AD A035961

USAAMRDL-TR-76-40A

(12)

EROSION PROTECTION FOR THE AH-1G LOW RADAR CROSS-SECTION MAIN ROTOR BLADE
VOLUME I - SAND AND RAIN EROSION EVALUATION

Hughes Helicopters
Division of Summa Corporation
Culver City, Calif. 90230

January 1977

Final Report for Period November 1975 to November 1976

Approved for public release;
distribution unlimited.

Prepared for

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
Fort Eustis, Va. 23604

EUSTIS DIRECTORATE POSITION STATEMENT

This report presents the selection, the erosion test results, and the radar measurements of elastomeric materials for use as a leading-edge erosion protection strip for composite AH-1G multitubular spar(MTS) main rotor blades. The work performed in this program has identified a suitable material that will give adequate sand and rain erosion protection for the AH-1G MTS blade and be compatible with the blade's radar cross-section reduction treatment. The material that exhibited the best erosion resistance and radar reduction enhancement has been selected for use on the AH-1G main rotor blade during the blade's flight test program.

Mr. John Shostak of the Military Operations Technology Division served as project engineer for this effort.

A

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

18

1. REPORT NUMBER: 19 USAARMDL-TR-76-40A

2. GOVT ACCESSION NO.: 9

3. RECIPIENT'S CATALOG NUMBER: rept.

4. TITLE (and Subtitle): 6 EROSION PROTECTION FOR THE AH-1G LOW RADAR CROSS-SECTION MAIN ROTOR BLADE, Volume I. Sand and Rain Erosion Evaluation.

5. TYPE OF REPORT & PERIOD COVERED: Final, November 1975-November 1976

6. PERFORMING ORG. REPORT NUMBER: HH76-191

7. AUTHOR(s): 10 Robert E. Head

8. CONTRACT OR GRANT NUMBER(s): 15 DAAJ02-76-C-0008

9. PERFORMING ORGANIZATION NAME AND ADDRESS: Hughes Helicopters, Division of Summa Corporation, Culver City, California 90230

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 16 62209A 1F262209AH76 00 131 EK

11. CONTROLLING OFFICE NAME AND ADDRESS: 11 Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia 23604

12. REPORT DATE: January 1977 17

13. NUMBER OF PAGES: 60 00

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 14 HH-76-191-Vol-1

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

12 61 p.

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)

Helicopter	Erosion Protection	Erosion Test
Rotor	Radar Cross Section	
Blade	Composite Structure	

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

The purpose of this program was to design, fabricate, and test components for the composite nonmetal Multi-Tubular Spar (MTS) main rotor blade for the AH-1G helicopter that would give good erosion protection in sand and rain environments, and have a low radar cross section. The report on this program is divided into two volumes: the first deals with erosion protection, and the second covers radar cross section.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

409164 1B

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

In this volume, Volume I, a screening process narrowed fifteen candidate erosion materials to two. These were subjected to MIL-SPEC sand and rain environments, which encompassed specified sand-particle and rain-droplet-size populations. Test conditions simulated an AH-1G rotor flying at 125 knots in a 1.89 inch-per-hour rain (959 fps tip speed) and the rotor hovering in ground effect (750 fps tip speed) in the sand cloud it blows up. The tests demonstrated that a 0.025-inch-thick polyurethane material gave the best protection and was easiest to apply and remove for replacement.

LWP

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

PREFACE

The two volumes of this report describe the work that Hughes Helicopters performed under Contract DAAJ02-76-C-0008 for the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory (USAAMRDL) to integrate erosion protection and low radar cross section into the AH-1G Multi-Tubular Spar main rotor blade being developed by Hughes Helicopters for the Eustis Directorate under Contract DAAJ02-74-C-0055.

This volume describes the erosion test work, which was done on a Hughes Helicopters whirlstand. The second volume describes the analytical RCS work, which was performed under subcontract by Emerson & Cuming, Inc., Canton, Massachusetts.

The USAAMRDL program monitor was Mr. John Shostak.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS – Continued

LIST OF TABLES

INTRODUCTION

The work reported here is supplementary to a baseline program to develop and flight test a Multi-Tubular Spar (MTS) composite main rotor blade for the AH-1G helicopter. The MTS blade is a composite of nonmetals except for tip weights and attachment bolt bushings, which are metal. It has good survivability against the 23mm HEI-T threat, and has a radar cross section smaller than the equivalent metal blade. To retain this low RCS, it can not use a metallic erosion protection strip along its leading edge as most rotor blades do. The purpose of the program reported here was to evaluate nonmetallic erosion protection materials, to analyze configurations for low RCS, and to test the RCS for the best configuration.

It has been known for some time that a metallic erosion strip (stainless steel, nickel, etc.) gives good protection in rain but quickly wears away in a sandy environment, while an elastomeric material behaves the opposite. Therefore, the purpose of this program was to discover a nonmetallic erosion material, compatible with low RCS, that could protect the blade from both rainy and sandy environments.

A number of candidate erosion materials were screened for suitability, and the two most promising were subjected to extensive sand and rain erosion tests. The sand erosion tests used sand defined in MIL-E-5007D, blown up in a cloud by the downwash of the test rotor while it was operating as an AH-1G rotor hovering in ground effect at a tip speed of 750 feet per second. The rain erosion tests used a rain drop population as described in MIL-STD-210, a 1.89-inch-per-hour rainfall rate, and a rotor tip speed of 959 feet per second. These tests showed that a polyurethane material is the most satisfactory for erosion protection.

DISCUSSION

EROSION TEST STAND

The erosion test stand, Figure 1, consists of a two-bladed rotor driven at a fixed (but adjustable) pitch by a hydraulic motor, an overhead rain spray rig, and boxes underneath for dispensing sand. The rotor consists of two shortened OH-6A main rotor blades with erosion material bonded to their leading edges near their tips.

The rain spray rig is a grid of plastic pipes with small orifices drilled through their bottom sides on 12-inch centers. The hole diameter determines the droplet size, while the hydraulic head applied to the array determines the rate of simulated rainfall. To spread the droplets uniformly at the plane of the rotor, the entire spray rig oscillates ±3 inches at a speed of approximately three times per minute. The rotor was operated at zero collective pitch (measured at 3/4-radius) for the rain erosion tests.

The sand was placed in two open-topped, 24 x 72 x 3.5-inch boxes located on the ground beneath the rotor. The centers of the boxes were directly beneath the 3/4-radius circle of the rotor, with their long axes tangent to the circle. Each box contained approximately 600 pounds of sand when full. In operation, the rotor collective pitch was set at 7 degrees to create downwash similar to that of the hovering AH-1G. This downwash blew the sand up in a cