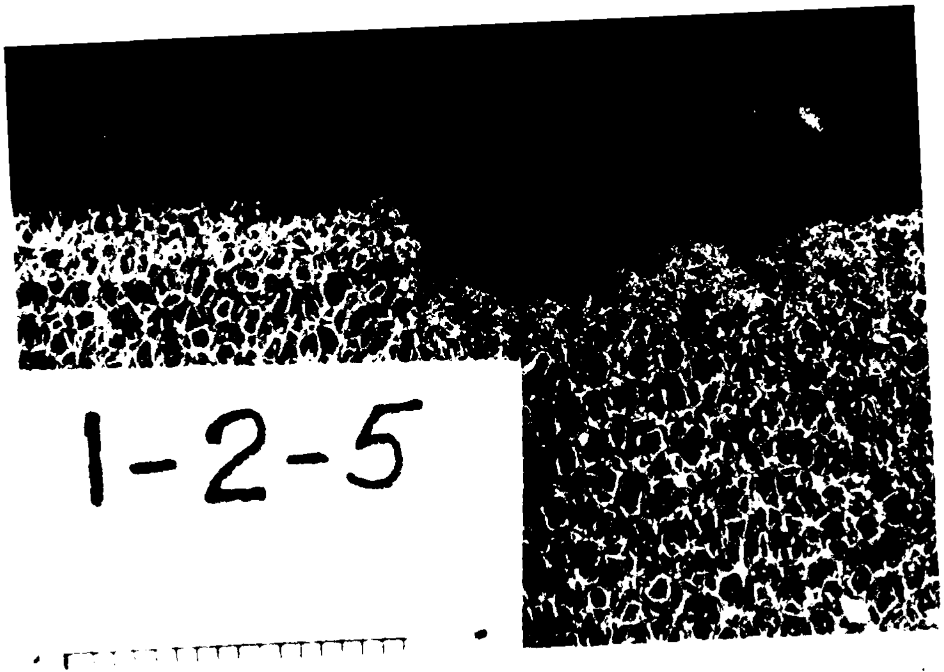


Figure A1-163. Sample 1-2-5, close-up cross-sectional view, upper left quadrant.

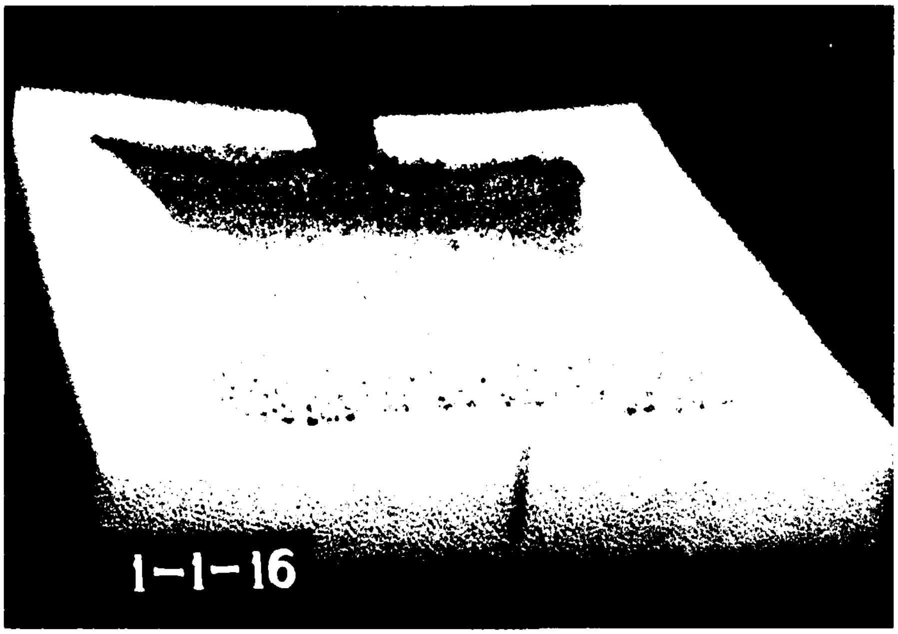


Figure A1-187. Sample 1-1-16, perspective front view.

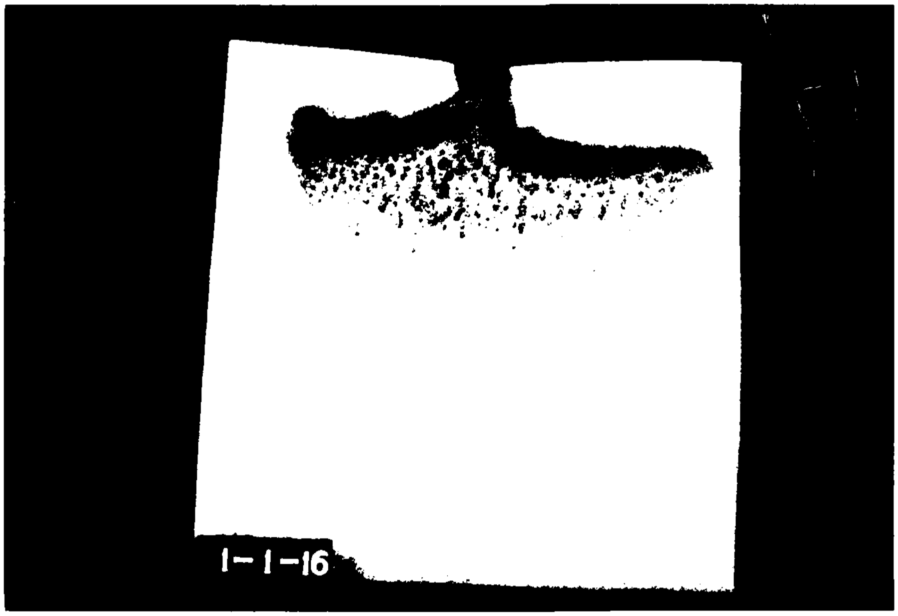


Figure A1-188. Sample 1-1-16, direct front view.

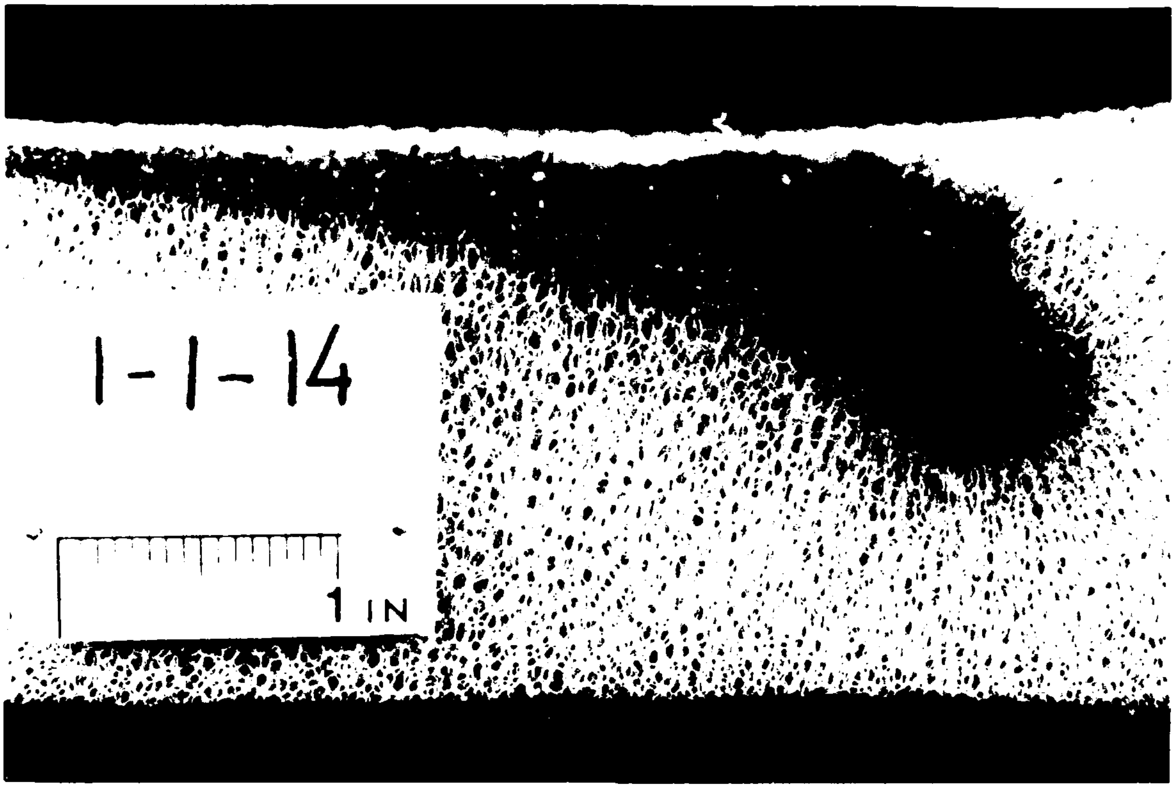


Figure A1-186. Sample 1-1-14, close-up cross-sectional view, upper left quadrant.

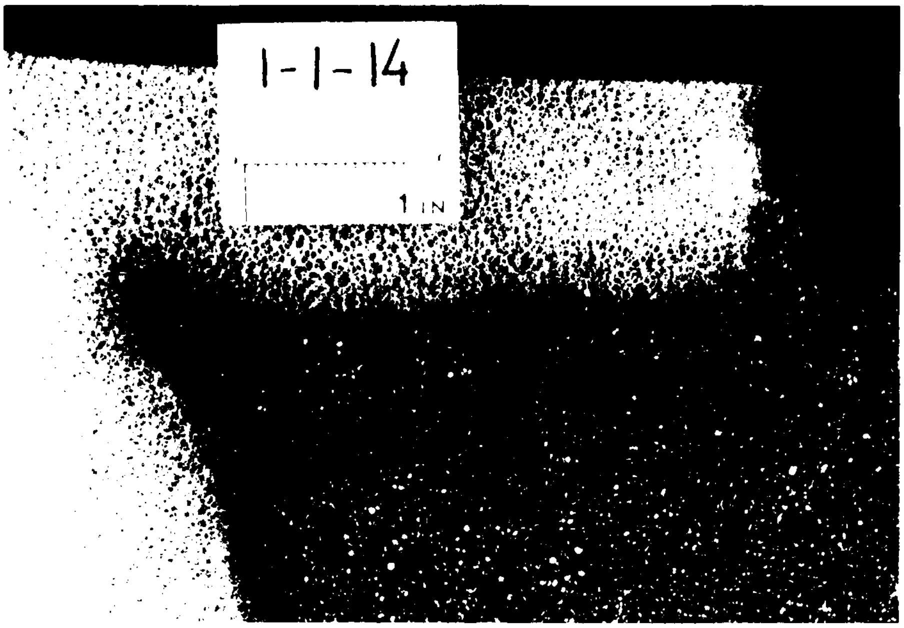


Figure A1-184. Sample 1-1-14, close-up front view, upper left quadrant.

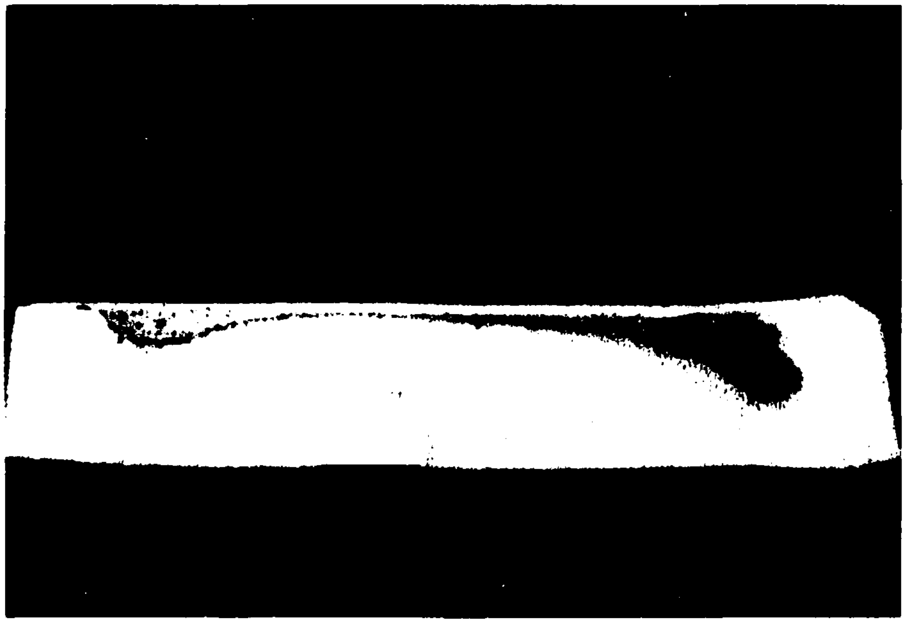


Figure A1-185. Sample 1-1-14, cross-sectional view.

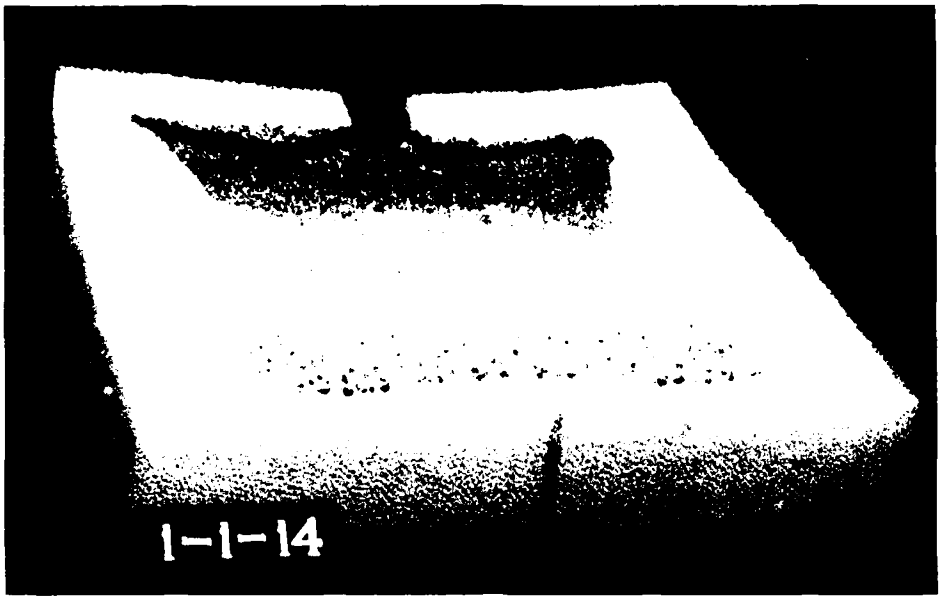


Figure A1-182. Sample 1-1-14, perspective front view.

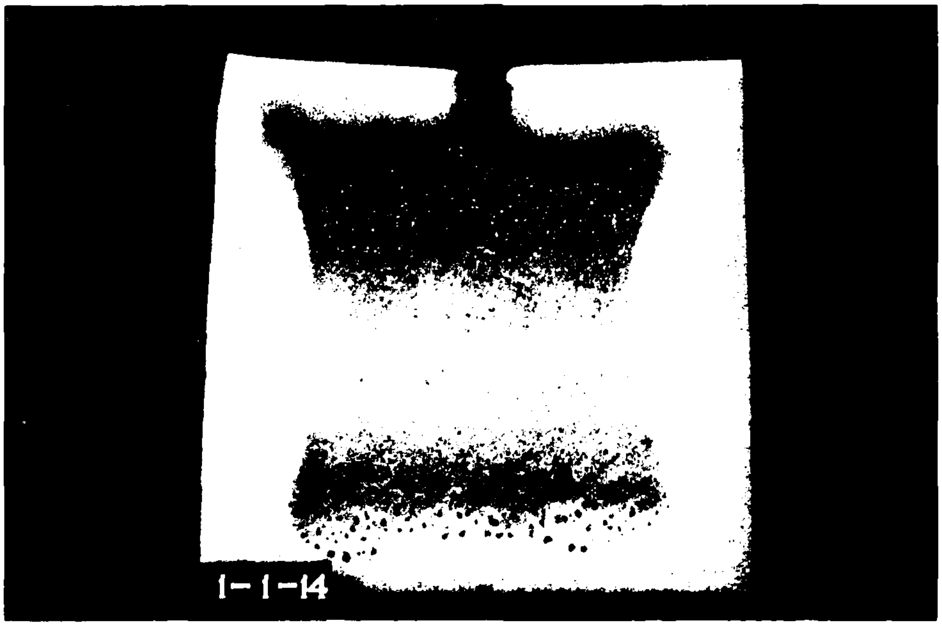


Figure A1-183. Sample 1-1-14, direct front view.

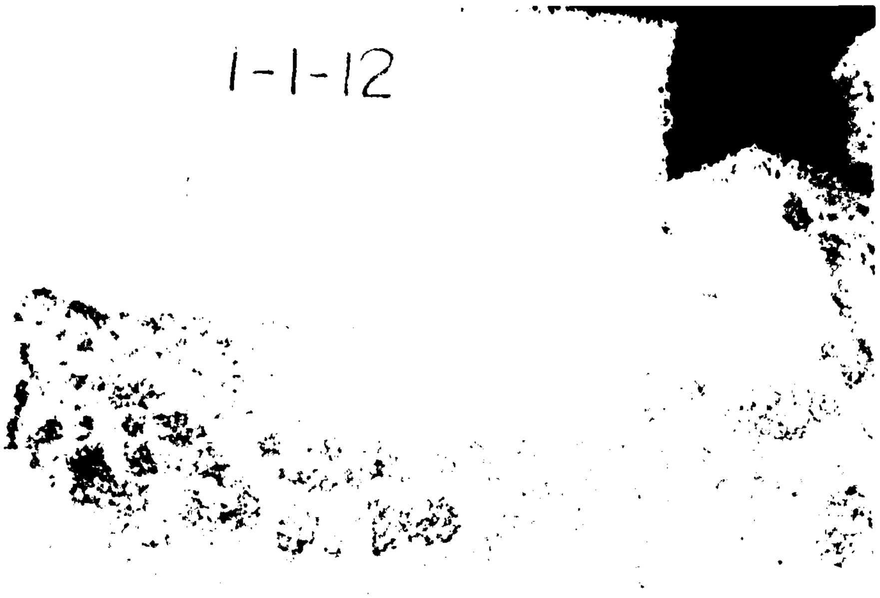


Figure A1-180. Sample 1-1-12, close-up view of front surface, upper left and central areas.

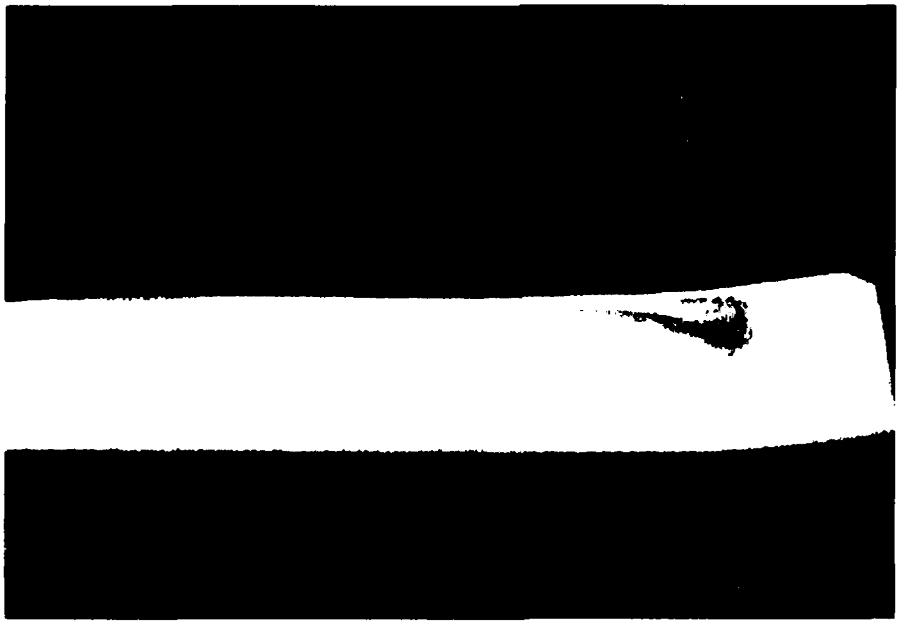


Figure A1-181. Sample 1-1-12, cross-sectional view.

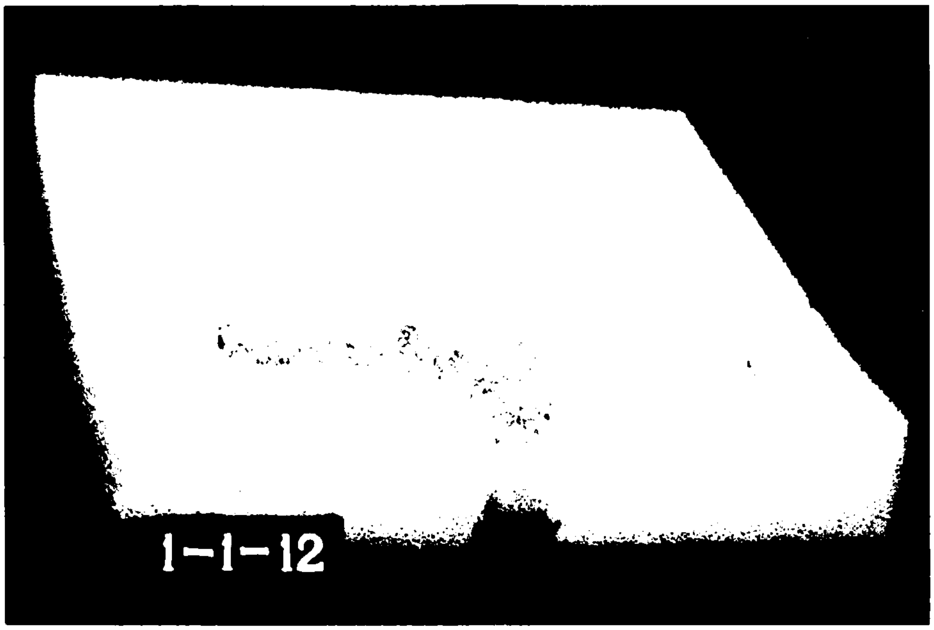


Figure A1-178. Sample 1-1-12, perspective front view.

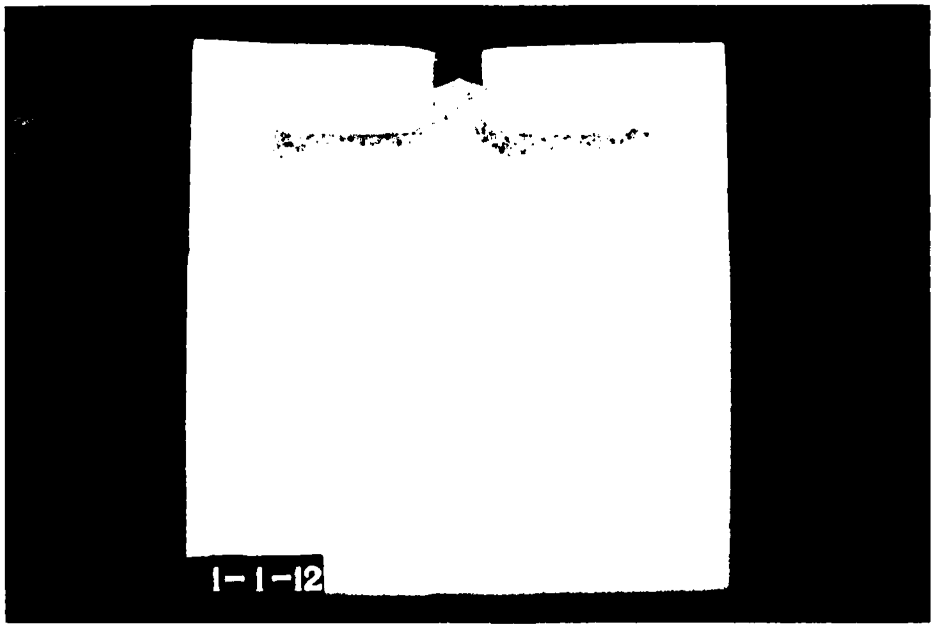


Figure A1-179. Sample 1-1-12, direct front view.

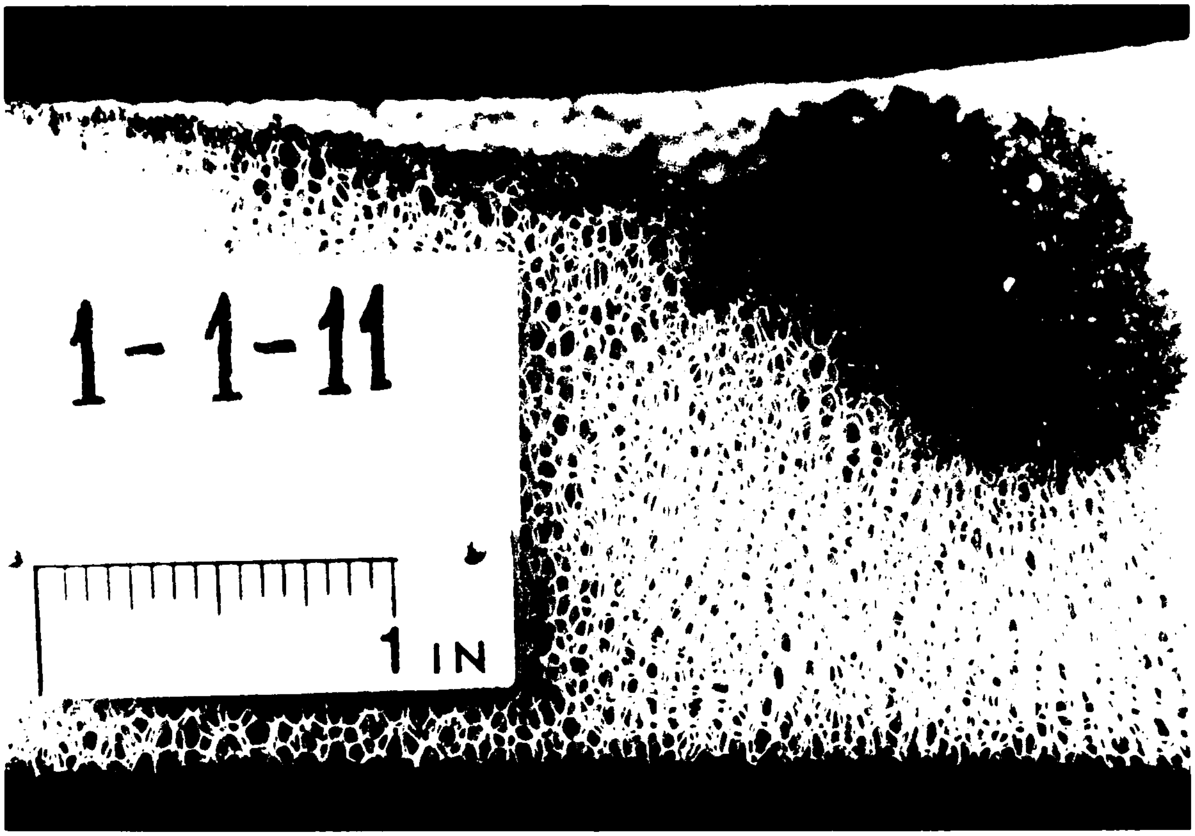


Figure A1-177. Close-up cross-sectional view, upper right corner.

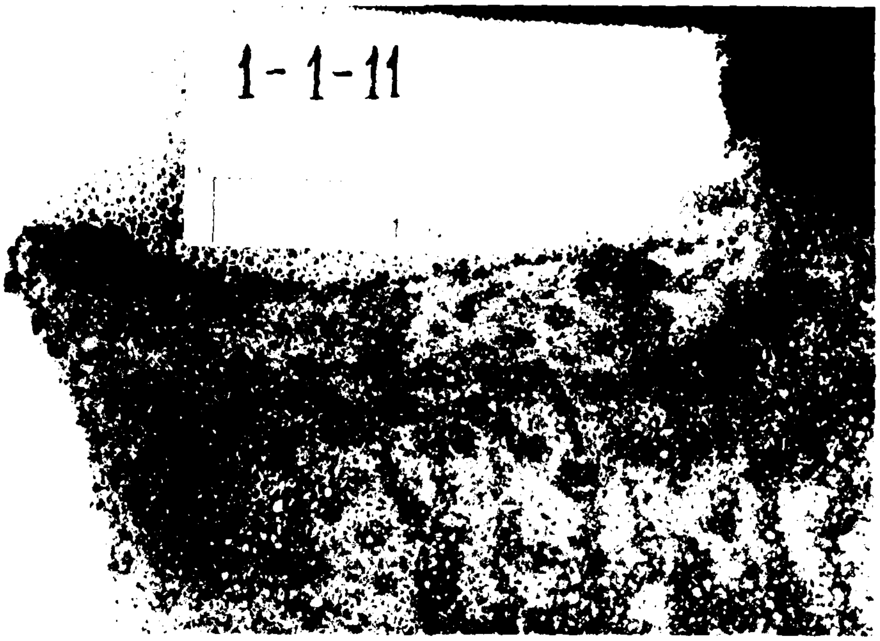


Figure A1-175. Sample 1-1-11, close-up view of front surface, upper left corner.

Figure A1-176. Sample 1-1-11, cross-sectional view.

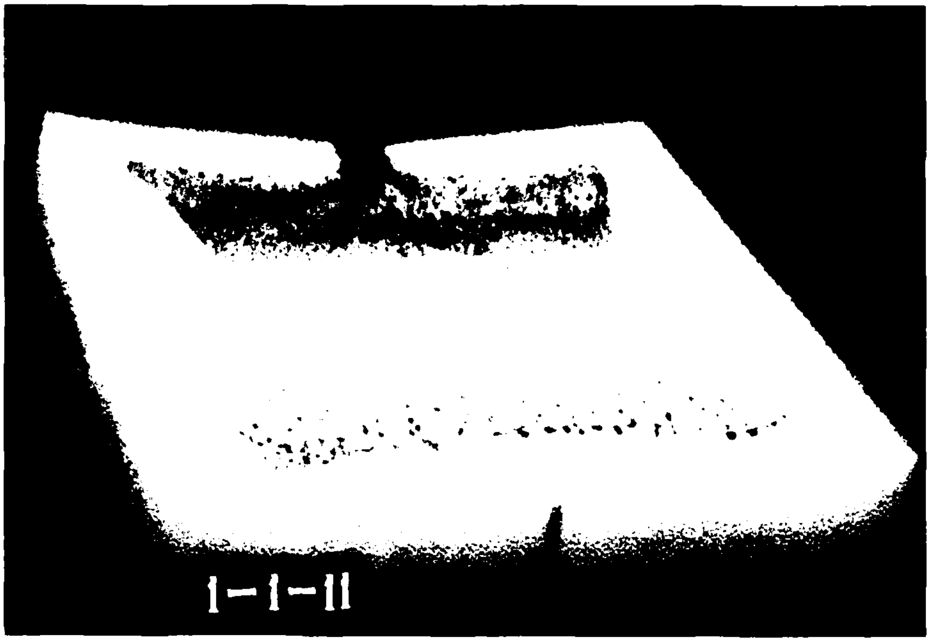


Figure A1-173. Sample 1-1-11, perspective front view.

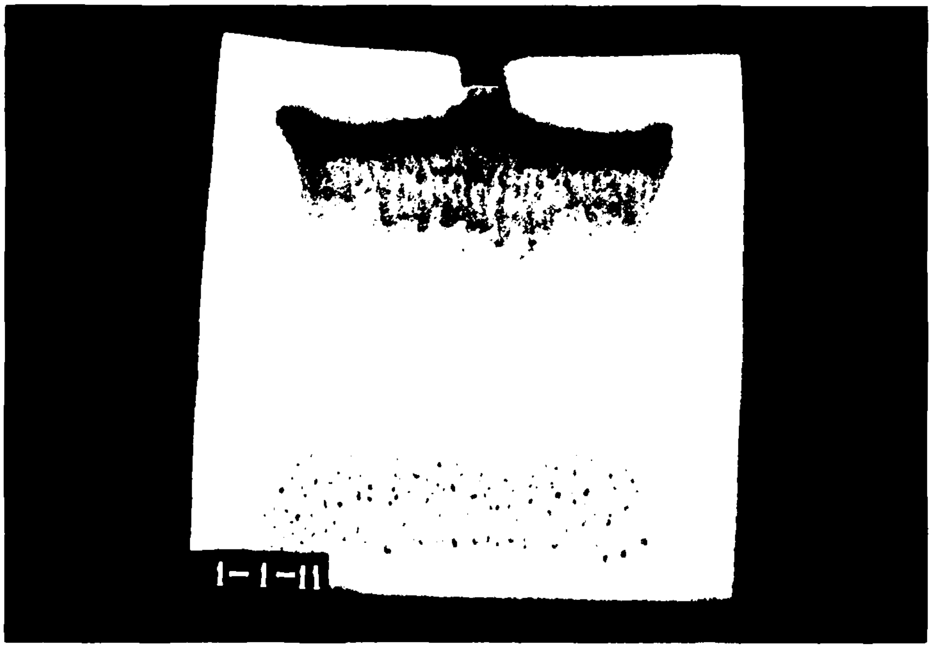


Figure A1-174. Sample 1-1-11, direct front view.

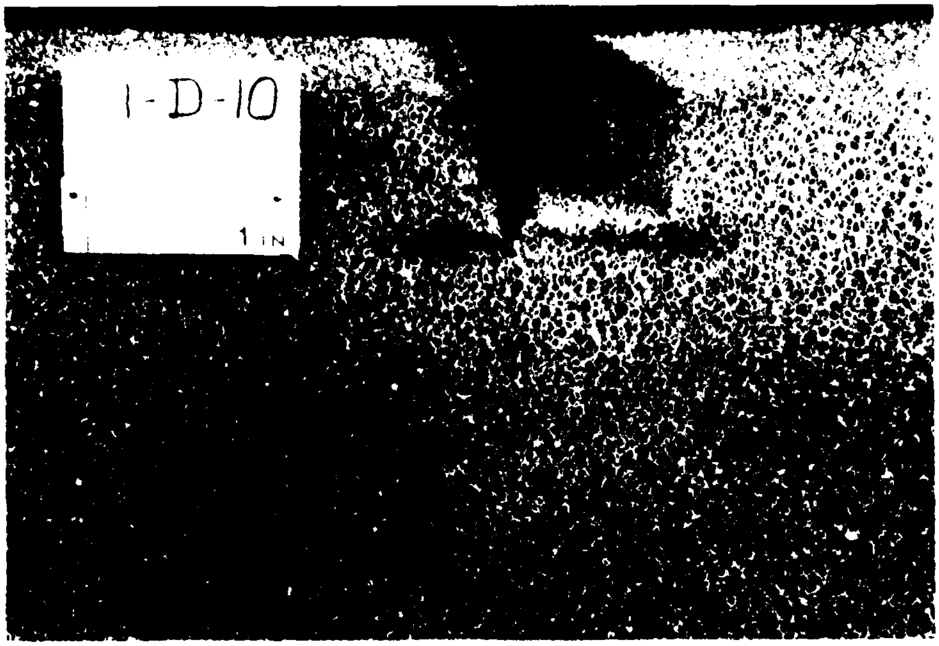


Figure A1-171. Sample 1-D-10, close-up view of front surface, upper left and central areas.

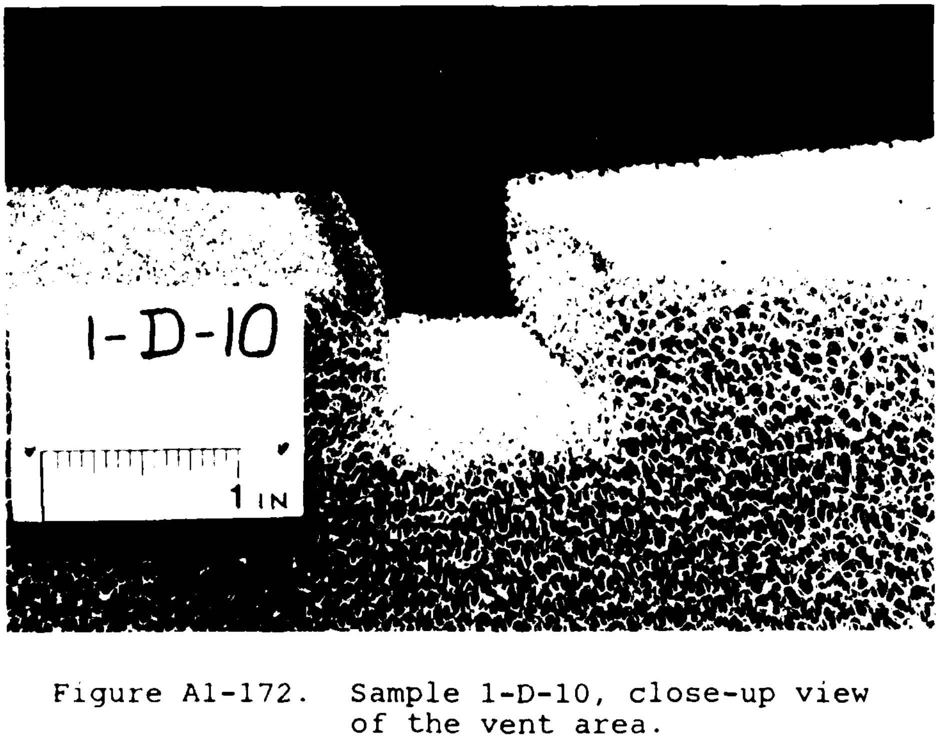


Figure A1-172. Sample 1-D-10, close-up view of the vent area.

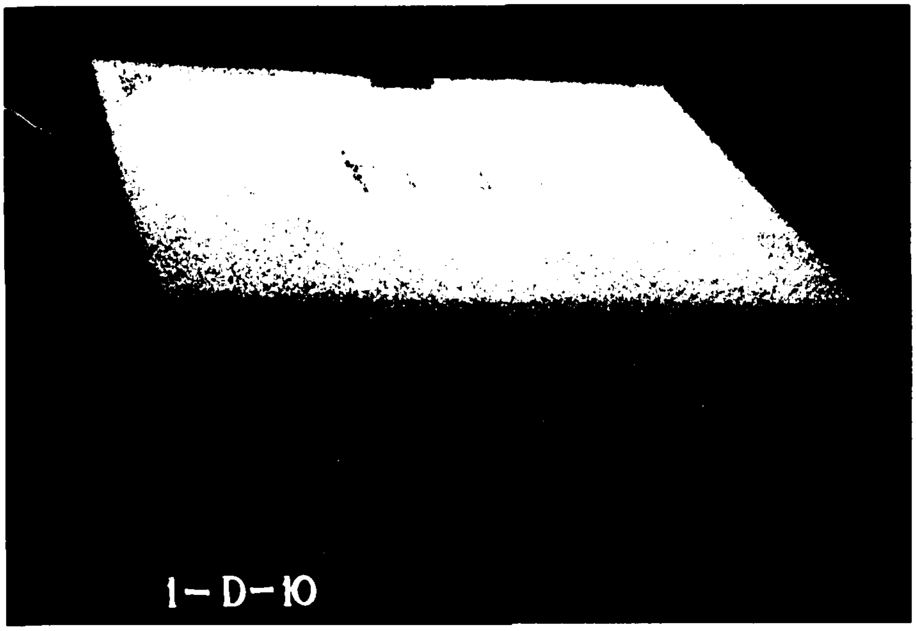


Figure A1-169. Sample 1-D-10, perspective front view.

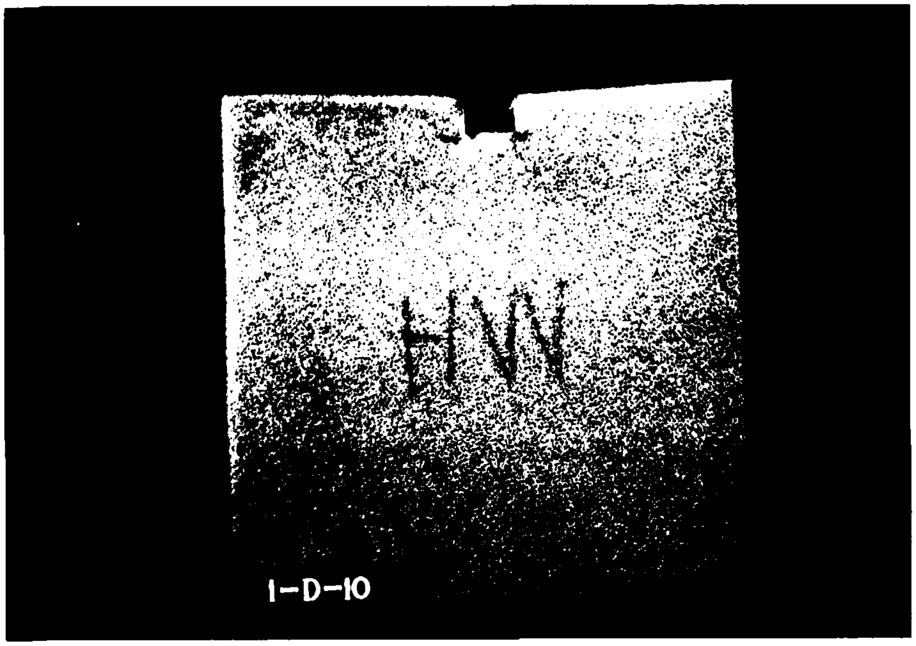


Figure A1-170. Sample 1-D-10, direct front view.

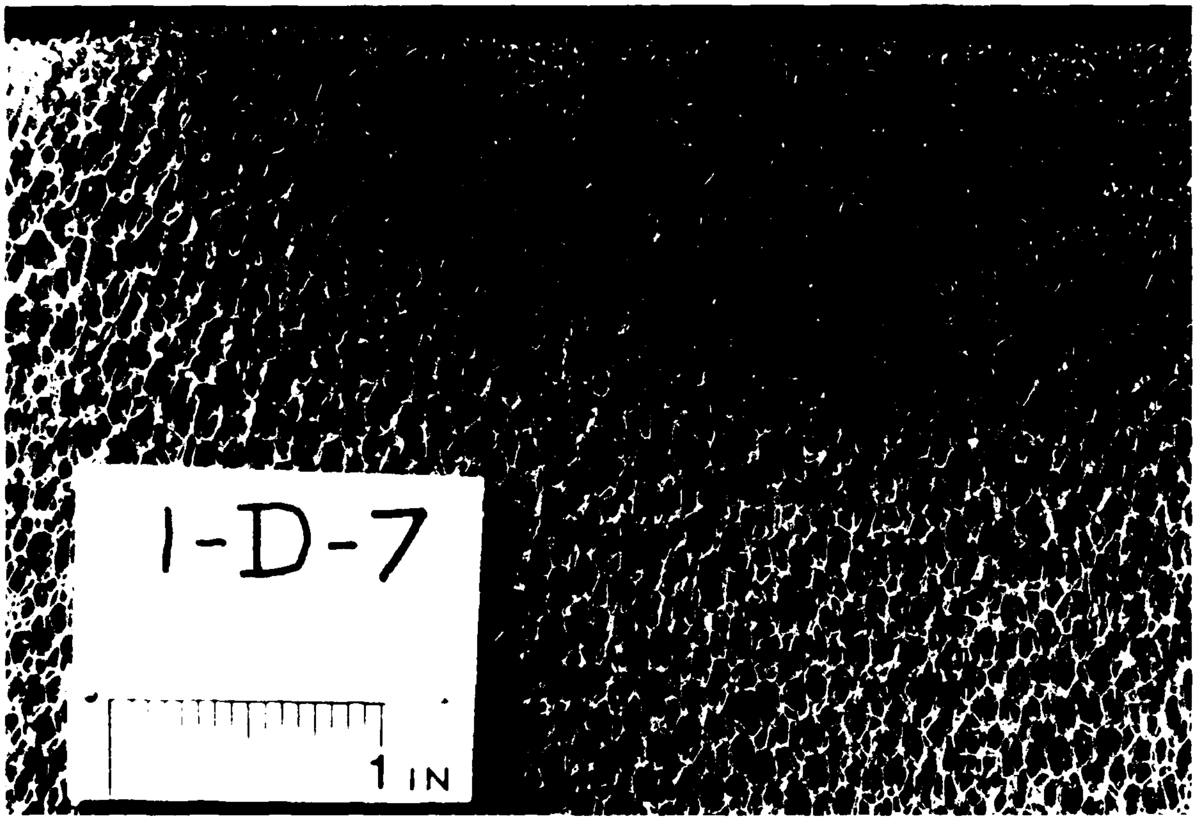


Figure A1-168. Sample 1-D-7, close-up cross-sectional view.

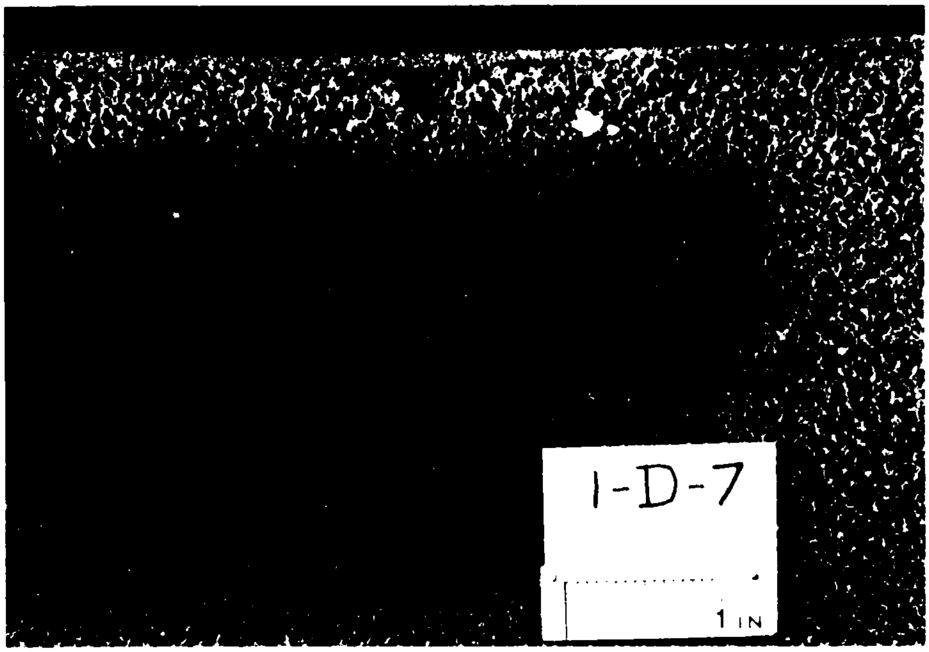


Figure A1-166. Sample 1-D-7, close-up view of front surface, upper right corner.

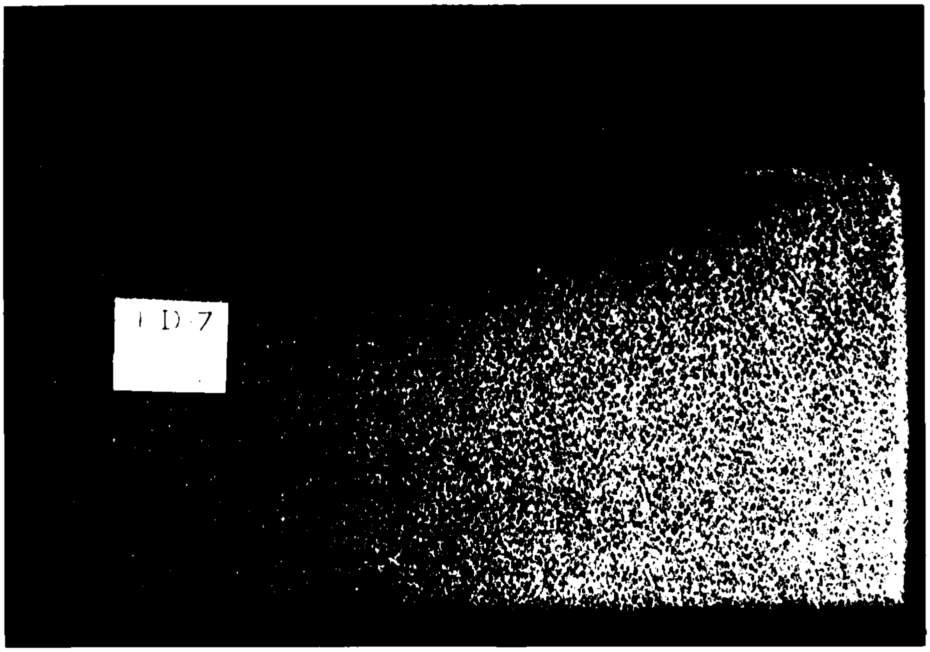


Figure A1-167. Sample 1-D-7, cross-sectional view.

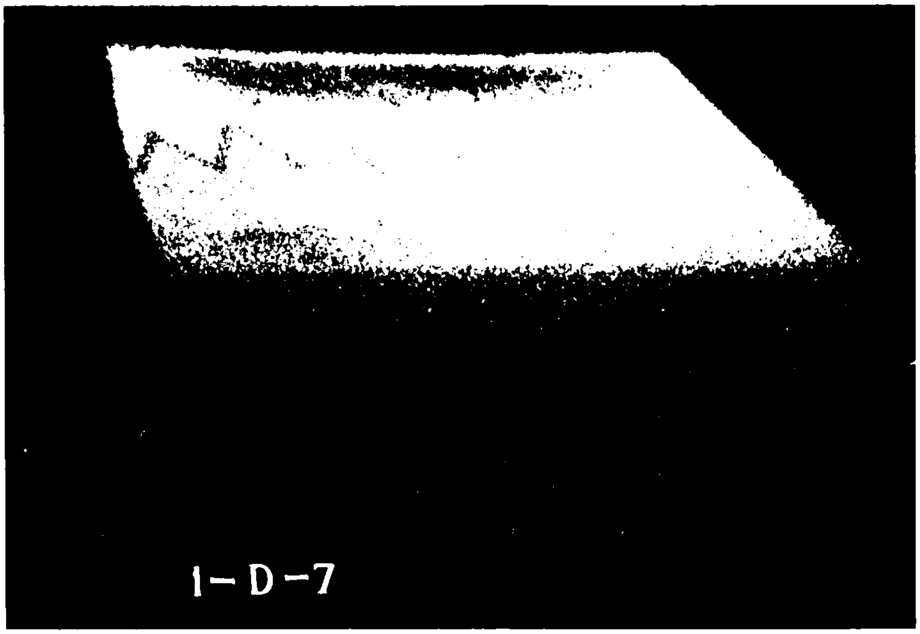


Figure A1-164. Sample 1-D-7, perspective front view.

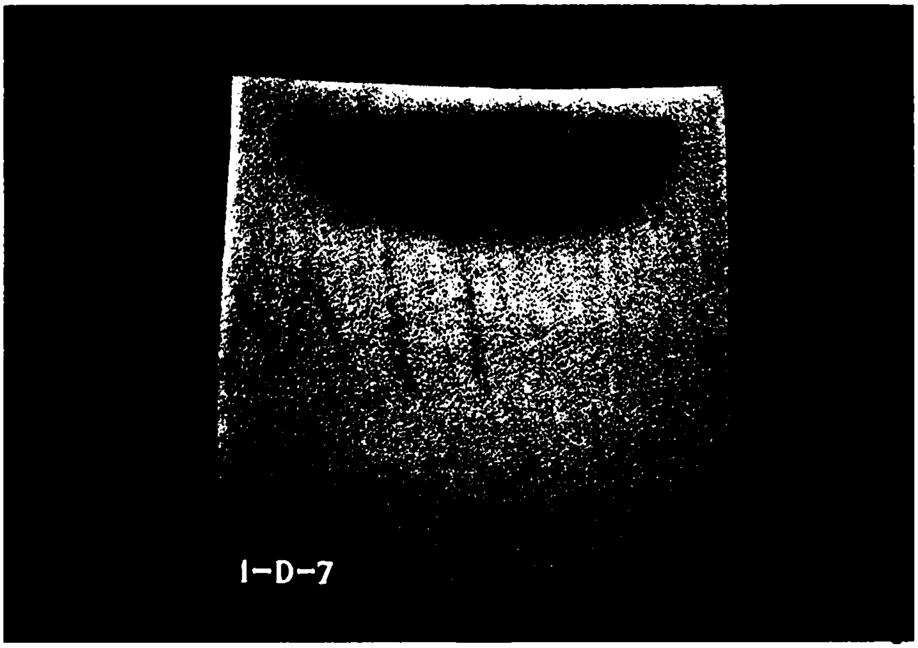


Figure A1-165. Sample 1-D-7, direct front view.

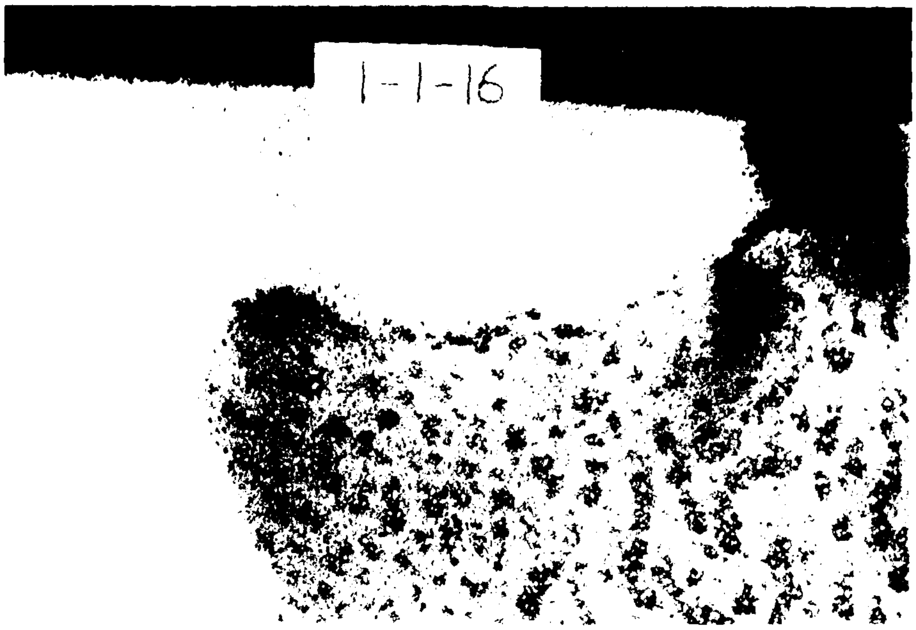


Figure A1-189. Sample 1-1-16, close-up front view, upper left quadrant.

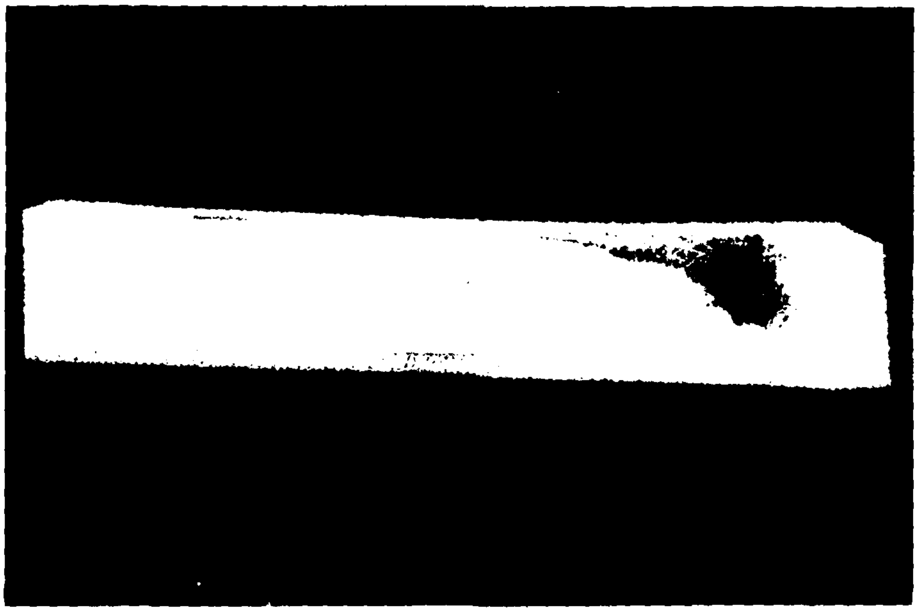


Figure A1-190. Sample 1-1-16, cross-sectional view.

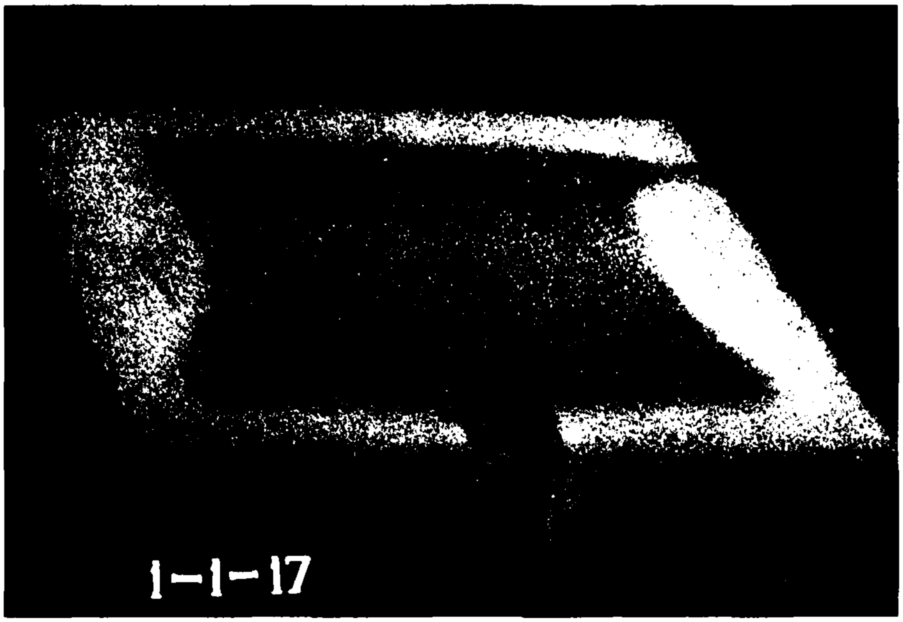


Figure A1-191. Sample 1-1-17, perspective front view.

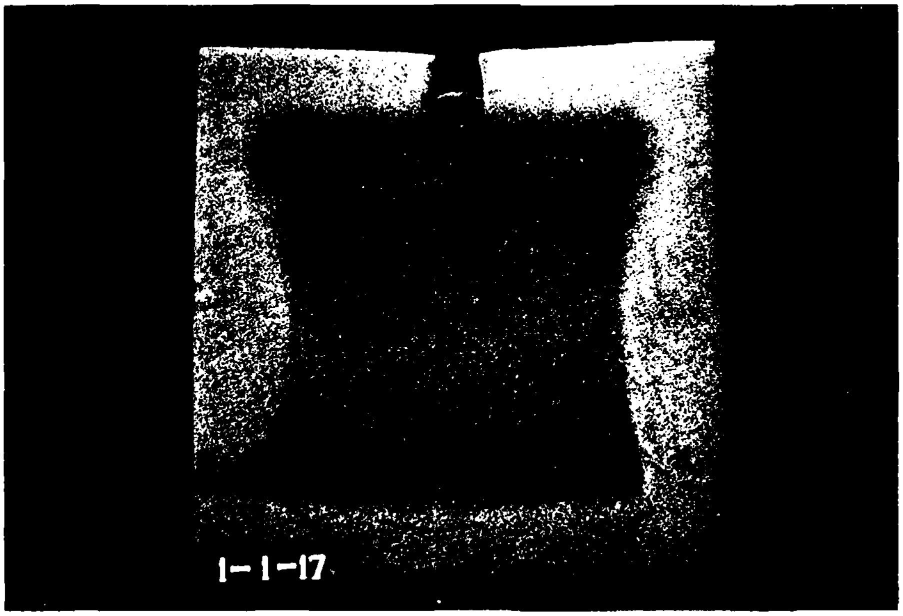


Figure A1-192. Sample 1-1-17, direct front view.

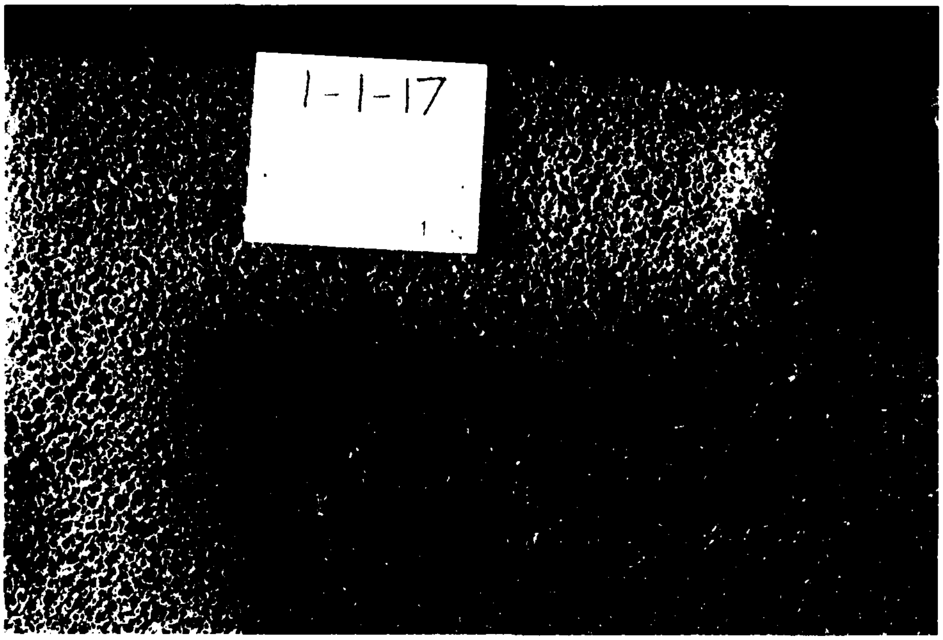


Figure A1-193. Sample 1-1-17, close-up front view, upper left quadrant.

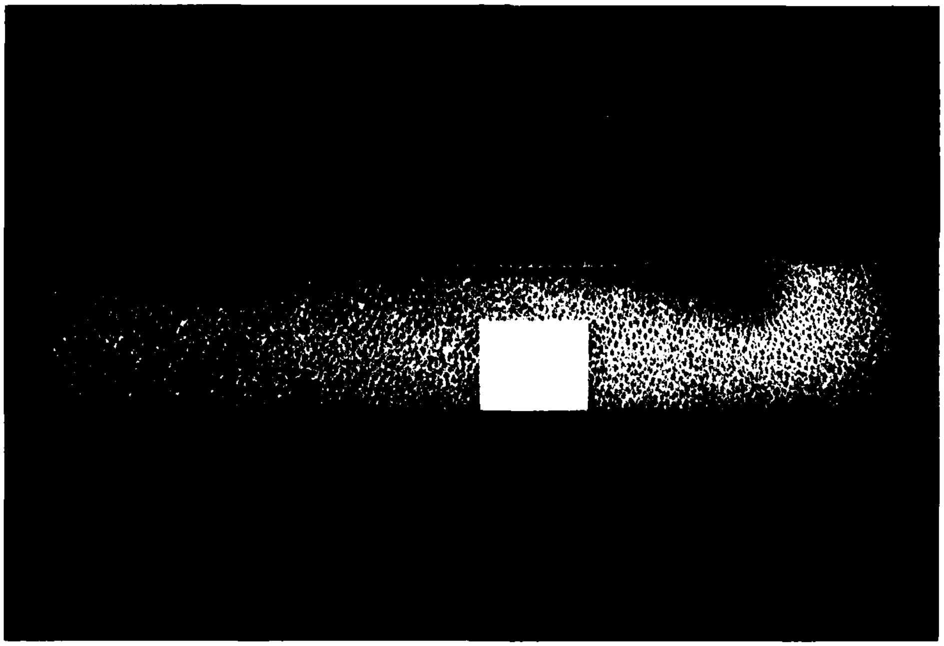


Figure A1-194. Sample 1-1-17, cross-sectional view.

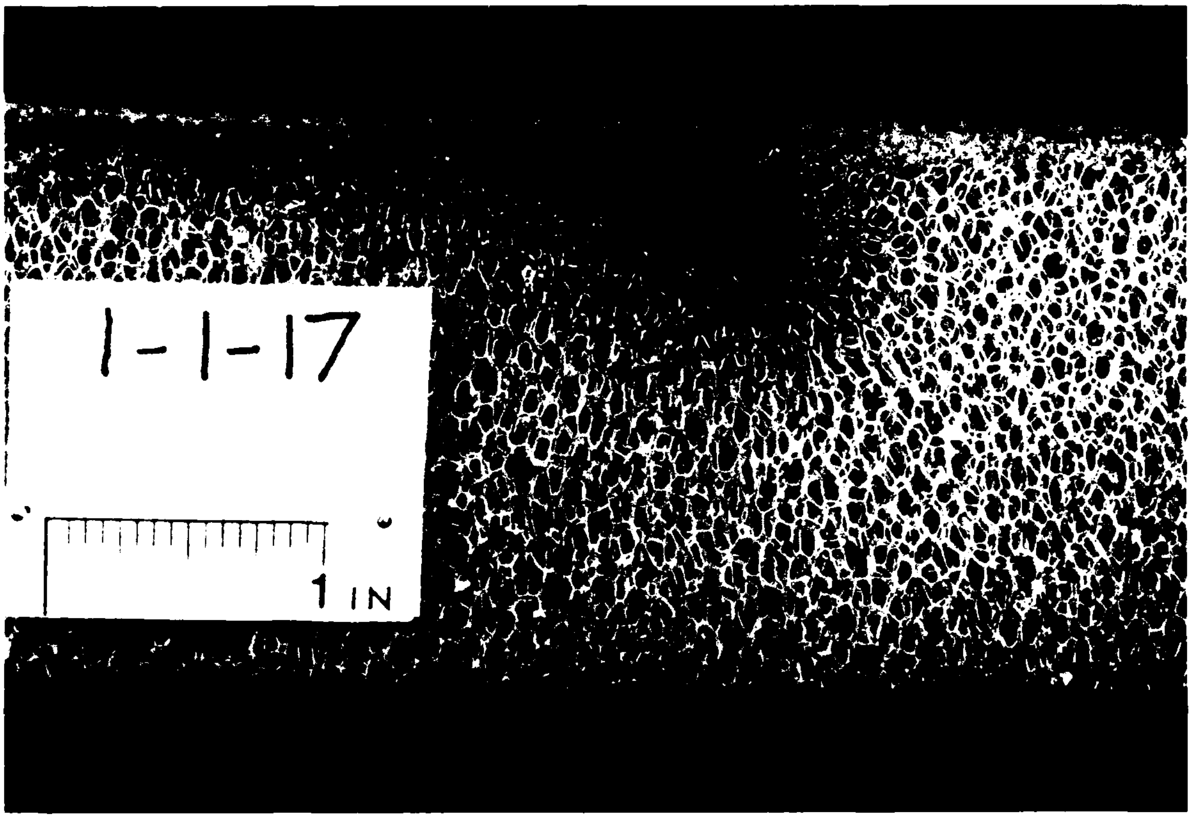


Figure A1-195. Sample 1-1-17, close-up cross-sectional view, upper left quadrant.

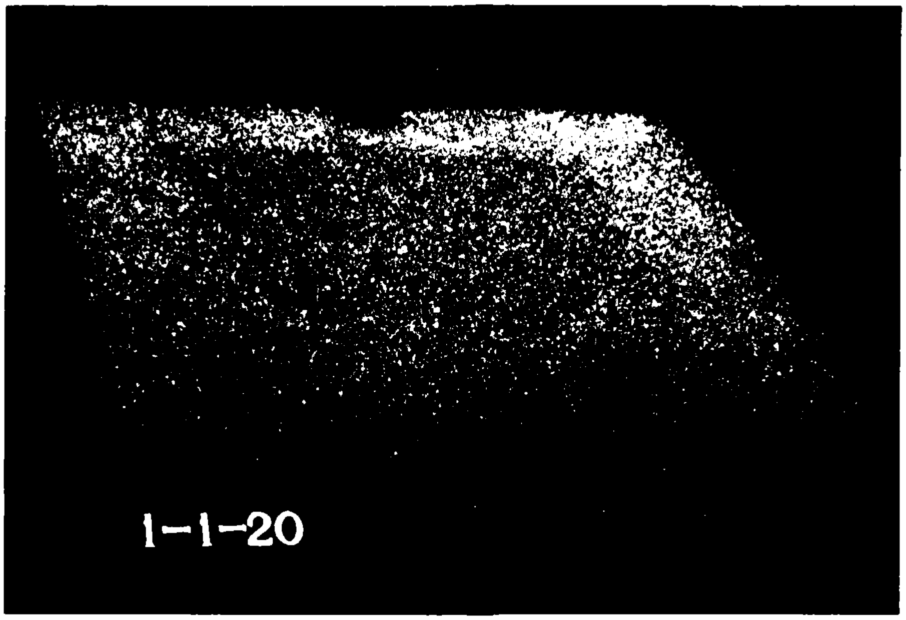


Figure A1-196. Sample 1-1-20, perspective front view.

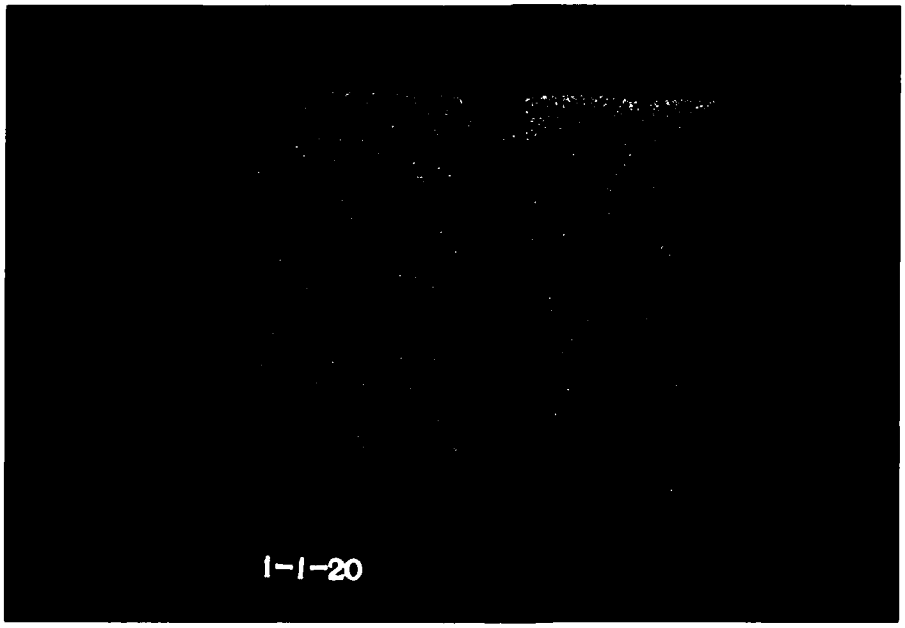


Figure A1-197. Sample 1-1-20, direct front view.

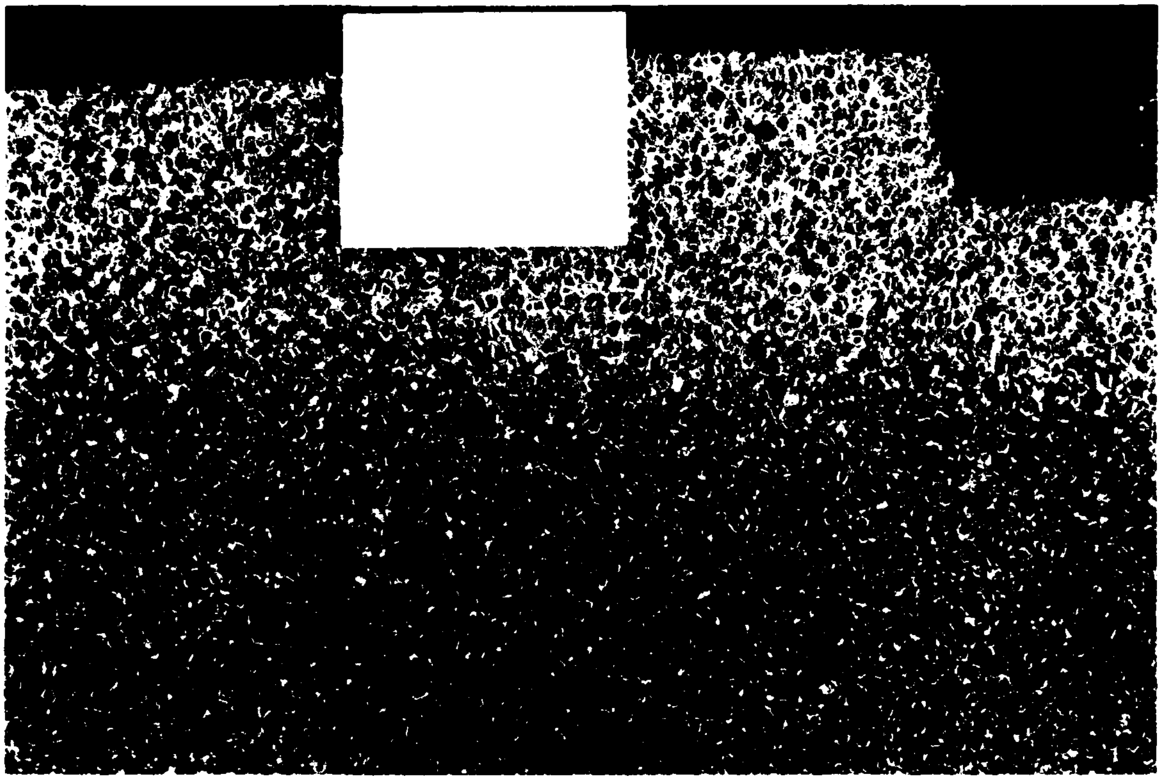


Figure A1-198. Sample 1-1-20, close-up front view, upper left quadrant.

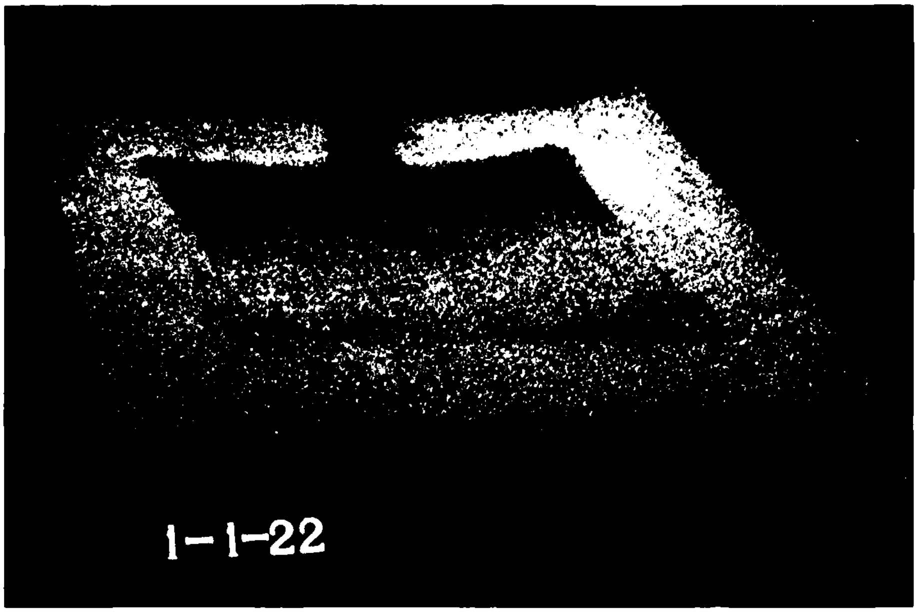


Figure A1-199. Sample 1-1-22, perspective front view.

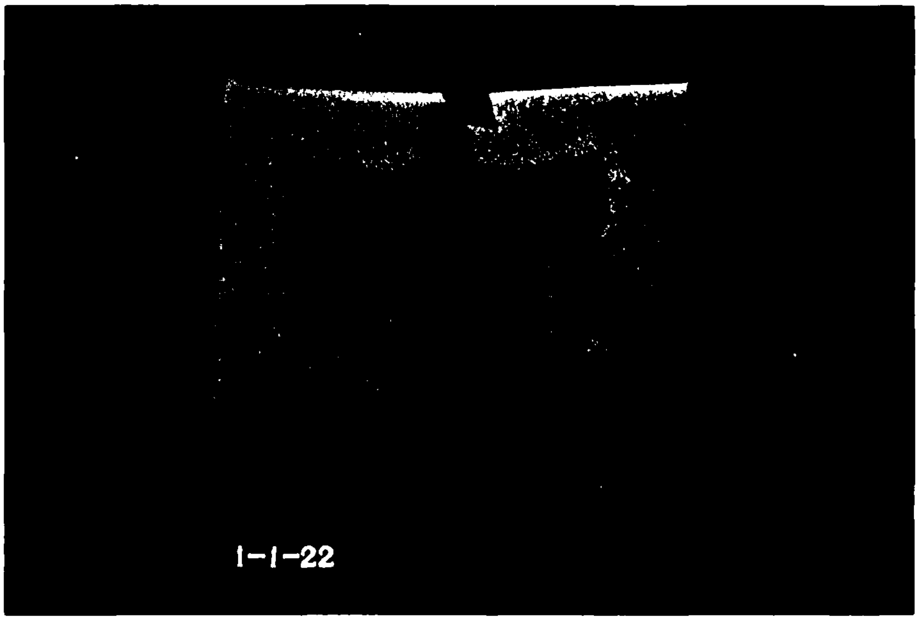


Figure A1-200. Sample 1-1-22, direct front view.

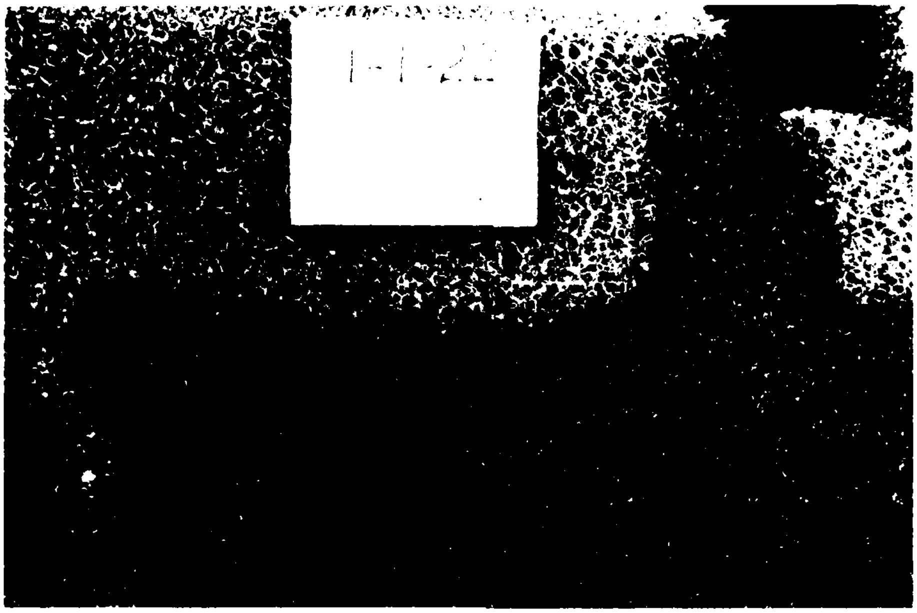


Figure A1-201. Sample 1-1-22, close-up front view, upper left quadrant.

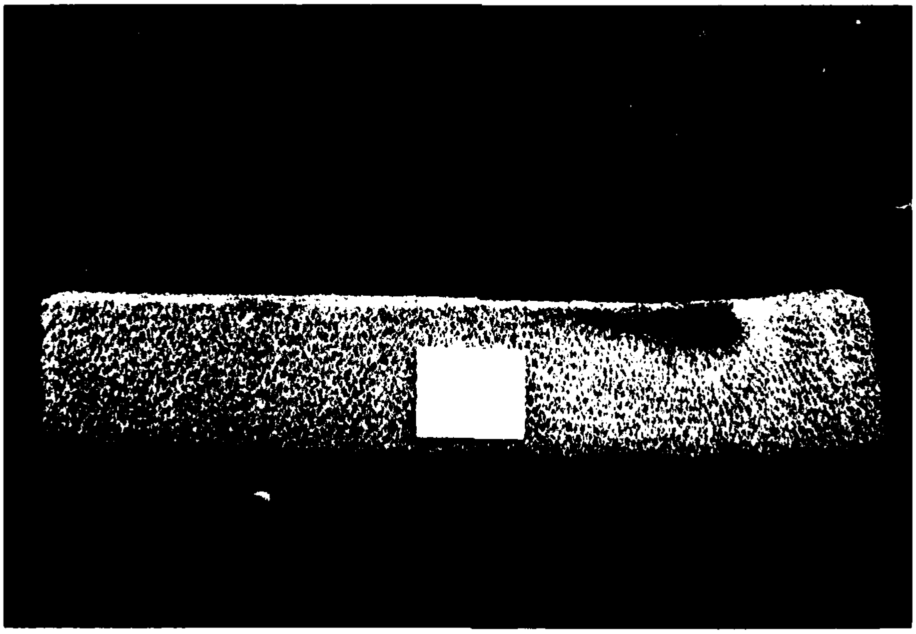


Figure A1-202. Sample 1-1-22, cross-sectional view.

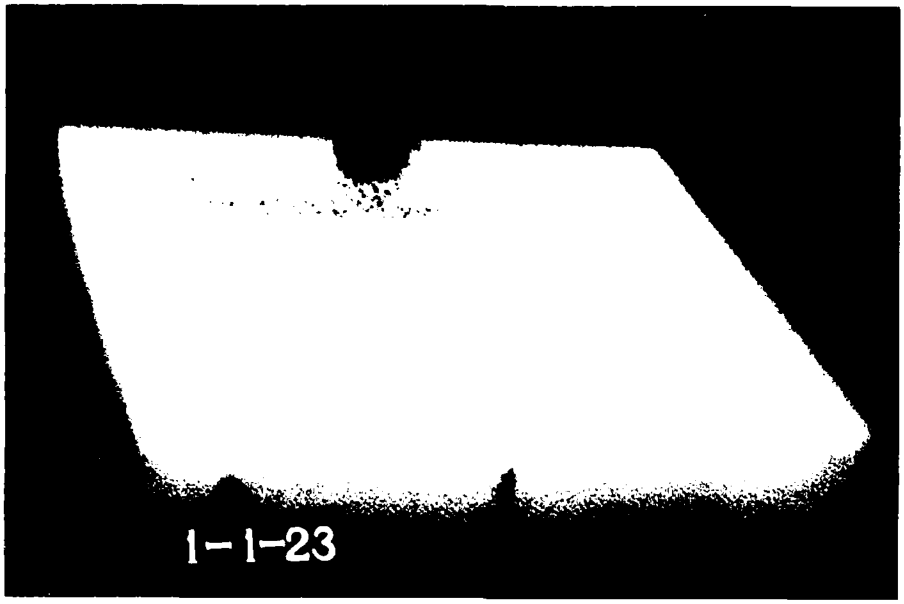


Figure A1-203. Sample 1-1-23, perspective front view.

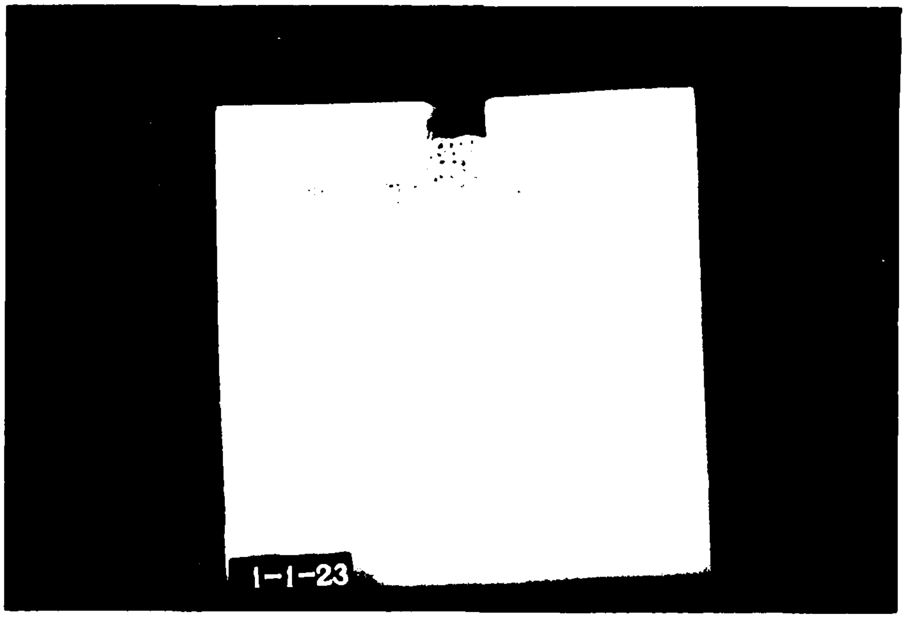


Figure A1-204. Sample 1-1-23, direct front view.

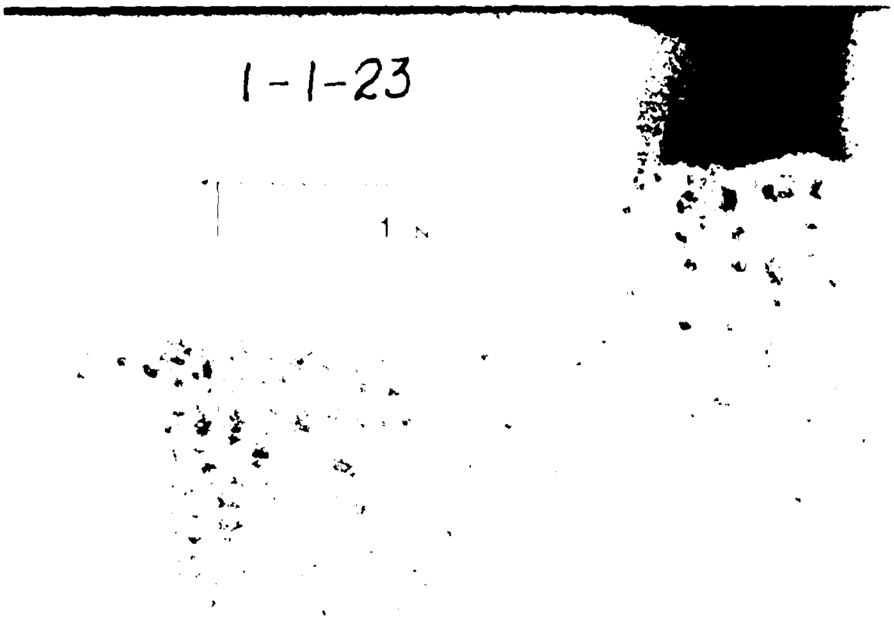


Figure A1-205. Sample 1-1-23, close-up front view, upper left quadrant.

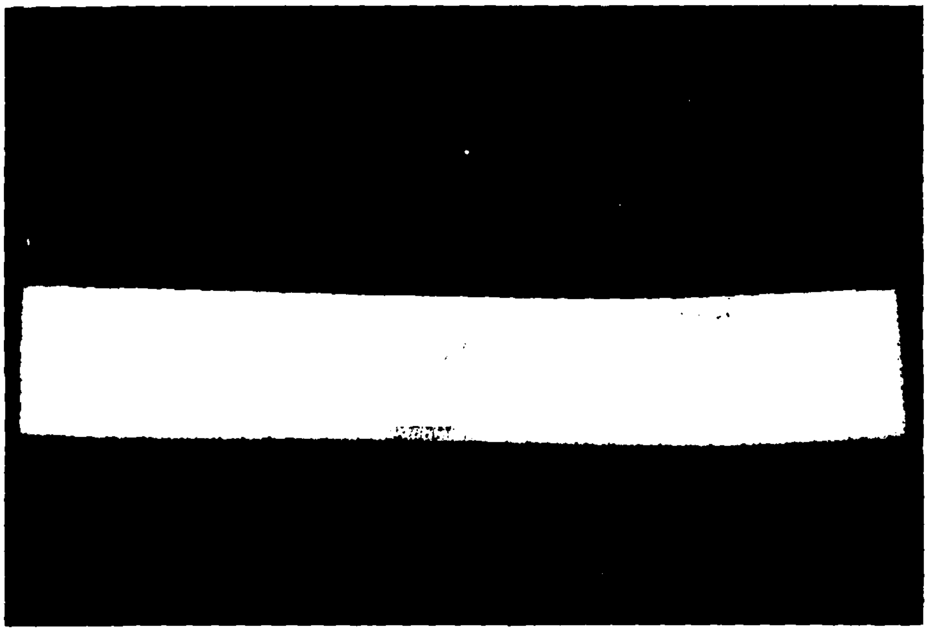


Figure A1-206. Sample 1-1-23, cross-sectional view.

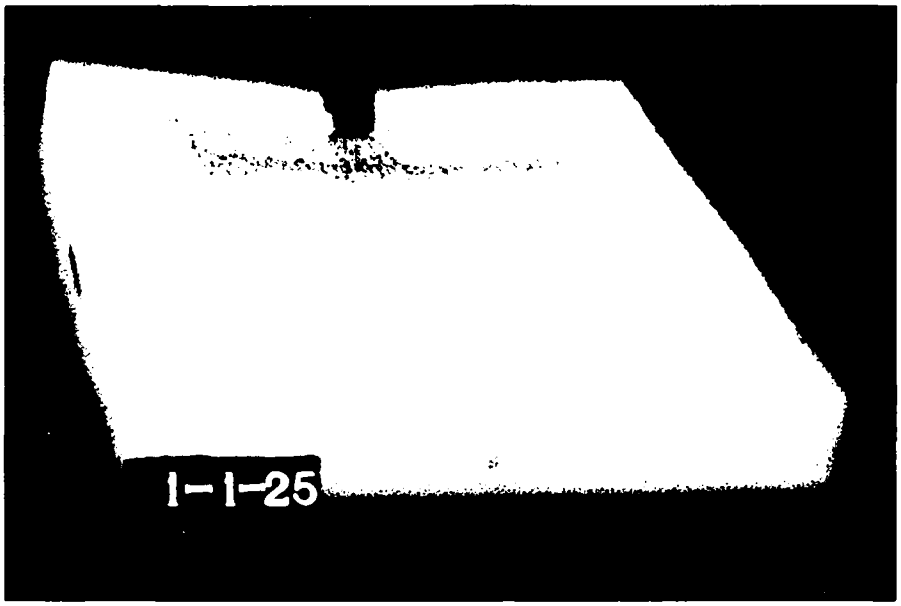


Figure A1-207. Sample 1-1-25, perspective front view.

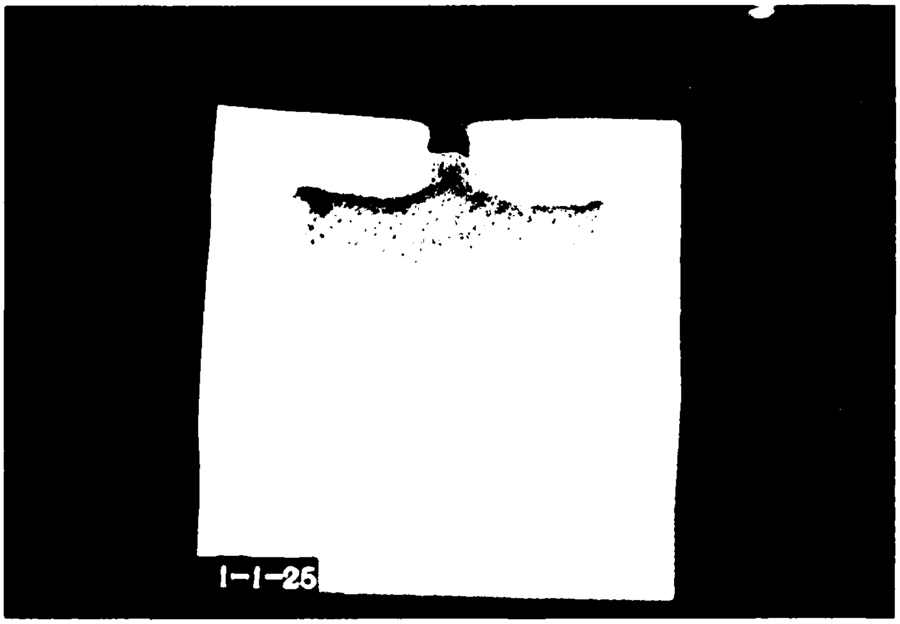


Figure A1-208. Sample 1-1-25, direct front view.

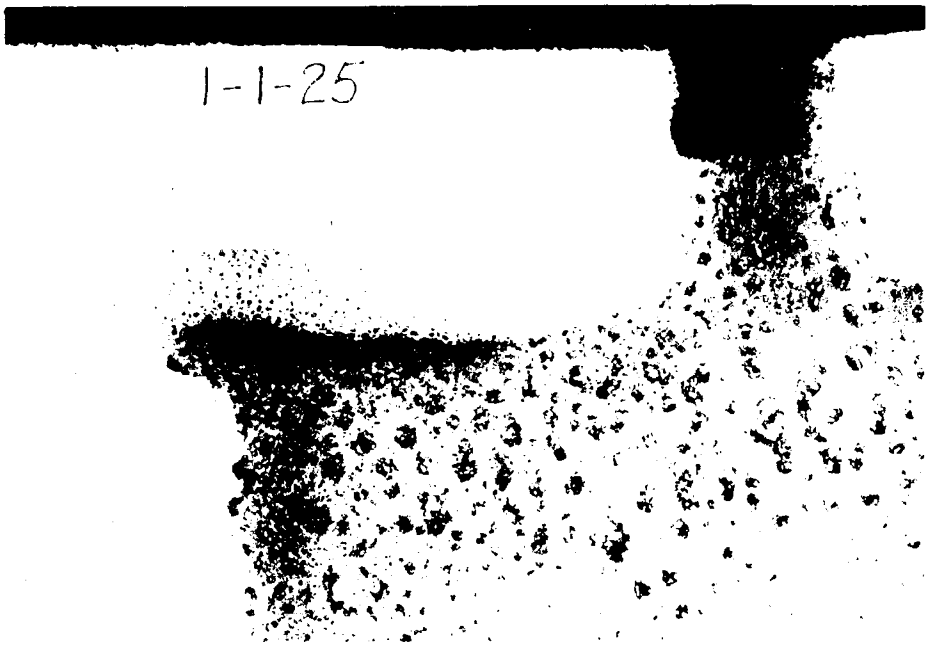


Figure A1-209. Sample 1-1-25, close-up front view, upper left quadrant.

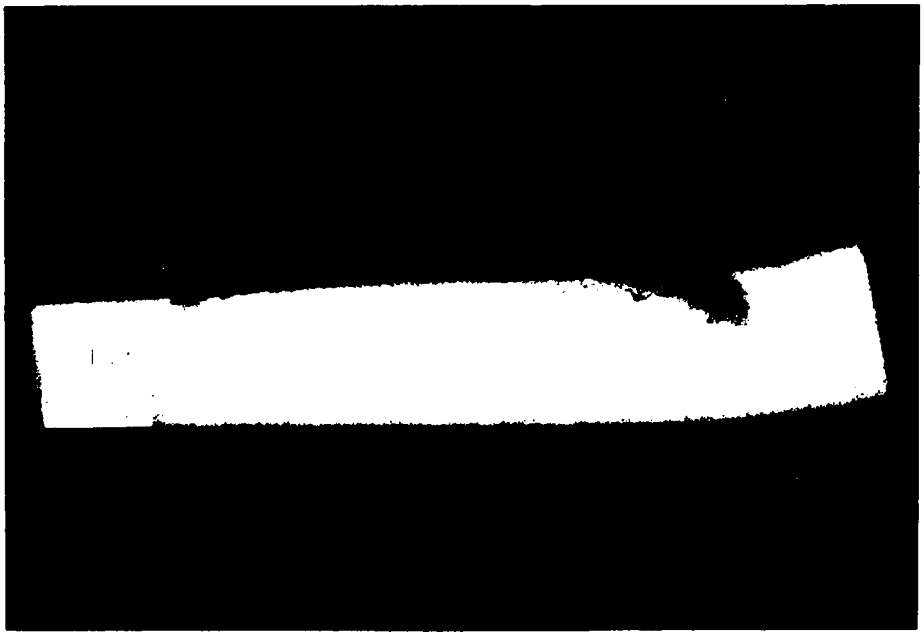


Figure A1-210. Sample 1-1-25, cross-sectional view.

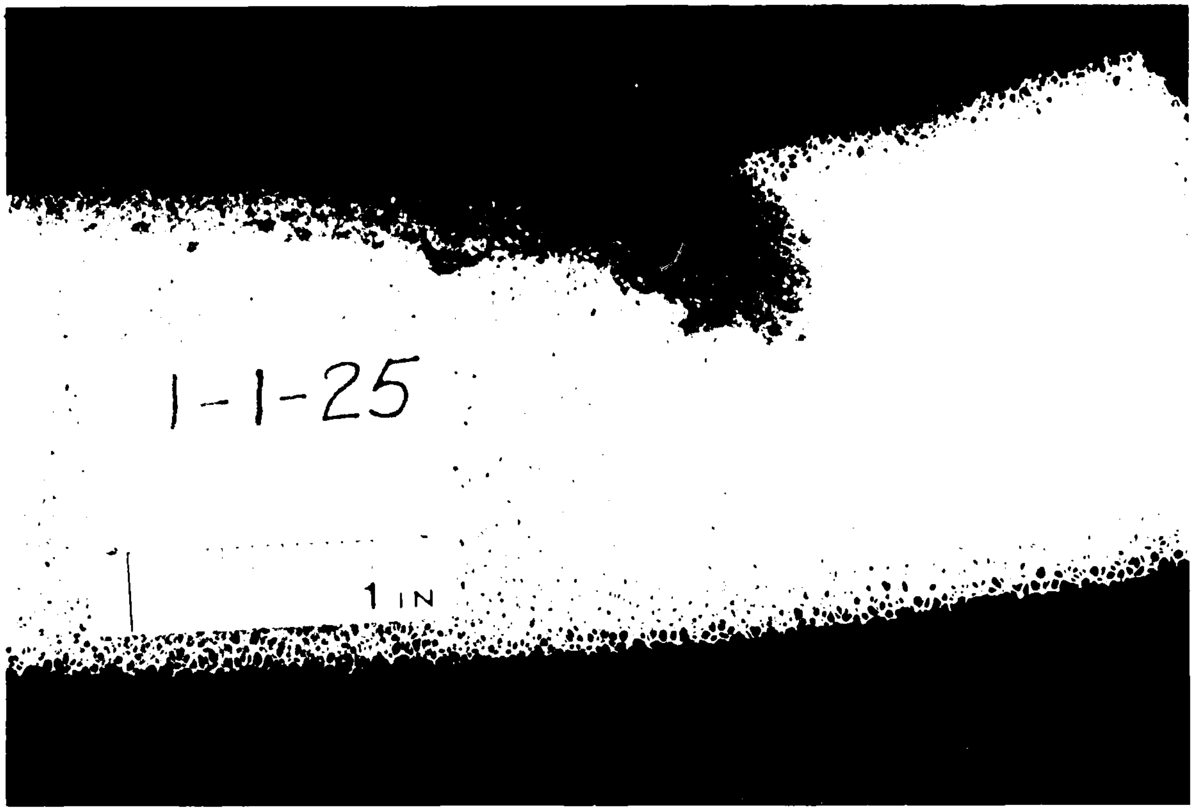


Figure A1-211. Sample 1-1-25, close-up cross-sectional view, upper left quadrant.

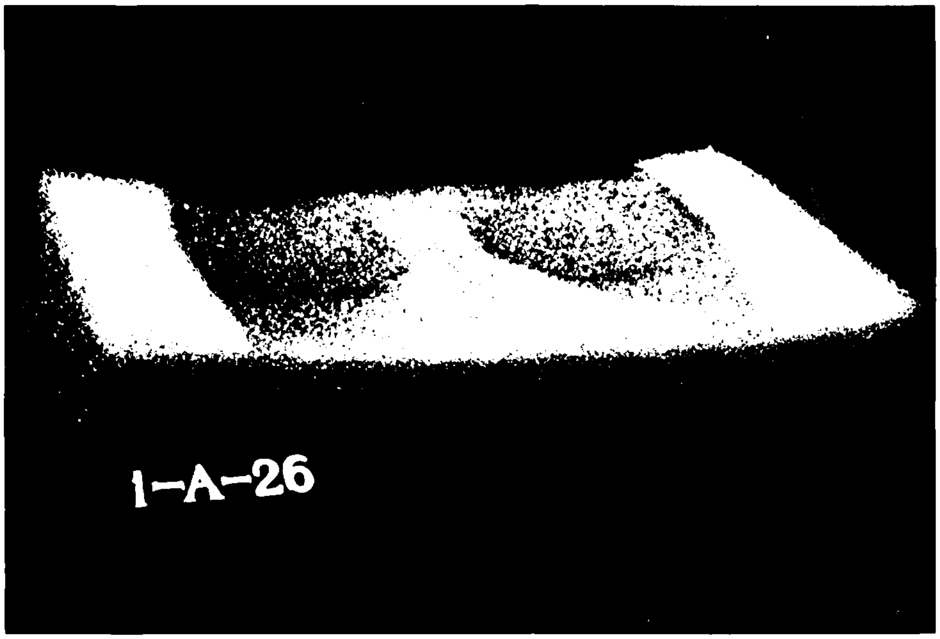


Figure A1-212. Sample 1-A-26, perspective front view.

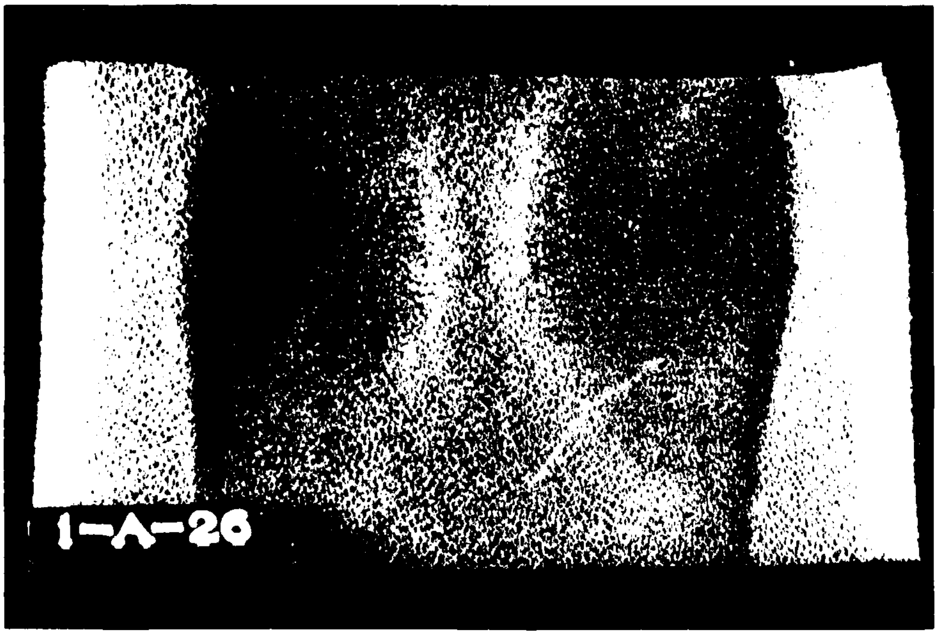


Figure A1-213. Sample 1-A-26, direct front view.

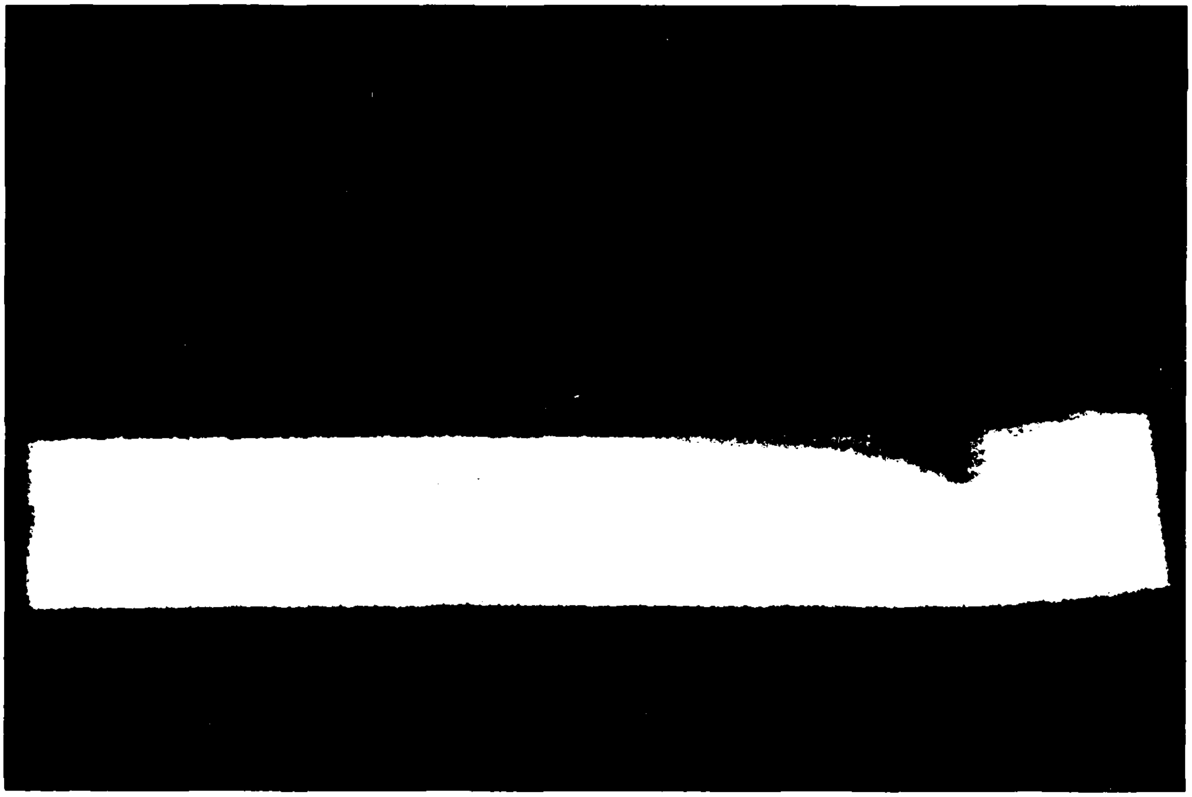


Figure A1-234. Sample 1-3-40, cross-sectional view.

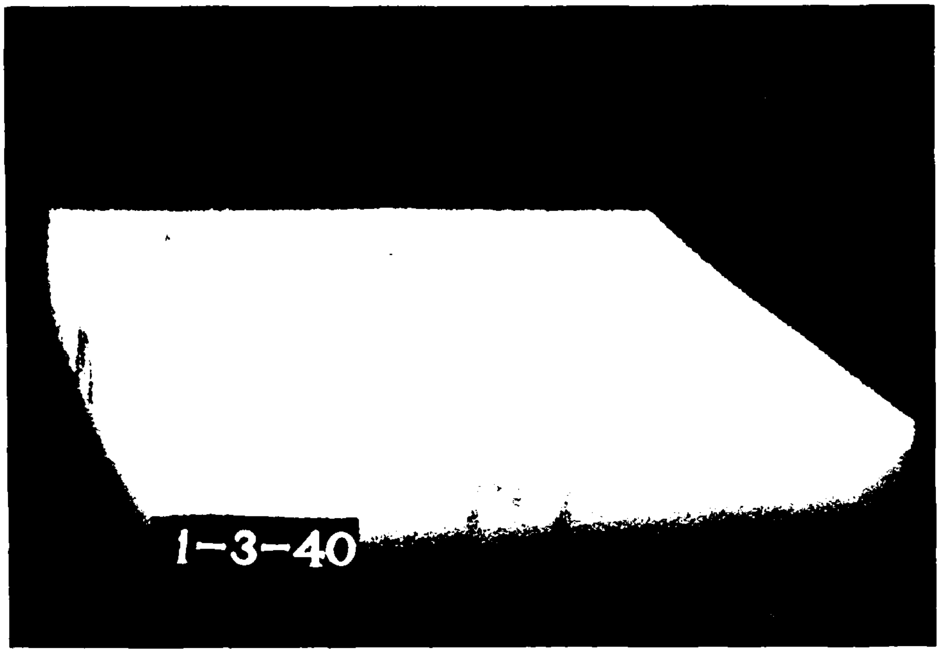


Figure A1-232. Sample 1-3-40, perspective front view.

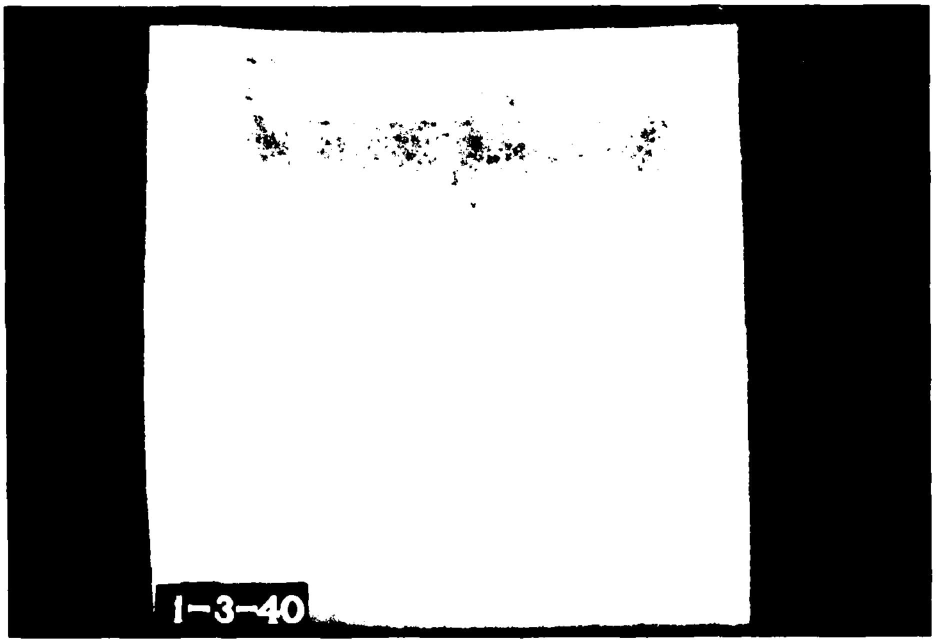


Figure A1-233. Sample 1-3-40, direct front view.

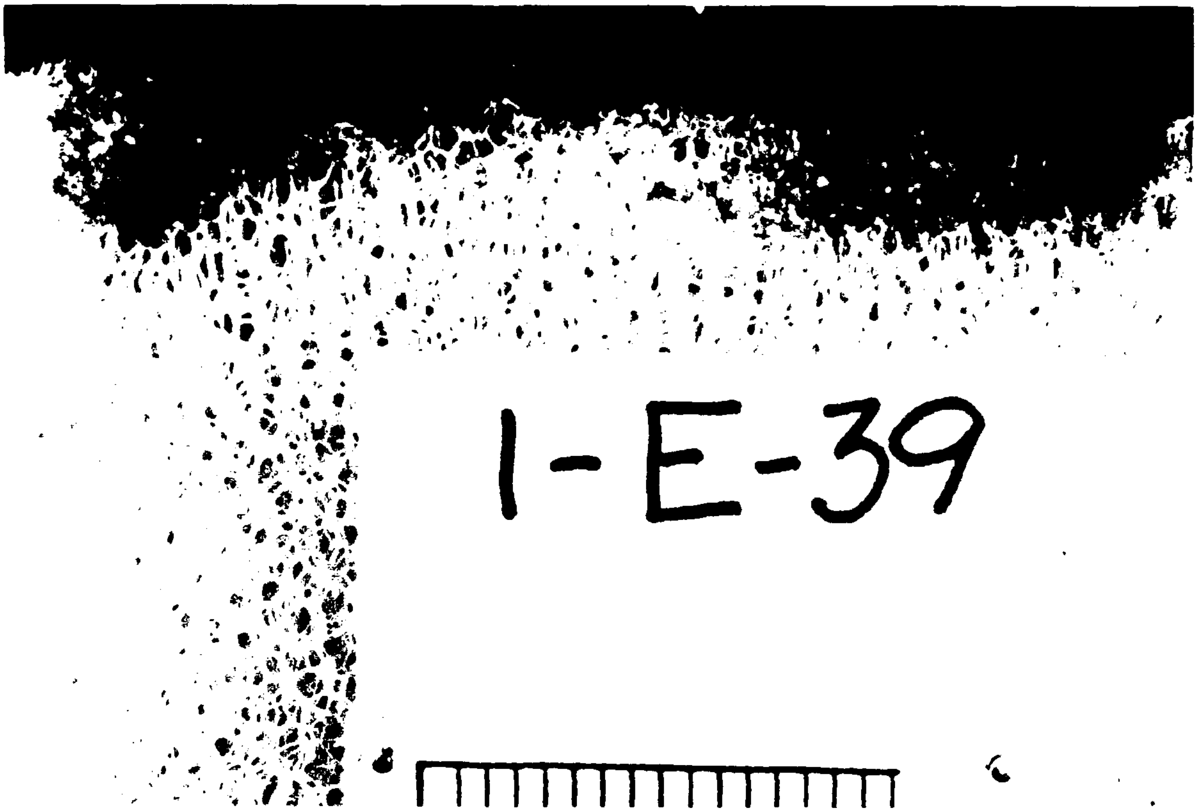


Figure A1-231. Sample 1-E-39, close-up cross-sectional view.

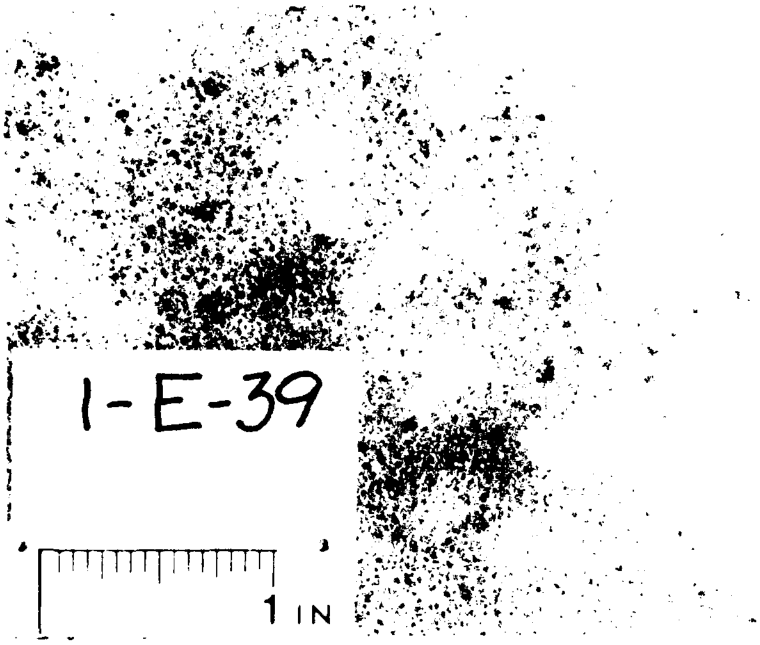


Figure A1-229. Sample 1-E-39, close-up view of front surface.

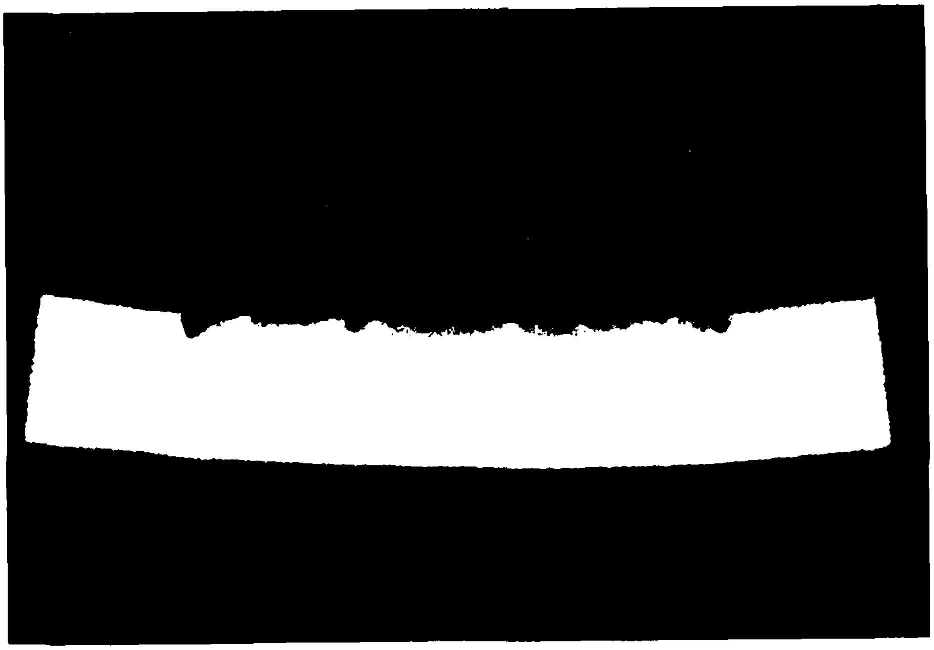


Figure A1-230. Sample 1-E-39, cross-sectional view.

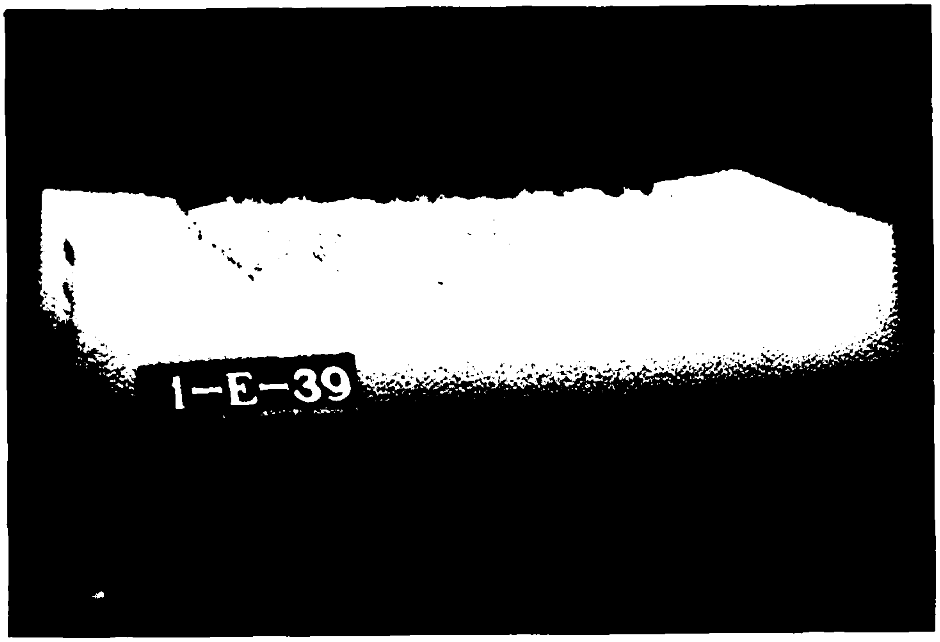


Figure A1-227. Sample 1-E-39, perspective front view.

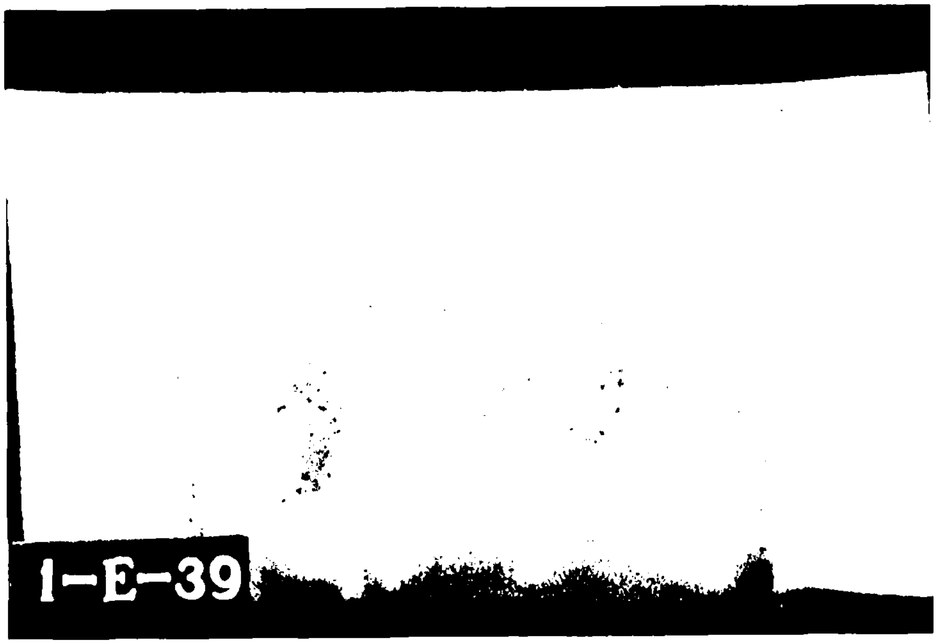


Figure A1-228. Sample 1-E-39, direct front view.

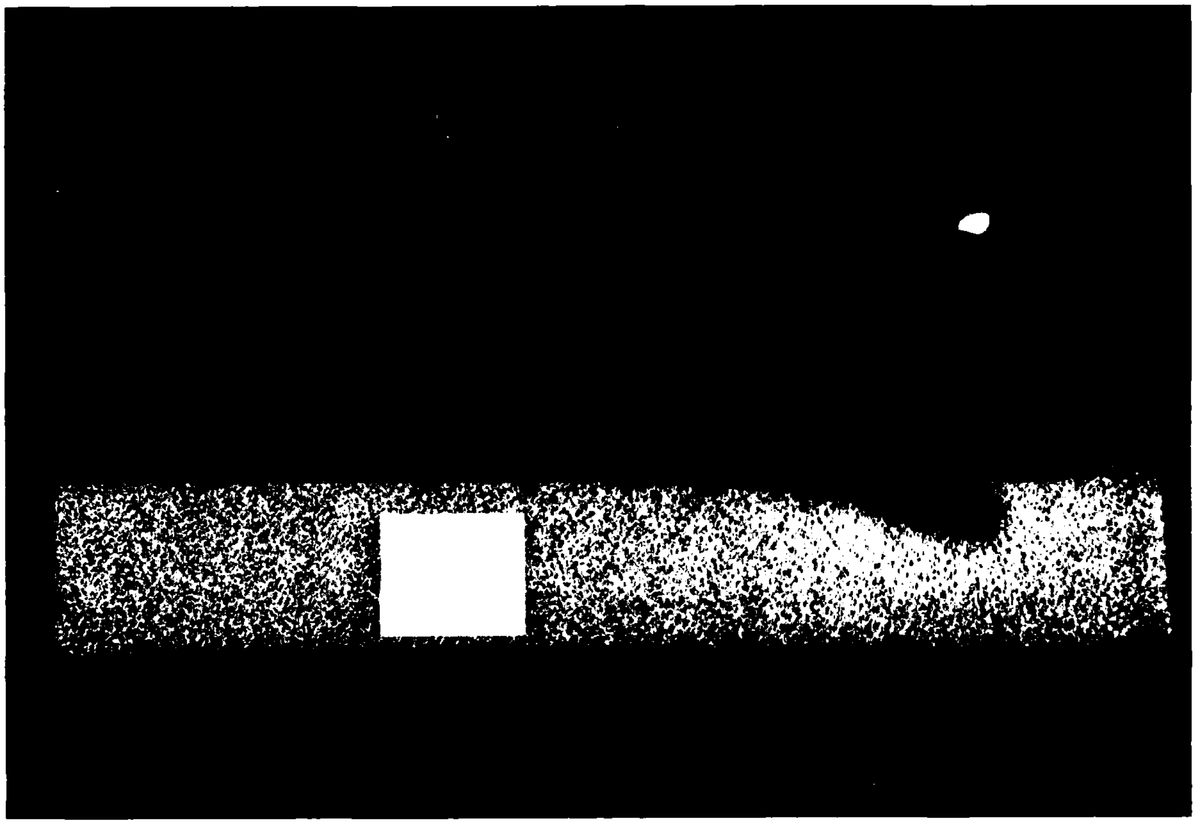


Figure A1-226. Sample 1-3-37, cross-sectional view.

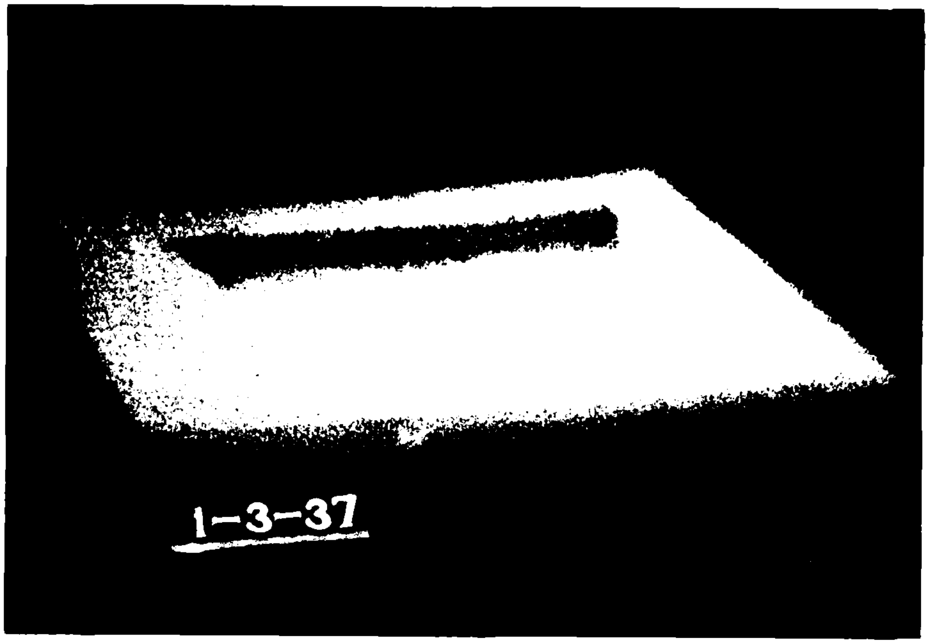


Figure A1-214. Sample 1-3-37, perspective front view.

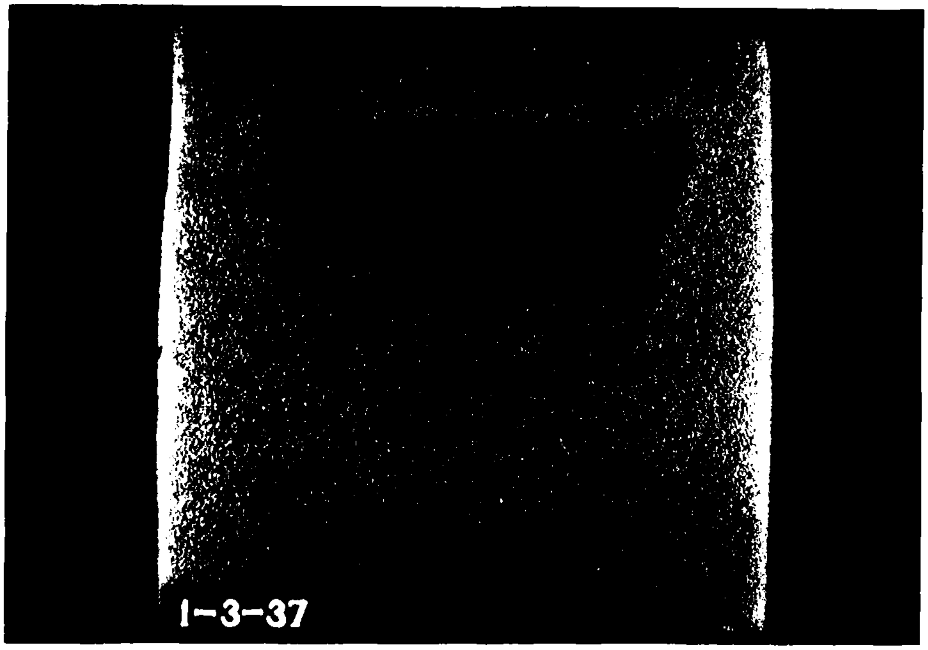


Figure A1-225. Sample 1-3-37, direct front view.

Figure A1-223. Sample 1-3-34, cross-sectional view.

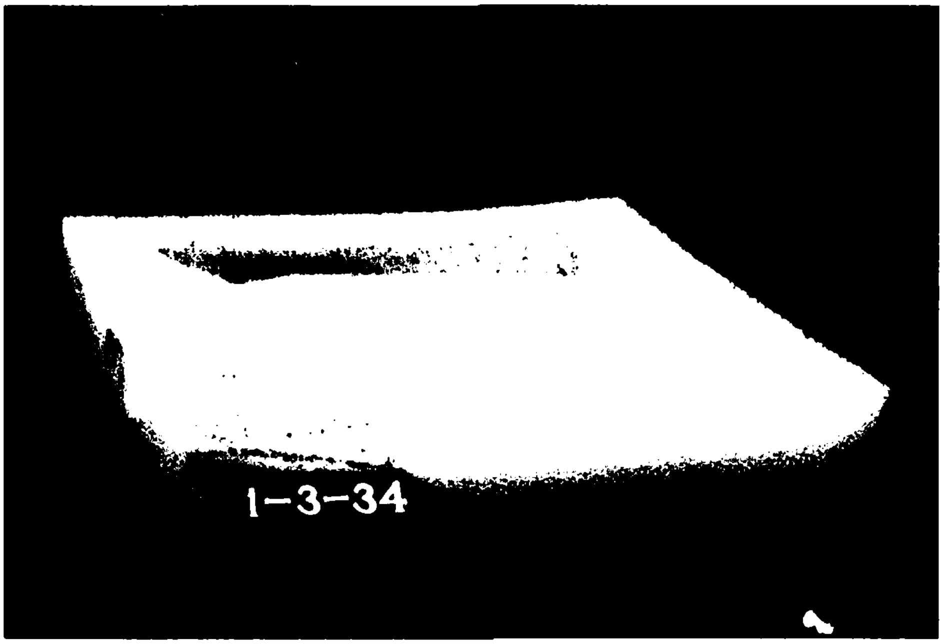


Figure A1-221. Sample 1-3-34, perspective front view.

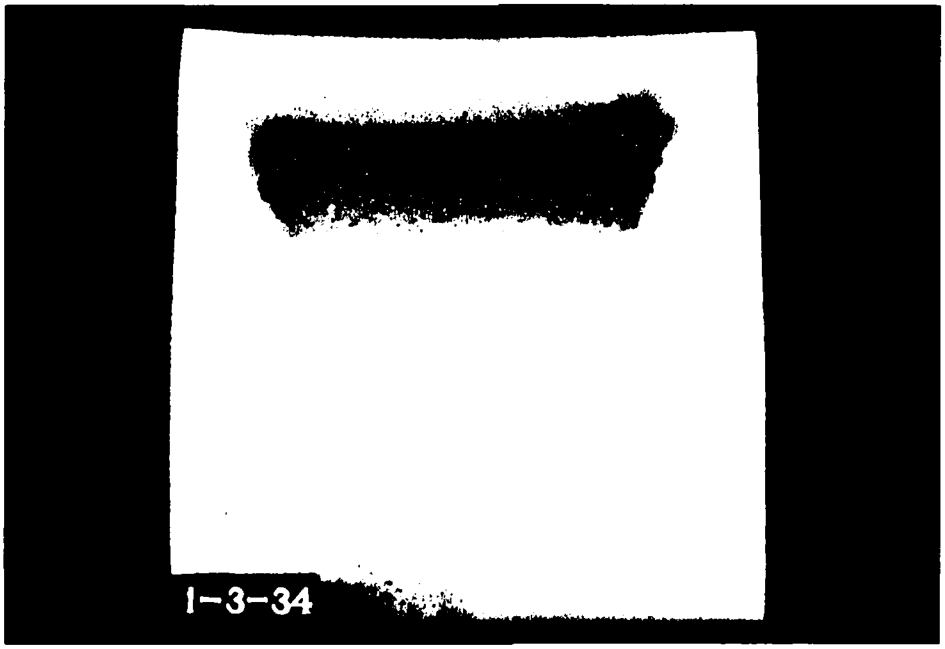


Figure A1-222. Sample 1-3-34, direct front view.

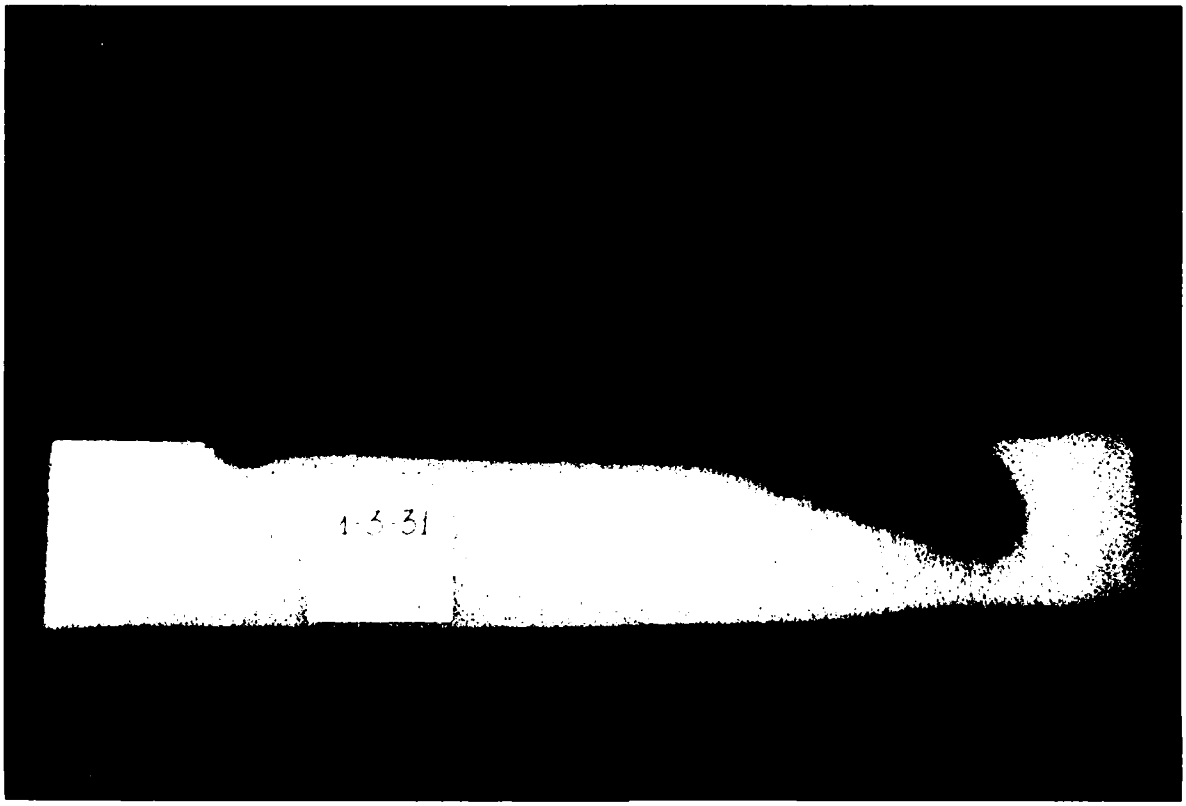


Figure A1-220. Sample 1-3-31, cross-sectional view.

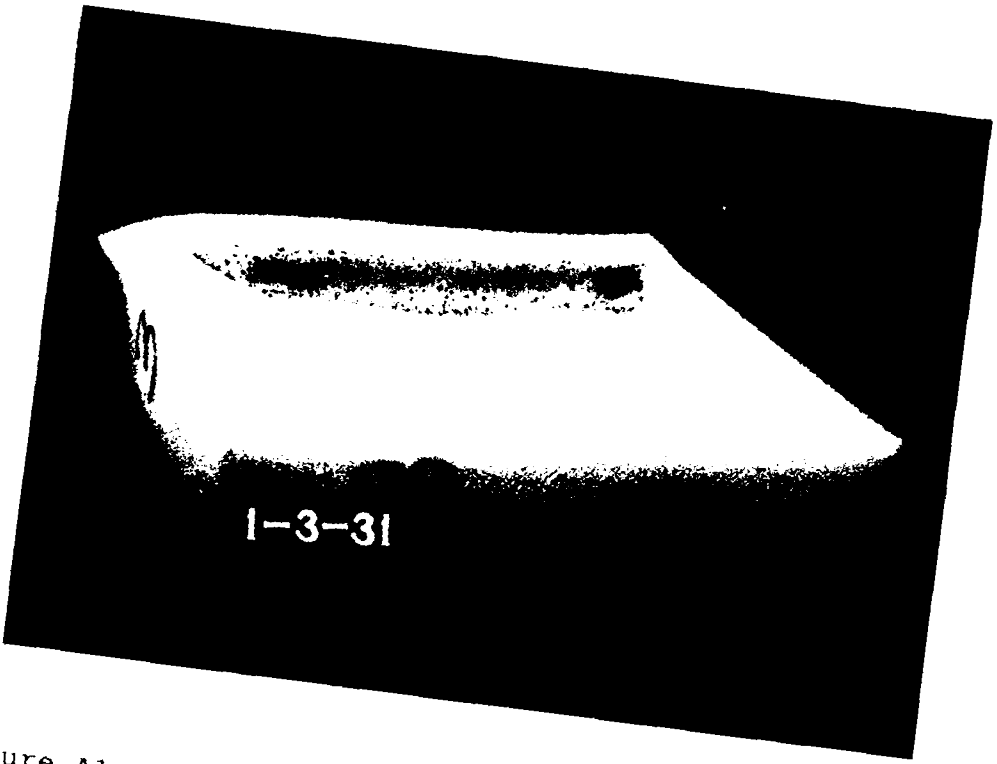


Figure A1-218. Sample 1-3-31, perspective front view.

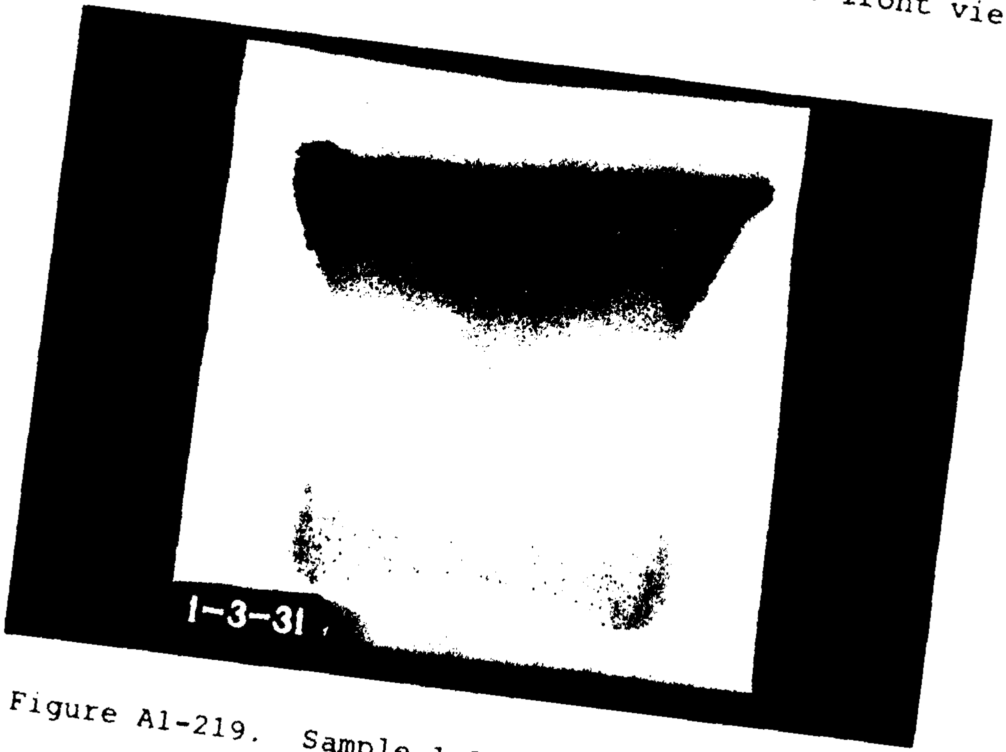


Figure A1-219. Sample 1-3-31, direct front view.

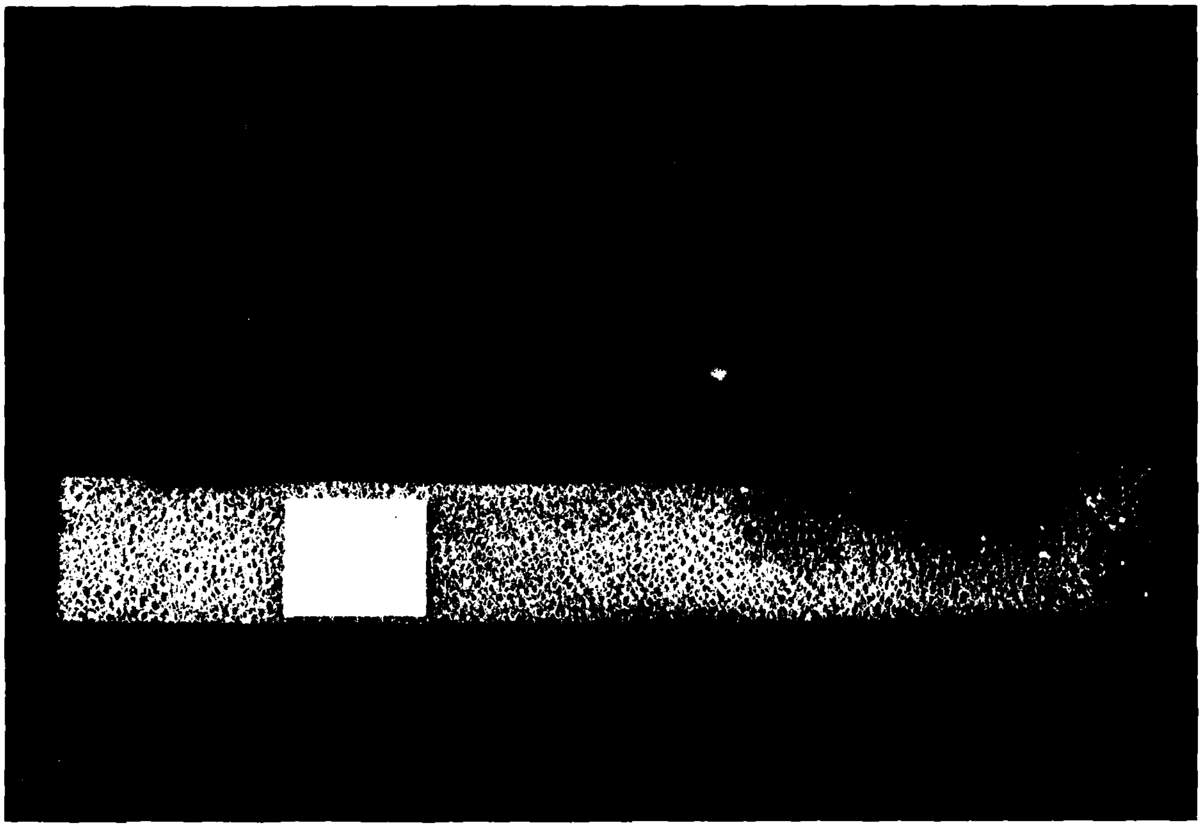


Figure A1-217. Sample 1-3-28, cross-sectional view.

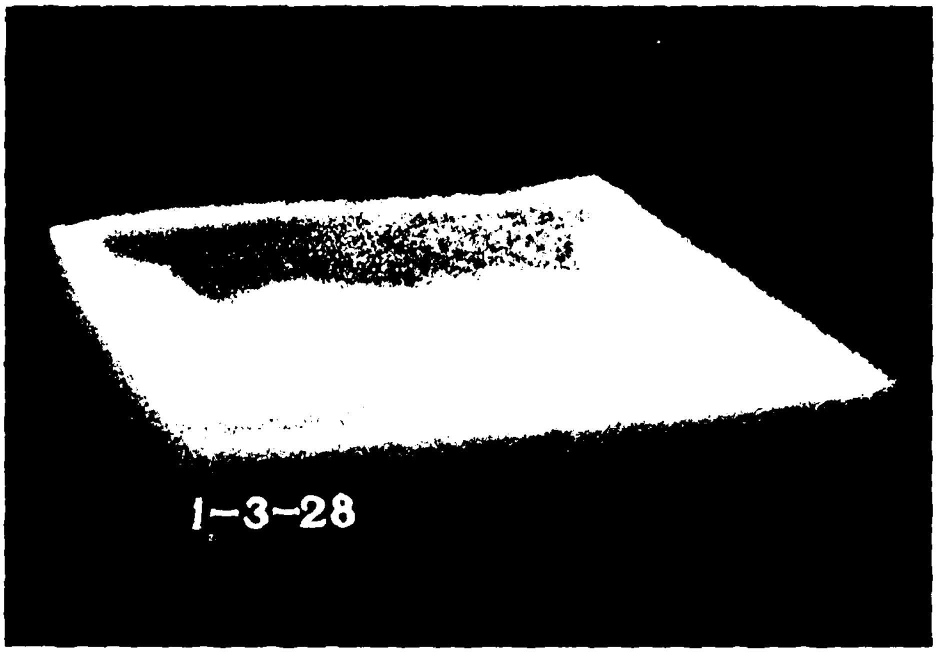


Figure A1-215. Sample 1-3-28, perspective front view.

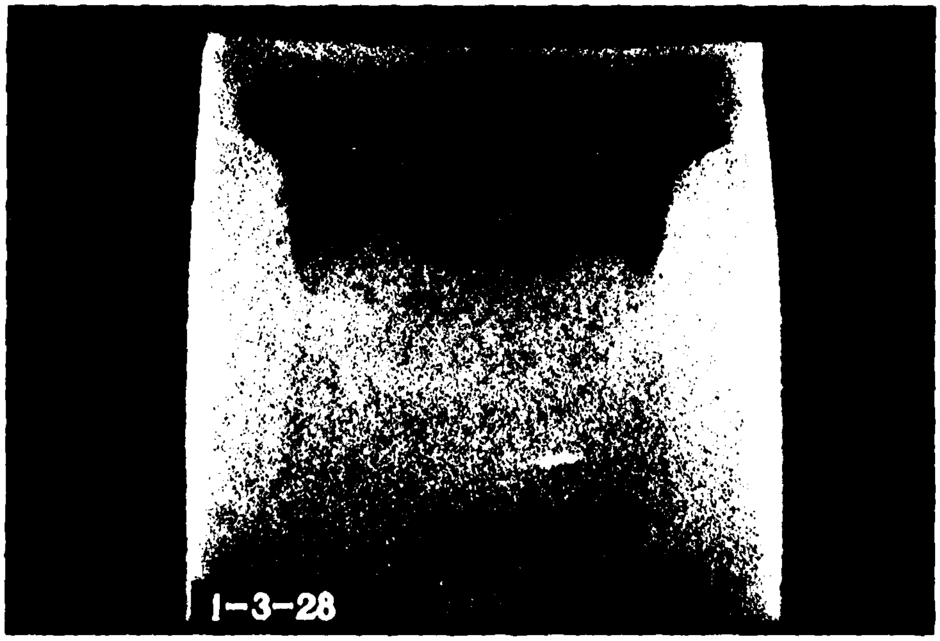


Figure A1-216. Sample 1-3-28, direct front view.

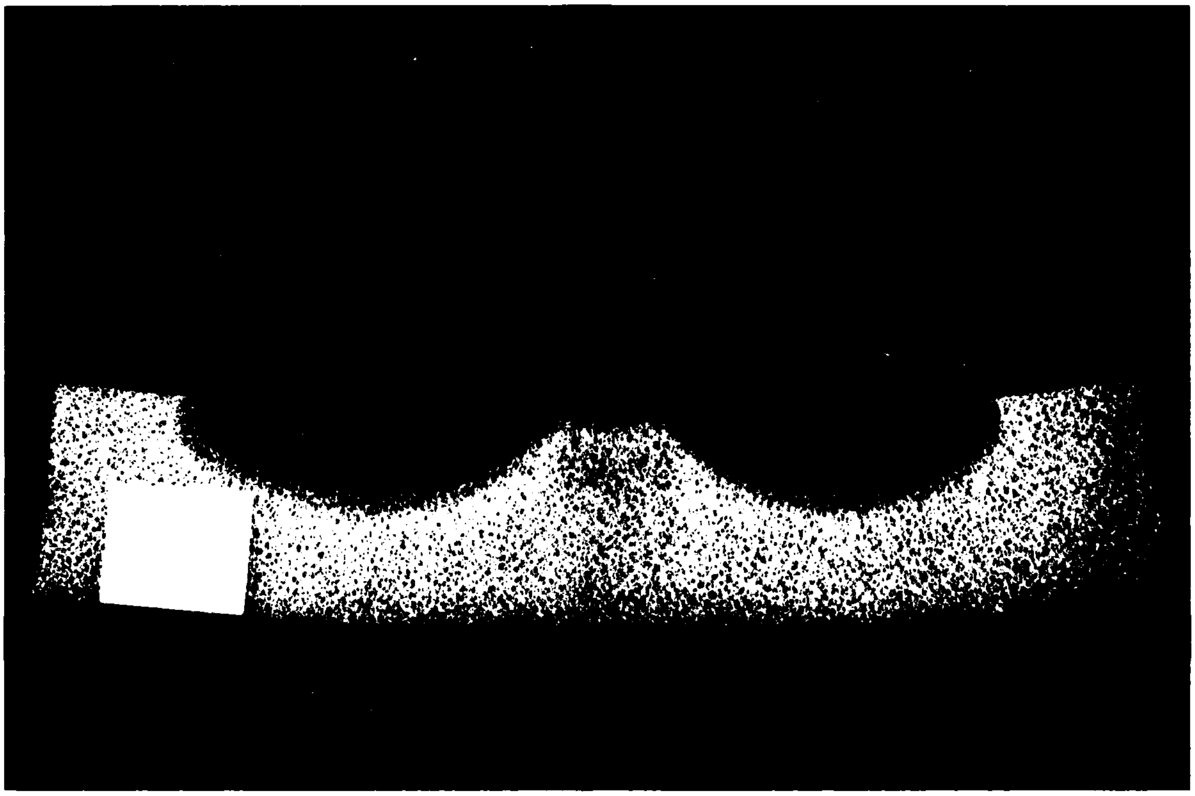


Figure A1-214. Sample 1-A-26, cross-sectional view.

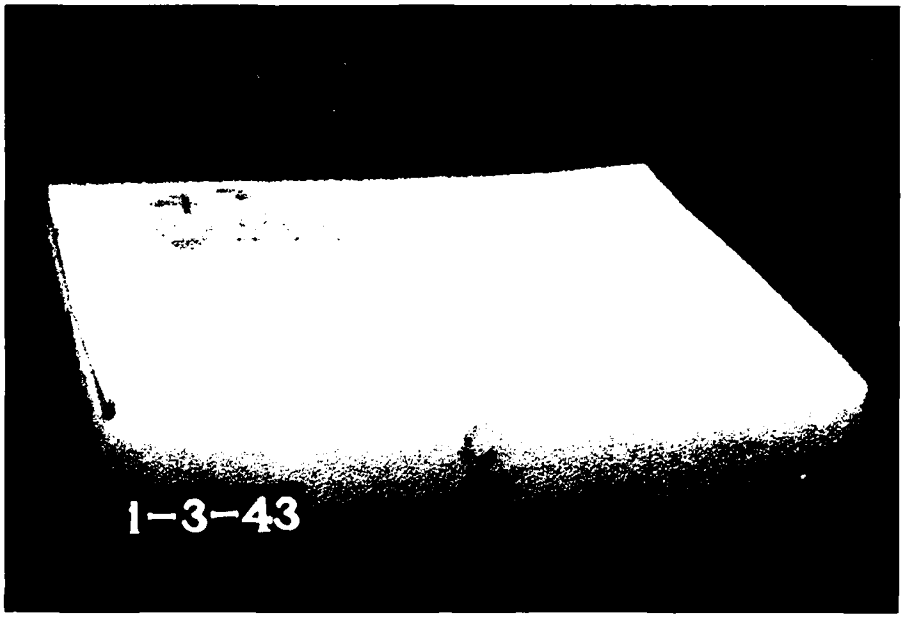


Figure A1-235. Sample 1-3-43, perspective front view.

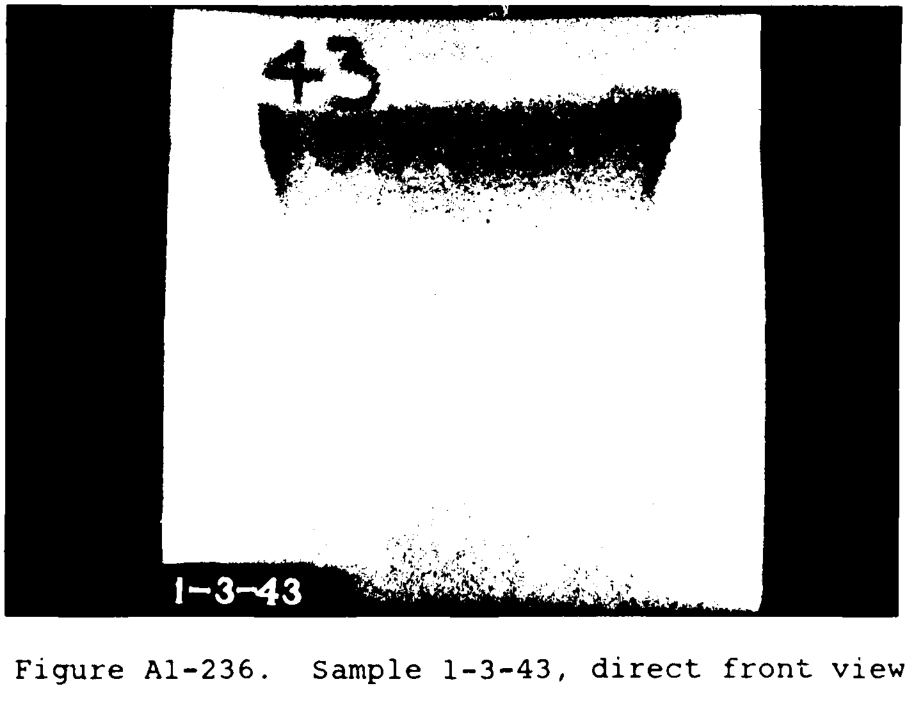


Figure A1-236. Sample 1-3-43, direct front view.

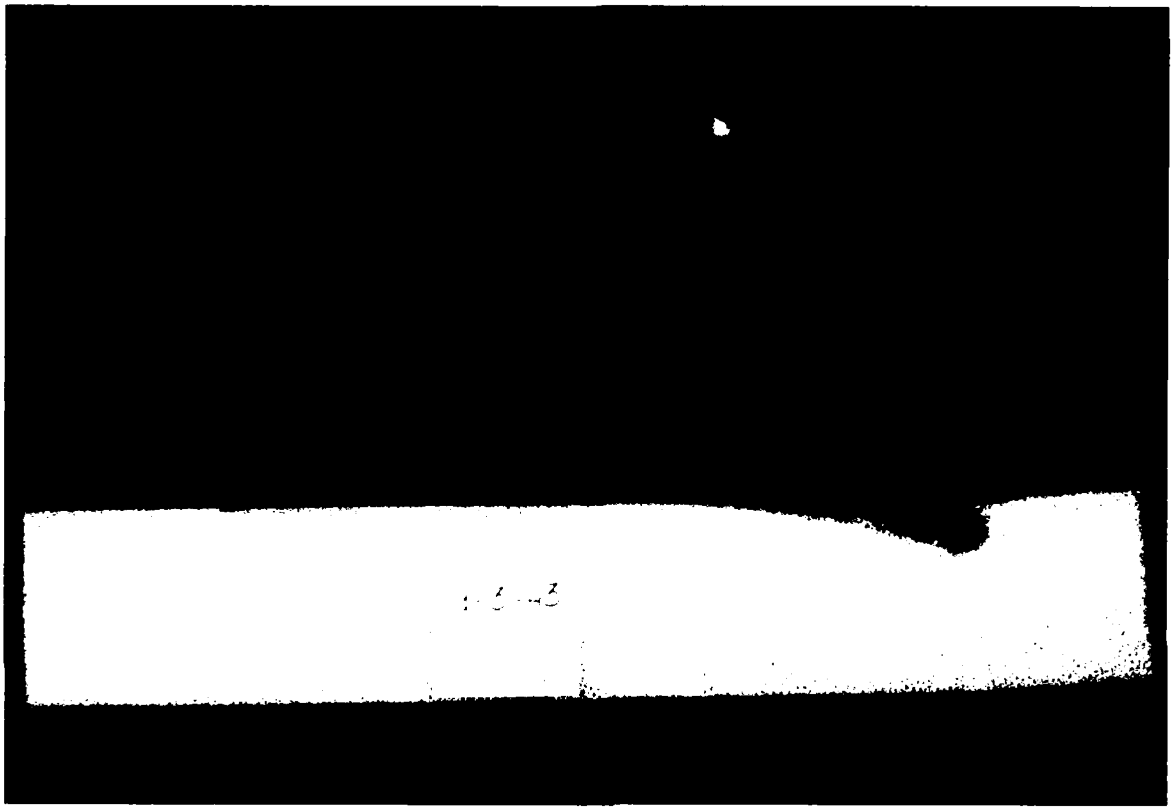


Figure A1-237. Sample 1-3-43, cross-sectional view.

APPENDIX 2

BROWN-STAINED BLUE FOAM IN F-4 AIRCRAFT

In 1977, a single F-4 aircraft, SN 69-7583, was retrofitted as a prototype with Type IV blue, coarse pore foam. This prototype kit was first used in evaluation tests in the McDonnel Aircraft Company F-4 fuel testing in February 1977 (Ref. A2-1) and it was then retrofitted into SN 69-7583. The foam was manufactured by SCOTFOAM Corporation and identified by Run Number W 9572. After 42 months of aircraft service, the blue foam was inspected during routine fuel tank service. A large amount of the foam was found to be stained brown in the areas of the level control valves, as shown in Figures A2-1 and A2-2. The white deposit on foam surface is silicone fuel tank sealant.

Samples were cut, as shown in Figure A2-3, and sent to SCOTFOAM Corporation and Union Carbide Corporation for analysis, to determine the source of the discoloration. From visual observations, this foam appeared to have experienced degradation. Therefore, physical properties of this foam were also determined. The results were compared with data for the blue foam used in the qualification tests (Ref. A2-2), that was also from Run W 9572. The difference in tensile strength between Slice 1 and Slice 2 (see Table A2-1) was at least partly due to pore size. From visual observation, Slice 1 had about 10 pores per inch (ppi) and Slice 2 had about 14 ppi. The overall average tensile strength of the brown-stained foam was about 20% lower than the average for the original foam (see Table A2-1). This decrease probably resulted from foam aging.

A2-1. J. M. Tirpack, "Validation of Extended Life Fuel Tank Foam," USAF PRAM Program Final Report, July 1977.

A2-2. T. O. Reed and W. D. Vahle, "Qualification Test Results for Scott Paper Company Hybrid Polyether Foam," Aeronautical Systems Division Technical Memorandum ENFEF-TM-79-08, December 1979.

Figure A2-1. F-4 brown-stained foam compared with new blue foam.

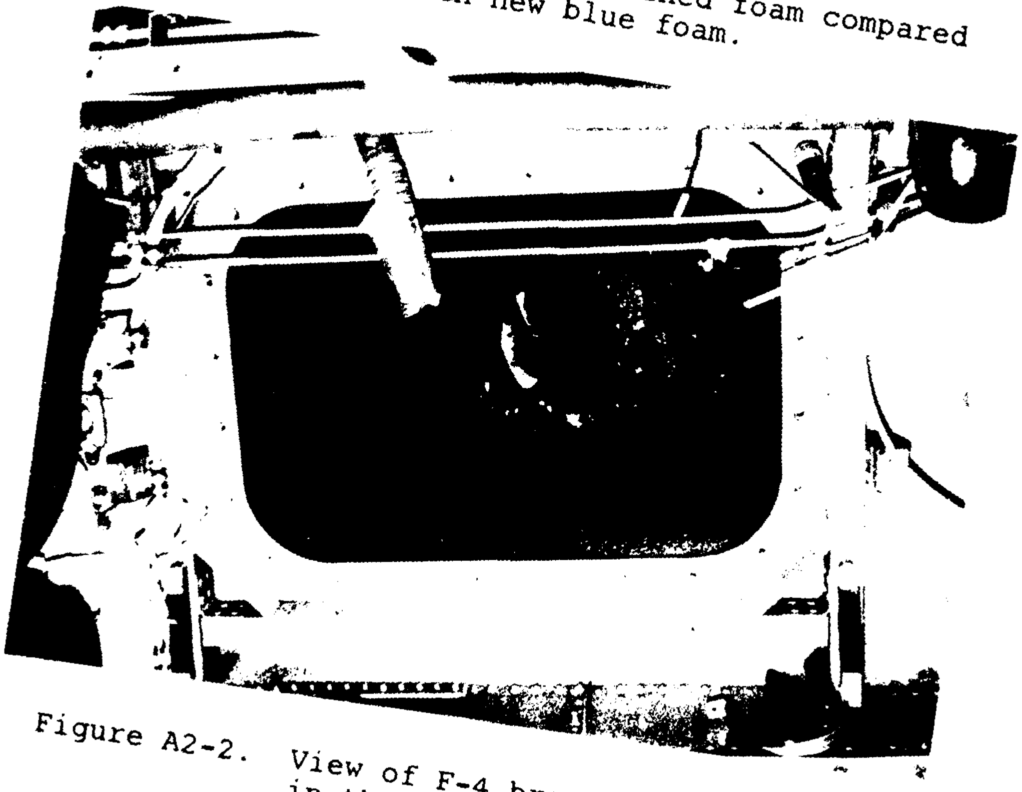
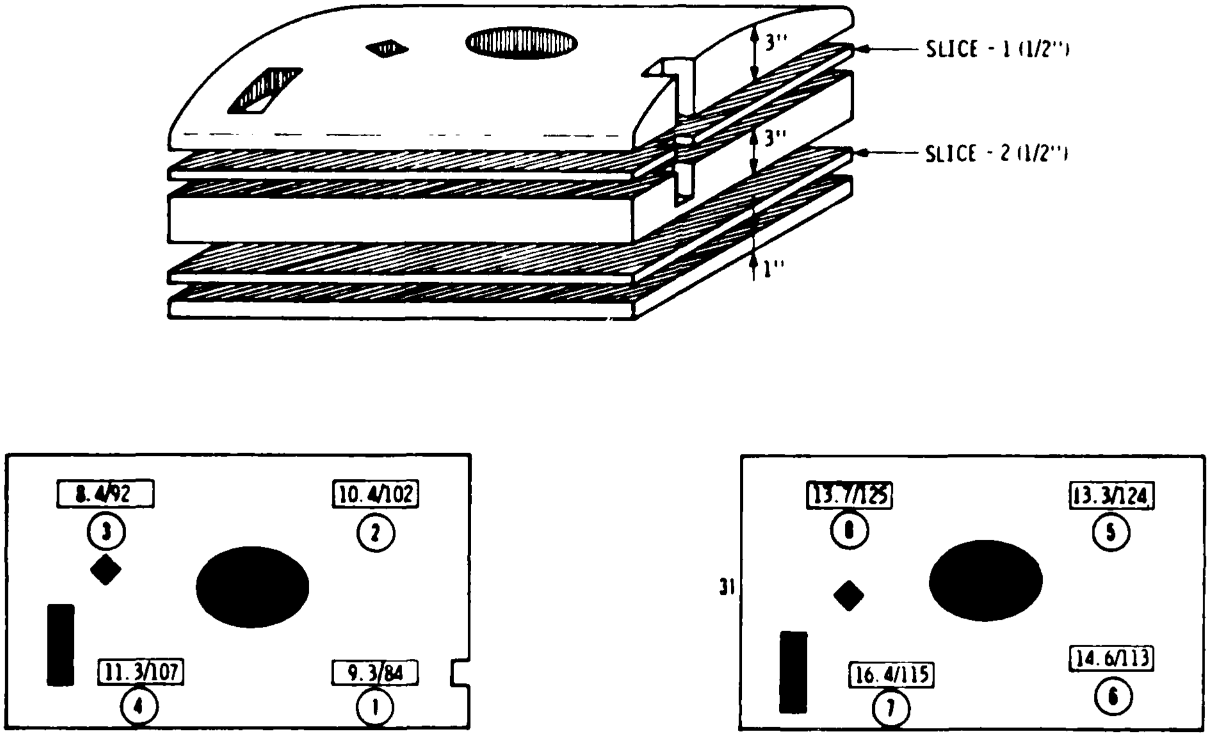


Figure A2-2. View of F-4 brown-stained foam in the fuel cell.



SLICE - 1
TENSILE LOCATIONS

SLICE - 2
TENSILE LOCATIONS

Figure A2-3. Sample locations, F-4 (brown-stained) foam.

Extraction tests were conducted on the F-4 foam and on new foam. Soxhlet extraction with perchloroethylene removed the blue color from both samples (see Table A2-2). With acetone, some of the brown stain was removed from the F-4 foam. Its color became bluish-green, whereas the fresh foam did not change color upon extraction with acetone. Elemental analysis of this extract (after removal of acetone) showed differences in carbon, hydrogen and oxygen content, compared to an acetone extract from the fresh blue foam (see Table A2-3). Infrared spectra of the acetone extracts also showed some differences in relative peak intensities (see Figures A2-4 and A2-5, and Table A2-4. Ultraviolet spectra were also determined on the acetone extracts, no differences were observed (see Figure A2-6).

The white-colored globules that were present throughout the brown-stained foam were also analyzed. Infrared spectra confirmed that they were composed of a silicone composition (e.g., a silicone sealant). There was also a finely divided powder suspended within the silicone globules, which was probably an inorganic filler.

Although the concentrations of most of the metals found in the F-4 foam were higher than in fresh foam (see Table A2-5), the most probable source of the discoloration was a leak-checking dye. Other potential sources for the discoloration were additives in the fuels and the fuel tank sealants. In Table A2-6 are given the chemical compositions of fuel additives required for JP-4 and JP-8.

The leak checking dyes consist of oil-soluble organic liquids that do not contain reactive amino groups. The polyurethane foams have a high propensity to absorb organic compounds.

The use of acetone and perchloroethylene, solvents that have low dielectric constants, for the Soxhlet extractions leads to elution of organic compounds that also have low dielectric constants.

TABLE A2-1. PHYSICAL PROPERTIES OF FOAM SAMPLES

	F-4 (brown-stained) foam			Original
	Sample location		Value	W957L
Tensile strength, psi	Slice #1:	1	9.3	
		2	10.4	
		3	11.3	
		4	8.4	
	Range		8.4-11.3	
	Average		9.9	
	Slice #2:	5	13.3	
		6	14.6	
		7	16.4	
		8	13.7	
	Range		13.3-16.4	
	Average		14.5	
	Overall range		8.4-16.4	11.2-19.0
	Overall average		12.2	15.1
Elongation, %	Slice #1:	1	84	
		2	102	
		3	107	
		4	92	
	Range		84-107	
	Average		96	
	Slice #2:	5	124	
		6	113	
		7	115	
		8	125	
	Range		113-125	
	Average		119	
	Overall range		84-125	109-194
	Overall average		108	135
Tear strength, psi			4.9	
			4.6	
			4.4	
	Average		4.6	3.90
Compression load deflection, psi	25%		0.32	0.42
	65%		0.97	0.73

TABLE A2-2. SOXHLET EXTRACTION RESULTS

Foam sample	Solvent	% Extractable	Foam color change
F-4 (brown-stained)	H_2O	3.0	None
F-4 (brown-stained)	Hexane	10.9	None
F-4 (brown-stained)	Perchloroethylene	12.8	To beige
Fresh blue foam	Perchloroethylene	2.7	To white
F-4 (brown-stained)	Acetone	7.4	To bluish green
Fresh blue foam	Acetone	4.2	None

TABLE A2-3. ELEMENTAL ANALYSIS RESULTS FOR EXTRACTS

Sample	%C	%H	%O	%N	Total
F-4 (brown-stained) foam extract	70.06	8.86	9.39	6.77	95.08
Fresh blue foam extract	67.77	8.51	13.52	6.76	96.56

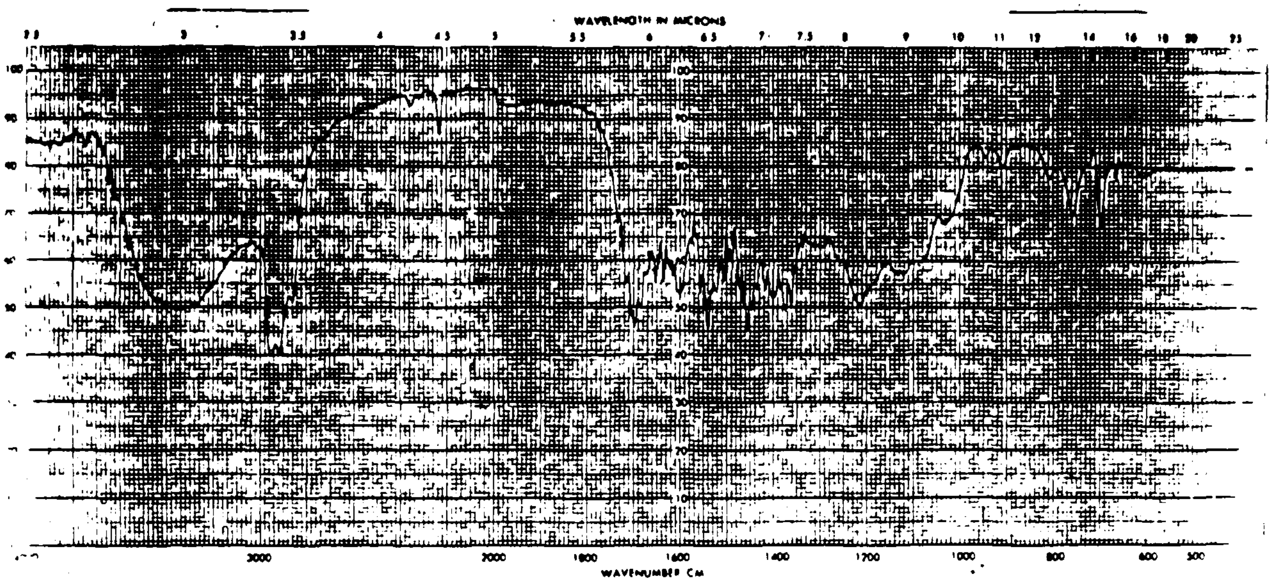


Figure A2-4. Infrared spectrum of acetone extract from F-4 (brown-stained) foam.

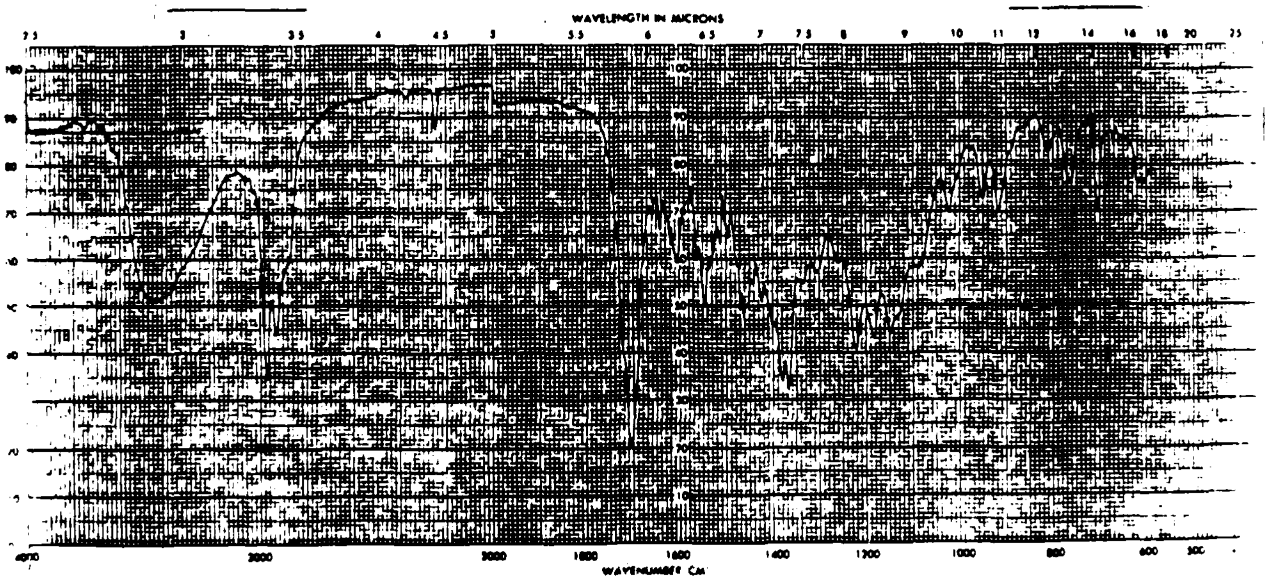


Figure A2-5. Infrared spectrum of acetone extract from fresh blue foam.

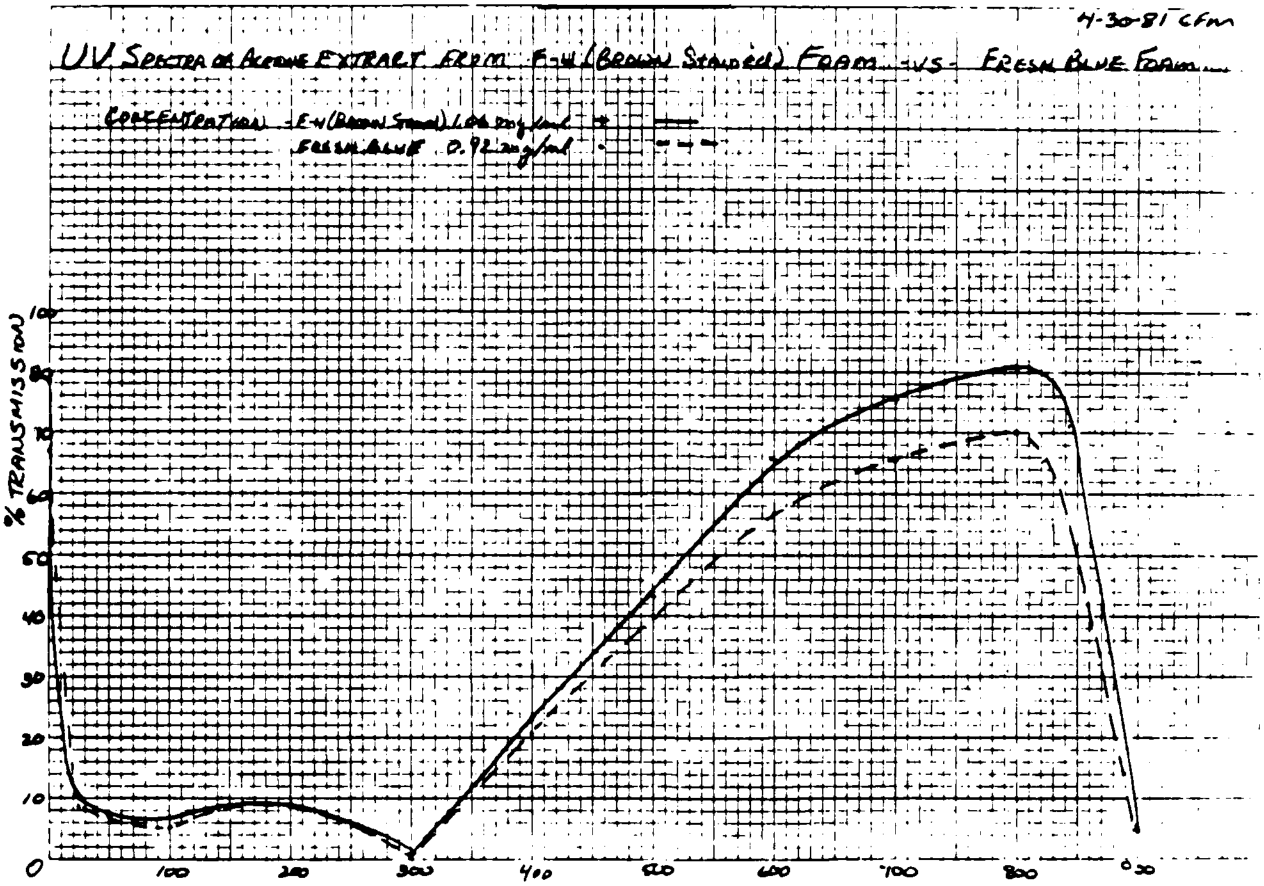


Figure A2-6. Ultraviolet spectra of acetone extracts from F-4 (brown-stained) foam and fresh blue foam.

TABLE A2-4. SUMMARY OF EXTRACTION TEST RESULTS

Extraction solvent	Fresh blue foam	Brown-stained foam
Perchloroethylene[a]	Color change to white 2.7 % weight loss	Color change to beige 12.8% weight loss
Acetone[a]	No color change 4.2 % weight loss IR - Urethane Acrylonitrile Styrene	Color change to bluish-green 7.5% weight loss IR - Urethane Acrylonitrile Styrene
Methanol[b]	No color change IR - Urethane Acrylonitrile Styrene	No color change IR - Urethane Acrylonitrile Styrene Alkylsulfonate

---

[a] Soxhlet extraction, performed by SCOTTFOAM Corporation.

[b] Room temperature extraction, performed by Union Carbide Corporation.

TABLE A2-5. RESULTS FOR METAL ANALYSES[a]

Metal	Fresh blue foam	Brown-stained foam
Aluminum	9	25
Barium	0.3	2
Calcium	11	31
Cadmium	1	115
Chromium	5.5	8
Copper	81	55
Iron	38	73
Magnesium	7	13
Manganese	0.25	1.3
Molybdenum	0.7	2
Sodium	14	121
Nickel	1	3
Lead	2.5	72
Antimony	3	4
Total ash	0.14	0.31

---

[a] Analyses performed by Union Carbide Corporation, using an inductively coupled plasma technique.

TABLE A2-6. FUEL ADDITIVES FOR JP-4 AND JP-8, AND FUEL LEAK TESTING DYES

Additive	Compositions	Amount added
Antioxidants	Hindered alkylphenols (e.g., 2,6-di-tert-butyl-4-methlyphenol)	0 to 24 mg/L
Metal deactivatcrs	N,N'-disalicylidene-1,2-propylenediamine and N,N'-disalicylidine-2,2-cyclohexlenediamine	0 to 5.8 mg/L
Corrosion inhibitors	Primarily fatty acids, (e.g., dilinoleic acid)	10 to 50 mg/L
Fuel system icing inhibitor	Ethylene glycol monomethyl ether	0.10 to 0.20%
Static dissipators	Shell ASA-3 -Chromium salt of alkyl-salicylic acid -Calcium salt of dodecyl-sulfosuccinic acid -Methacrylate-vinylpyridine copolymer	1 to 2 ppm
	Dupont Stadis 450 -Polysulfone copolymer -Polymeric polyamide	

TABLE 1 (A5-1)

EXPOSURE SCHEDULE FOR BLUE FOAMS

Group No.	Total Exposure (Hours) Time	Date In the Sunlighter	Date Out of Sunlighter
1	40	6-7-83 9:00 a.m.	6-9-83 5:00 p.m.
2	80	6-7-83 9:00 a.m.	6-14-83 5:00 p.m.
3	120	6-9-83 5:00 p.m.	6-20-83 5:00 p.m.
4	160	6-14-83 5:00 p.m.	6-24-83 5:00 p.m.
5	200	6-20-83 5:00 p.m.	6-29-83 5:00 p.m.

Group 1 → 7-1-1, 7-1-2, 7-1-3, 7-1-4
Group 2 → 7-2-1, 7-2-2, 7-2-3, 7-2-4
Group 3 → 7-3-1, 7-3-2, 7-3-3, 7-3-4
Group 4 → 7-4-1, 7-4-2, 7-4-3, 7-4-4
Group 5 → 7-5-1, 7-5-2, 7-5-3, 7-5-4

A like number of samples of each type foam were subjected to accelerated agings in JP-5 aircraft fuel. Wide-mouth, one quart glass containers were used to hold two foam specimens submersed in JP-5. The jar openings were covered with aluminum foil, and lids were installed. The containers were maintained at 200°F in a Thelco Model 18 air oven. At the completion of each cycle, the lids were removed and the fuel was poured off. The specimens were returned to Monsanto in the glass containers. The fuel aging schedule is shown in Table 6.

INTRODUCTION

The facilities of the University of Dayton Research Institute were utilized for conditioning a number of samples of reticulated foam materials. Specimens cut from blue, red, and yellow foams were subjected to ultraviolet exposure, accelerated aging in humidity, and accelerated aging in aircraft fuel. Schedules for the aging procedures were provided by Monsanto Research Corporation. Specimens were returned to Monsanto at the completion of each weekly cycle.

PROCEDURE

The Sunlighter IV ultraviolet test chamber was utilized for ultraviolet exposures of foam specimens for up to 200 hours, according to the testing code provided by Monsanto. The blue foams were exposed according to the schedule shown in Table 1. Chamber temperature and observed specimen discolorations were recorded daily. These are summarized in Table 2.

After completing the exposures for 20 blue foam specimens, the same procedure was repeated for the red and yellow foam specimens. The aging schedule for the red and yellow foams is shown in Table 3. Chamber temperature and observed specimen discolorations are listed in Table 4. The only anomoly noted during either aging cycle was an inadvertent heater operation during the Group V red and yellow foam exposure, allowing the chamber temperature to increase approximately 15 degrees above the nominal chamber temperature of 125°F for approximately 48 hours.

The same quantities of foams were exposed to accelerated aging in a Blue M Humid Flow humidity cabinet. Test conditions were maintained at 200°F and 95 percent relative humidity. The testing code for this accelerated aging was also provided by Monsanto. Aging of the red and yellow foam specimens was discontinued at the end of the third week. Both the red and yellow foams had undergone complete reversion at that time. Humidity agings are listed in Table 5.

UDR-TR-83-85

FIRE SAFETY OF FOAMS

Prepared For:

Monsanto Research Corporation

Prepared By:

J. N. Dues
L. D. Pike
D. McCullum

UNIVERSITY OF DAYTON
RESEARCH INSTITUTE
DAYTON, OHIO 45469

August 1983

The University of Dayton

August 9, 1983

Monsanto Research Corporation
Attn: Mr. Leo Parts
Dayton Laboratory
1515 Nicholas Road
Dayton, Ohio 45407

SUBJECT: Monsanto Purchase Order D25759

Dear Mr. Parts:

Enclosed are two copies of a report entitled "Fire Safety of Foams" documenting the aging cycles of blue, red, and yellow reticulated foam samples.

Sincerely,

Benjamin H. Wilt

Benjamin H. Wilt
Research Engineer

BHW/skl

Enclosures

RESEARCH INSTITUTE
300 College Park Dayton, Ohio 45469-0001

APPENDIX 5

REPORT ON ACCELERATED AGING OF FOAM SPECIMENS IN SIMULATED SUNLIGHT TEST CHAMBER, HUMIDITY CABINET, AND AIR OVEN

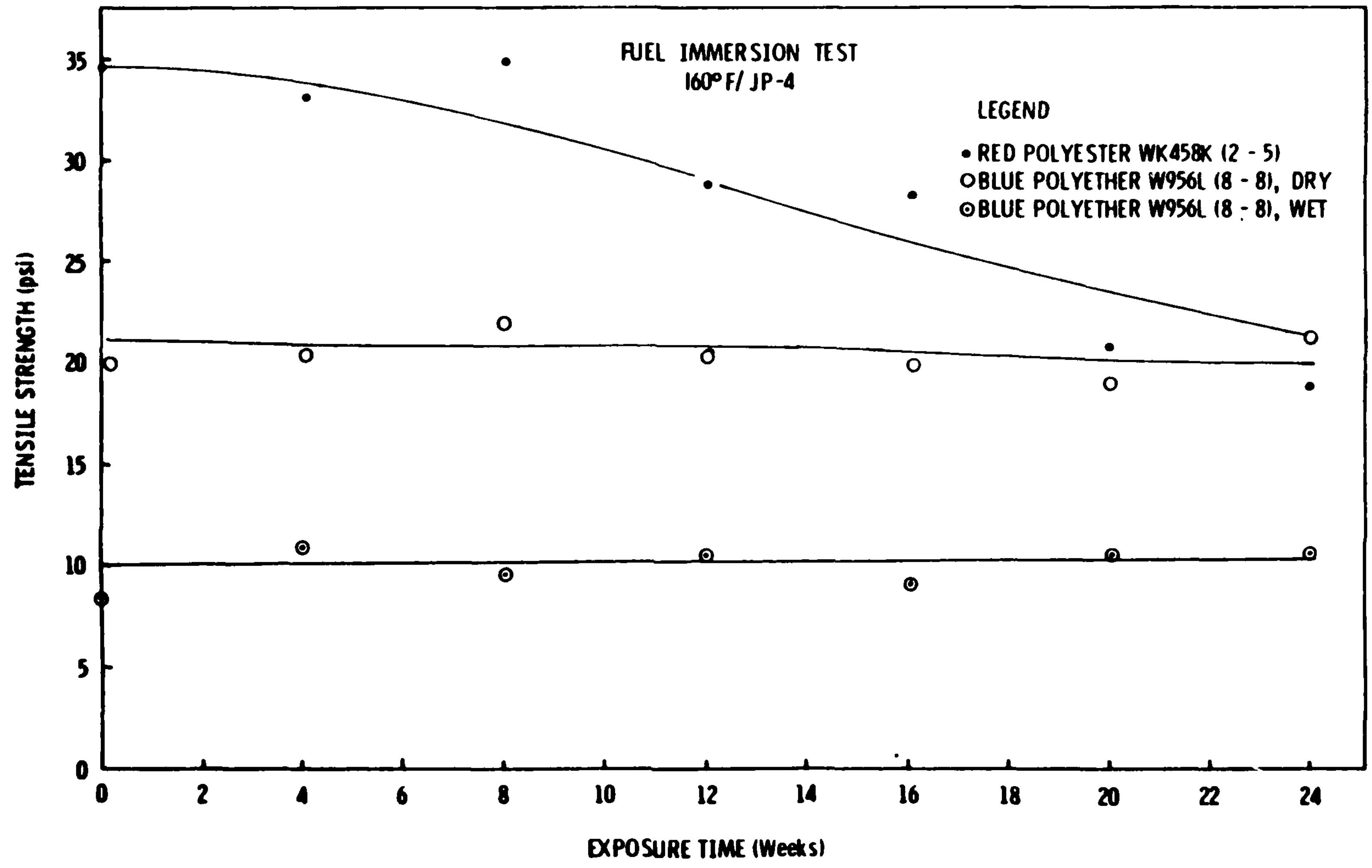


Figure A4-2. Tensile strengths of polyurethane foam in accelerated fuel immersion aging tests.

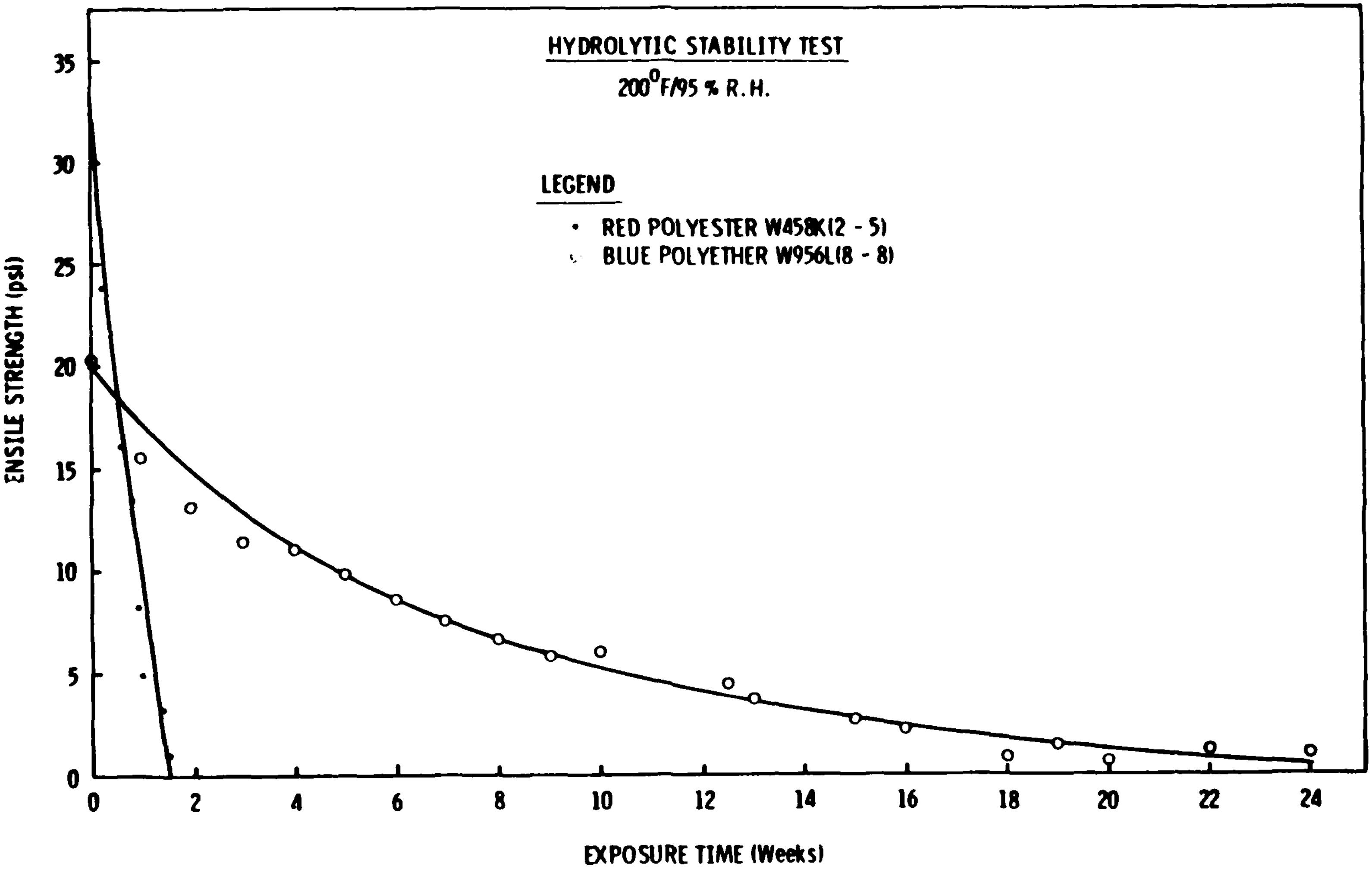


Figure A4-1. Tensile strengths of polyurethane foam in accelerated aging tests in air.

APPENDIX 4

TENSILE STRENGTHS OF POLYURETHANE FOAMS AS FUNCTIONS OF AGING

(Data from Reference 1, cited in the text of this report.)

These gases and the suspended inorganic particles (K_2SO_4 and PbO) are ingested into the fuel system through the overboard vent mast located on the bottom and near the tail section of the aircraft. The vent mast is designed to provide a 0.5 psig pressure on the fuel system. During gun firing, the aircraft is typically descending and air containing the gun gases flows into the fuel sytem to maintain the 0.5 psig pressure.

Figure A3-1. Red foam from A-10 aircraft (SN 75-00293) vent collector tank.

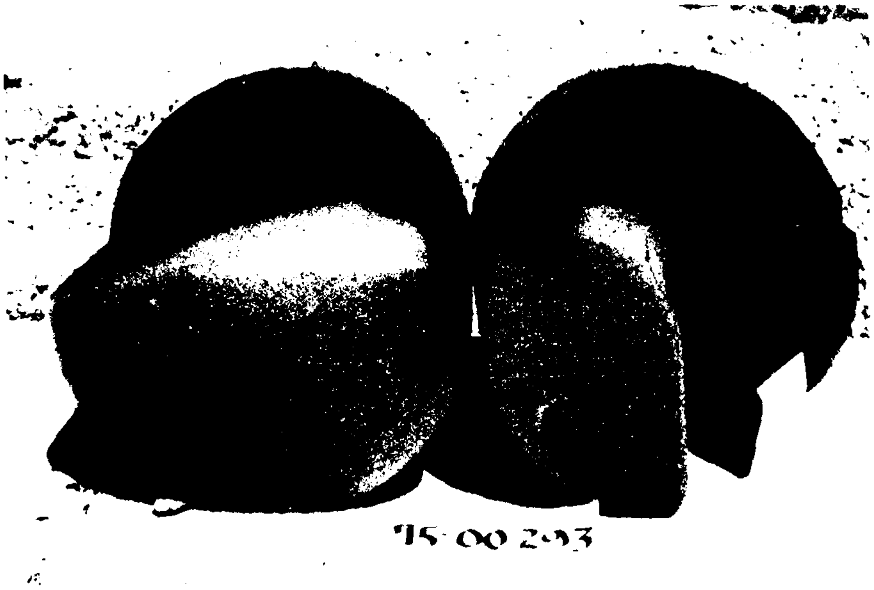


Figure A3-2. End view of red foam vent collector tank kit.

In 1981, an A-10 aircraft, SN-75-00293, that contained Type III red, polyester foam, was inspected for potential fire damage to the foam. Visual inspection of the foam in the vent collector tank revealed a very dark stain or burn pattern in the void area around the overboard vent tube (see Figures A3-1 and A3-2). A close visual examination revealed that the foam had not been burned or damaged, but that the discoloration was caused by a deposit on the surface. It was also noted that the overall color of the foam was a dark red or orange which is a characteristic of aged red foam. The age of the foam in this aircraft was approximately 4 years.

Infrared (IR) and emission spectroscopic analyses were performed by the AF Materials Laboratory on this vent collector tank red foam, to determine the position and source of the deposit. The IR analysis revealed no difference between the blackened portion, and the unaffected part of the foam sample. Also, a GPC analysis did not indicate the presence of any thermal degradation products in the blackened foam. An aqueous extract of the blackened foam gave a strong positive test for potassium and nitrate ions. This result provides a strong indication that the black stain was a result of gun gas deposition on the foam.

The A-10 aircraft is equipped with a CAS 30 mm cannon; each round contains approximately 2300 grains of propellant. A black powder primer, which is about 1% of the total propellant, is composed of about 75% KNO_3, 15% carbon and 10% sulfur. When the round is fired, the propellant is converted almost totally to gases in the following percentages (by volume): 45.9% CO, 8.8% CO_2, 17.4% H_2O, 17.0% H_2, 10.5% N_2, 0.08% K_2SO_4, and 0.075% PbO.

APPENDIX 3

ANALYSIS OF SOOT-STAINED RED FOAM IN A-10 AIRCRAFT

According to data in Table A2-2, 12.8% of mass was extracted with perchloroethylene from the F-4 foam; its color was changed to beige. Fresh foam lost 2.7% mass upon extraction and its color was changed to white. Acetone extracted 7.4% mass from the F-4 foam, changing its color to bluish-green; 4.2% mass was extracted from the new foam with acetone, without color change.

The perchloroethylene extraction test results indicate that the substances which caused discoloration were extracted along with the blue pigments used in the foam. In acetone tests, the discoloring substances were removed without affecting the blue dyes. The beige and bluish green colors, resulting from these tests, could be due to the aging of the foam while in the aircraft.

TABLE 2 (A5-2)

BLUE FOAM SPECIMEN DISCOLORATION AND CHAMBER TEMPERATURE DURING OPERATION OF SUNLIGHTER

Discoloration	Temp.	Date
All specimens in Groups I and II are about 1/8" discolored on top surface	124°F	6-8-83
All specimens in Groups I and II are about 1/4" discolored on top surface	126°F	6-9-83
All Group II specimens have 1/4" discoloration. All Group III specimens have 1/8" discoloration	126°F	6-10-83
Both Groups II and III - all specimens discolored to about 1/4"	123°F	6-13-83
Both Groups II and III - all specimens discolored to about 1/4"	124°F	6-14-83
Specimens in Group III are about 1/2" discolored Specimens in Group IV are about 1/8" discolored	125°F	6-15-83
Group III about 1/2" discolored Group IV about 1/4" discolored	125°F	6-16-83
Group III about 1/2" discolored Group IV about 1/4" discolored	125°F	6-17-83
Group III about 1/2" discolored Group IV about 1/4" discolored	122°F	6-20-83
Group IV about 1/4" discolored Group V about 1/8" discolored	123°F	6-22-83

TABLE 2 (CONCLUDED) (A5-2)

BLUE FOAM SPECIMEN DISCOLORATION AND CHAMBER TEMPERATURE DURING OPERATION OF SUNLIGHTER

Discoloration	Temp.	Date
Group IV about 1/2" discolored Group V about 1/8" discolored	123°F	6-22-83
Group IV about 1/2" discolored Group V about 1/4" discolored	123°F	6-23-83
Group IV (out) specimens were about 1/2" discolored Group V about 1/8" discolored	125°F	6-24-83
Group V specimens are about 3/8" discolored	124°F	6-27-83
Group V specimens are about 3/8" discolored	125°F	6-28-83
Group V specimens about 1/2" discolored	126°F	6-29-83

TABLE 3 (A5-3)

EXPOSURE SCHEDULE FOR RED AND YELLOW FOAMS

Group No.	Total Exposure (Hours) Time	Date In the Sunlighter	Date Out of Sunlighter
1	40	7-5-83 9:00 a.m.	7-7-83 5:00 p.m.
2	80	7-5-83 9:00 a.m.	7-12-83 5:00 p.m.
3	120	7-7-83 5:00 p.m.	7-18-83 5:00 p.m.
4	160	7-12-83 5:00 p.m.	7-22-83 5:00 p.m.
5	200	7-18-83 5:00 p.m.	7-27-83 5:00 p.m.

Group 1 → Red 7-6-1 Yellow 7-11-1
7-6-2 7-11-2

Group II → Red 7-7-1 Yellow 7-12-1
7-7-2 7-12-2

Group III → Red 7-8-1 Yellow 7-13-1
7-8-2 7-13-2

Group IV → Red 7-9-1 Yellow 7-14-1
7-9-2 7-14-2

Group V → Red 7-10-1 Yellow 7-15-1
7-10-2 7-15-2

TABLE 4 (A5-4)

RED AND YELLOW FOAM SPECIMEN DISCOLORATION AND CHAMBER TEMPERATURE DURING OPERATION OF SUNLIGHTER

Discoloration	Temp.	Date
About 1/16" discoloration on all specimens in Groups I and II	124°F	7-6-83
About 1/8" discoloration on all specimens in Groups I and II	124°F	7-7-83
About 1/8" discoloration on all specimens in Groups II About 1/6" discoloration on specimens in Group III	125°F	7-8-83
All specimens in Group III about 1/16" discoloration All specimens in Group II about 1/8" discoloration	125°F	7-11-83
All specimens in Group III about 1/8" discoloration All specimens in Group II about 1/4" discoloration	124°F	7-12-83
All specimens in Group III about 1/8" discoloration All specimens in Group IV about 1/16" discoloration	123°F	7-13-83
All specimens in Group III about 3/16" discoloration All specimens in Group IV about 1/8" discoloration	124°F	7-14-83
All specimens in Group III about 1/4" discoloration All specimens in Group IV about 1/8" discoloration	123°F	7-15-83

TABLE 4 (CONCLUDED) (A5-4)

RED AND YELLOW FOAM SPECIMEN DISCOLORATION AND CHAMBER TEMPERATURE DURING OPERATION OF SUNLIGHTER

Discoloration	Temp.	Date
All specimens in Group III about 5/16" discoloration All specimens in Group IV about 3/16" discoloration	125°F	7-18-83
All specimens in Group IV about 3/16" discoloration All specimens in Group V about 1/16" discoloration	123°F	7-19-83
All specimens in Group IV about 3/16" discoloration All specimens in Group V about 1/8" discoloration	125°F	7-20-83
All specimens in Group IV about 1/4" discoloration All specimens in Group V about 1/8" discoloration	124°F	7-21-83
All specimens in Group IV about 1/4" discoloration (out of QU) All specimens in Group V about 3/16" discoloration	124°F	7-22-83
All specimens in Group V about 1/4" discoloration*	126°F**	7-25-83
All specimens in Group V about 3/8" discoloration	126°F	7-26-83
All specimens in Group V about 3/8" discoloration	126°F	7-27-83

*Heated inadvertantly, turned on from 7-22-83 to 7-25-83; chamber temperature was about 140°F.

**Temperature was taken at 5:00 p.m.

TABLE 5 (A5-5)

EXPOSURE SCHEDULE FOR BLUE, RED, AND YELLOW FOAMS. ACCELERATED AGING AT 200°F, 95% RH

Foam	Exposure time, weeks				
	1	2	3	4	5
Blue	8-1-1	8-2-1	8-3-1	8-4-1	8-5-1
	-2	-2	-2	-2	-2
	-3	-3	-3	-3	-3
	-4	-4	-4	-4	-4
Red	8-6-1	8-7-1	8-8-1	8-9-1	8-10-1
	-2	-2	-2	-2	-2
Yellow	8-11-1	8-12-1	8-13-1	8-14-1	8-15-1
	-2	-2	-2	-2	-2

TABLE 6 (A5-6)

EXPOSURE SCHEDULE FOR BLUE, RED, AND YELLOW FOAMS. ACCELERATED AGING AT 200°F IN JP-5

Foam	Exposure time, weeks				
	1	2	3	4	5
Blue	9-1-1 -2 -3 -4	9-2-1 -2 -3 -4	9-3-1 -2 -3 -4	9-4-1 -2 -3 -4	9-5-1 -2 -3 -4
Red	9-6-1 -2	9-7-1 -2	9-8-1 -2	9-9-1 -2	9-10-1 -2
Yellow	9-11-1 -2	9-12-1 -2	9-13-1 -2	9-14-1 -2	9-15-1 -2

APPENDIX 6

EMISSION SPECTROGRAPHIC ANALYSIS REPORT ON POLYURETHANE FOAM FROM AN A-10 AIRCRAFT

BOWSER-MORNER Testing Laboratories, Inc.
CORPORATE ADDRESS • 420 Davis Ave • P O Box 51 • Dayton, Ohio 45401-0051 • 513/253-8805
TOLEDO DISTRICT • 122 S St Clair St • P O Box 838 • Toledo, Ohio 43696-0838 • 419/255-8200
KENTUCKY DISTRICT • Route 8 West • P O Box 636 • Maysville, Kentucky 41056-0636 • 606/564-6711

LABORATORY REPORT

Report to
Monsanto Research Corporation
P. O. Box 8 Station B
Dayton, Ohio 45407
Attn: Mr. Leo Parts

Date February 14, 1983
Laboratory No N 020320
Authorization D-24325

Report on Spectrographic Comparative Analysis of Foam Samples for Metallic Contamination:

TEST PROCEDURE:

The submitted foam sample was suspected to be contaminated with unknown oxides or residues. The contaminated foam was separated from the non-contaminated portion. The contaminated foam and the non-contaminated foam were ashed and the residues from the ash were analyzed by spectrographic procedures. We utilized the DC arc for a total energy transformation and photographed the spectra that was produced.

Note:

X indicates that the element is present in the non-contaminated portion of the foam. The numerical comparative data is graduated from IX (the least intense) to 100X (the greatest intensity).

- continued -

Monsanto Research Corporation
Page 2
Lab. No.: N 020320

TEST RESULTS:

Element	Non-Contaminated	Contaminated	Portion
Potassium			Major*
Aluminum	X	25 to 100X	Major
Iron	X	15 to 30X	Major
Silicon	X	15 to 30X	Major
Lead	X	20 to 50X	Major
Manganese	X	15 to 30X	Minor
Magnesium	X	15 to 30X	Minor
Tin	X	2X	Trace
Copper	X	5X	Trace
Titanium	X	10X	Minor
Nickel	<X	5X	Trace
Calcium	<X	15 to 30X	Minor
Boron	<X	4X	Trace
Sodium	X	20 to 50X	Major

Major: estimate >10%
Minor: estimate 1 to 10%
Trace: estimate <1.0%

*Methodology used was not appropriate for proper numerical comparison.

Respectfully Submitted,

BOWSER-MORNER, Inc.
Samuel Lucas Jr.
Samuel Lucas, Jr.
Chief Chemist
Special Metals Chemistry

1-Client
2-File
SL/pc

APPENDIX 7

SURFACE ANALYSIS REPORT ON POLYURETHANE FOAM FROM AN A-10 AIRCRAFT

The University of Dayton

February 15, 1983

Mr. Leo Parts
Monsanto Research Corp.
Dayton Laboratory
Dayton, Ohio 45407

Dear Mr. Parts:

The filter material was initially analyzed using scanning electron microscopy (SEM) in conjunction with energy dispersive x-ray analysis (EDXA). The back of the filter, which was not discolored, was used as a control.

SEM photographs (see Figures 1 and 2) show the typical morphology of the deposit. At higher magnification in Figure 3 it can be seen that the deposit is an agglomerate of particles approximately 2 μm in diameter. EDXA of this area (see Figure 4) showed it to be high in K with a small amount of Pb and Fe. EDXA is only sensitive to those elements whose atomic weight is greater than Na. This means that the lighter elements such as C, O, and N which certainly are present, will not show any characteristic peaks.

Figure 5 shows the control sample which has no deposit on it. The EDXA spectra (see Figure 6) showed primarily background which is indicative of primarily light elements. A trace of K is present in the control which is probably the result of some of the contaminant which penetrated the filter.

Figure 7 shows a low magnification view using a light microscope. This photograph shows that the white deposit is not a continuous film, but does cover most of the filter surface. In order to obtain chemical information about the K in the deposit, including the light elements, x-ray photoelectron spectroscopy was used. Figure 8 shows the low resolution scan of the bulk. The high resolution scan as seen in Figure 8, shows the presence of a carbonate peak.

Since the deposit is primarily K, it is very likely to be a

RESEARCH INSTITUTE
300 College Park Dayton, Ohio 45469-0001

compound like potassium carbonate. The remaining elements Al, Si, Pb and Fe constitute less than 3% of the deposit and are probably not significant in your search for a contaminate source.

I still have the sample. Let me know if you need additional data.

Sincerely,

J. Douglas Wolf

JDW/lsh

Enclosures

Figure A7-1. Deposit on filter (10X).

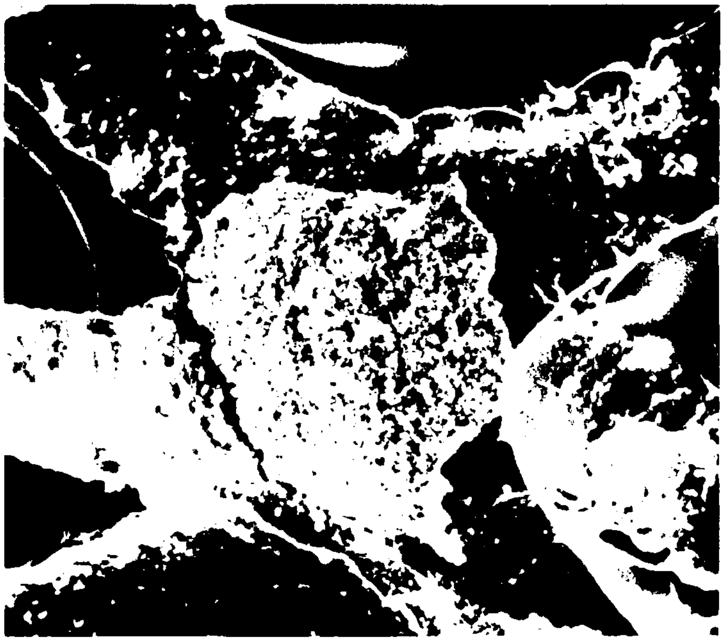


Figure A7-2. Deposit on filter (100X).

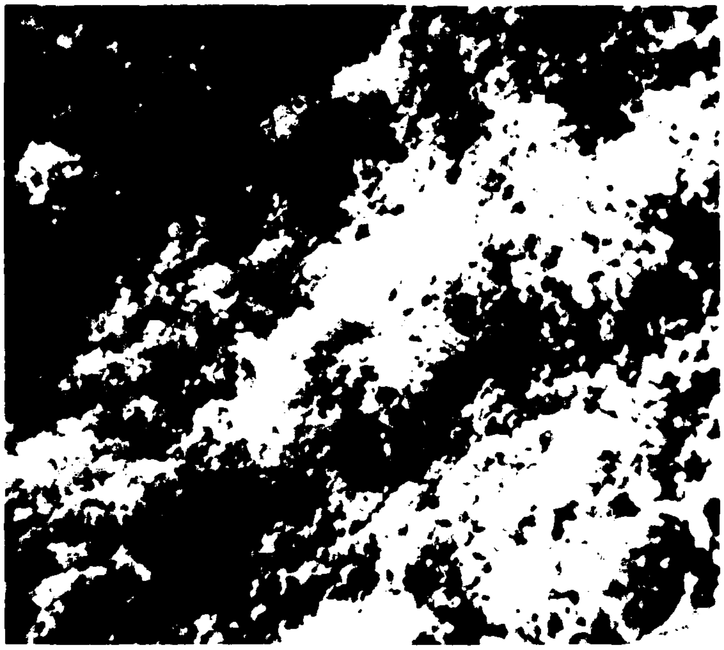


Figure A7-3. Deposit on filter (1000X).

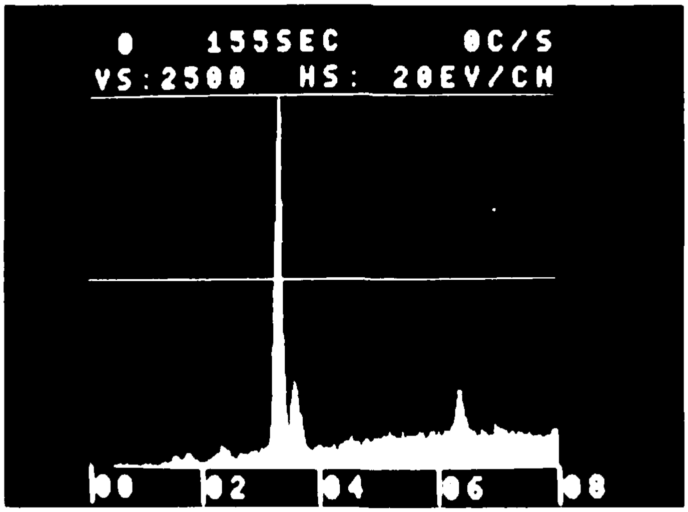


Figure A7-4. EDXA spectra of deposit on filter.

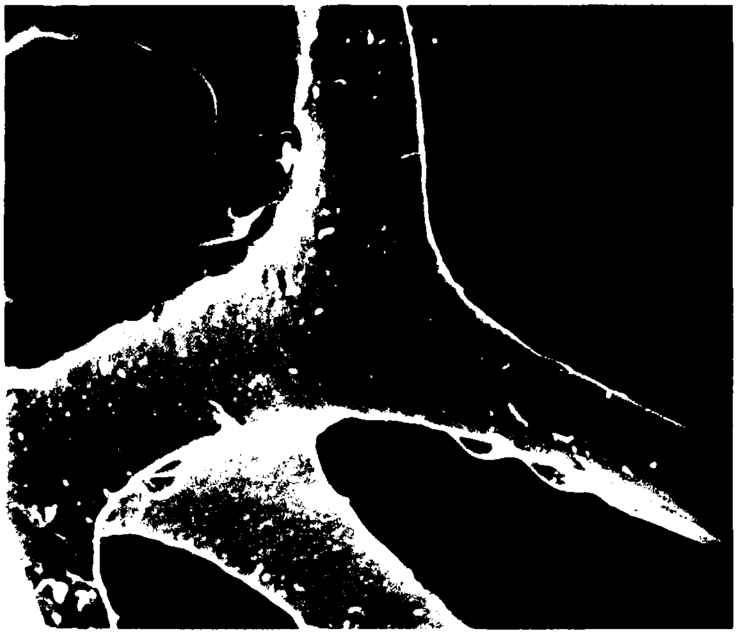


Figure A7-5. Control sample (100X).

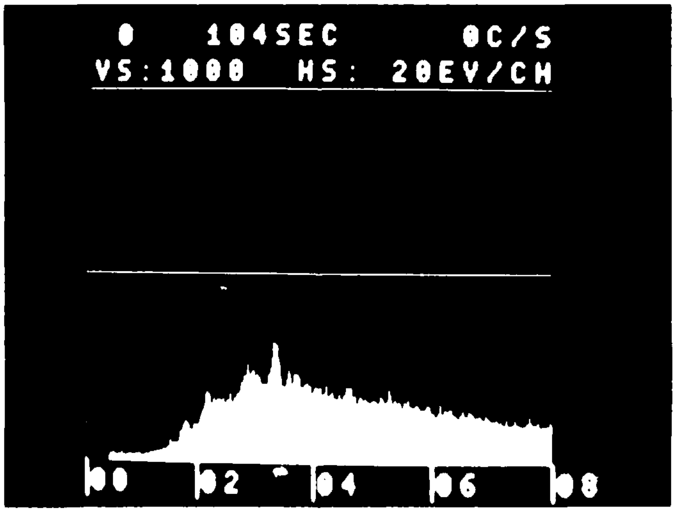


Figure A7-6. EDXA of control.

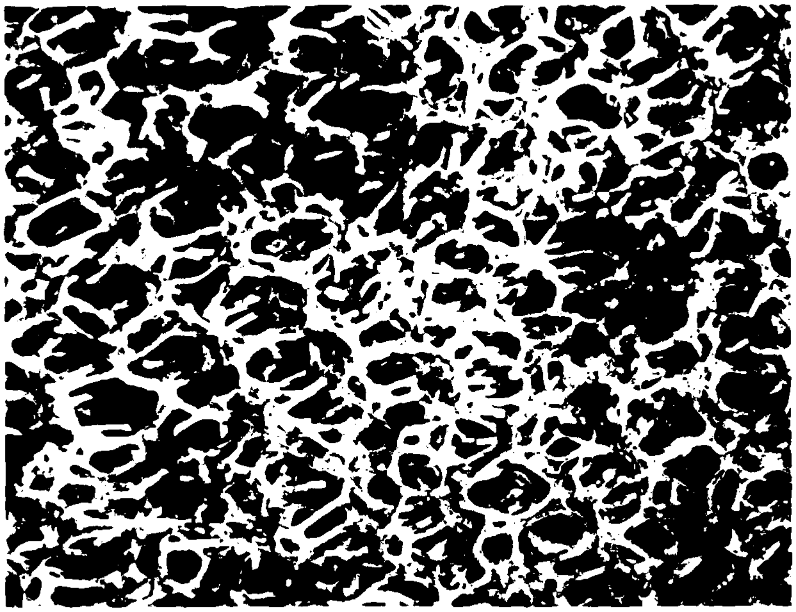


Figure A7-7. Light microscope photograph of deposit (white areas) 50X.

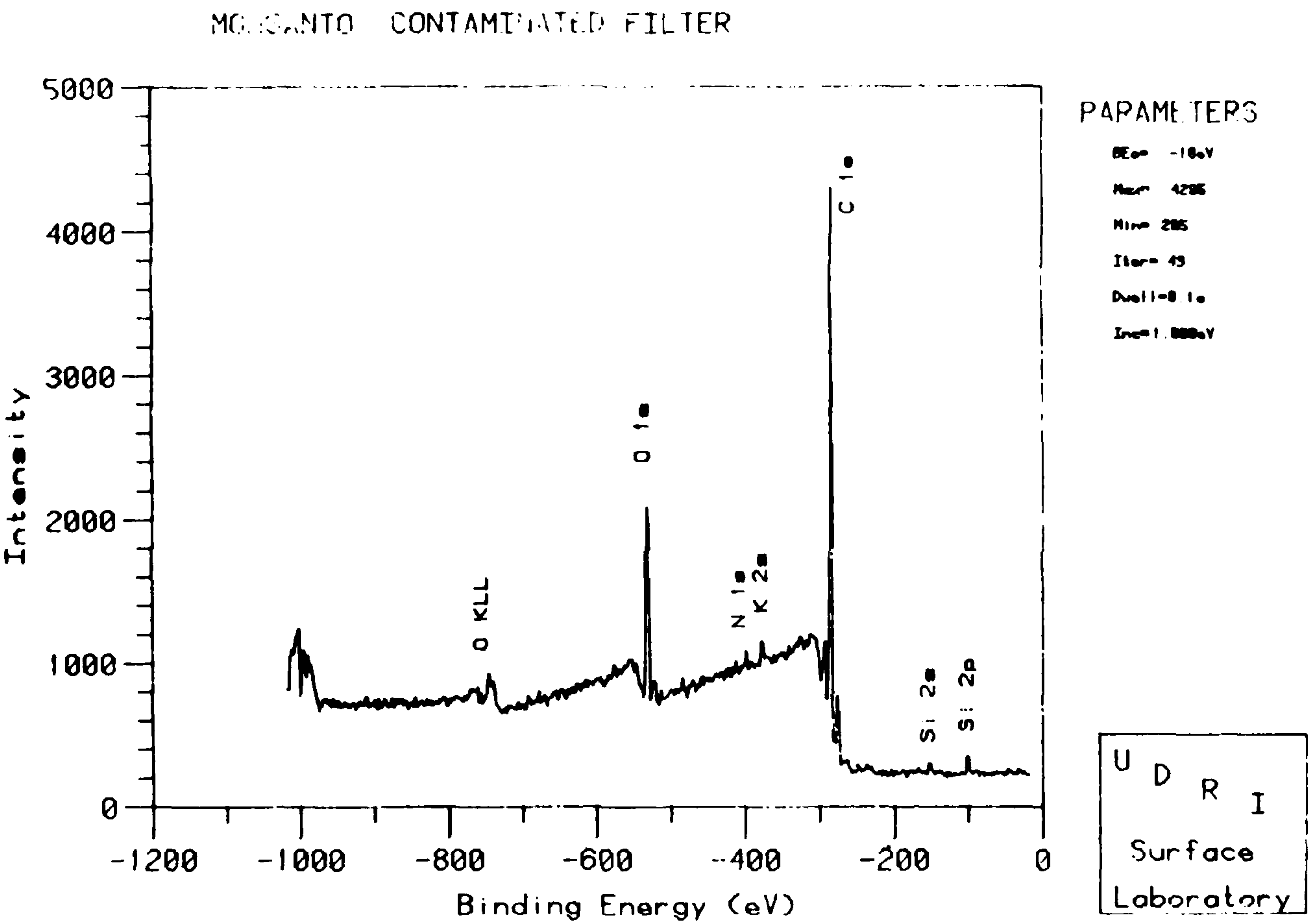


Figure A7-8. Low resolution XPS scan.

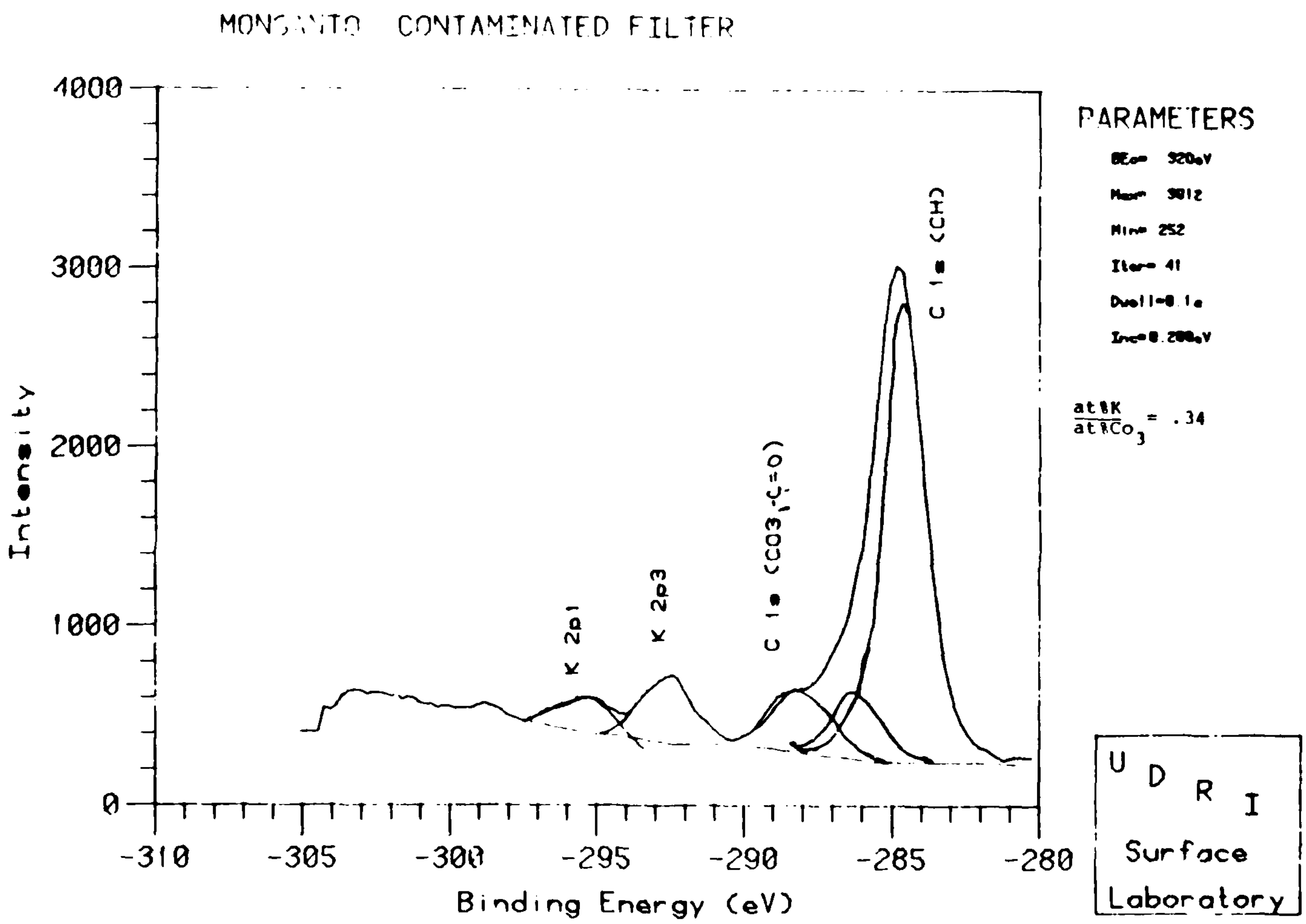


Figure A7-3. High resolution XPS scan.

U S GOVERNMENT PRINTING OFFICE 1984 — 560-028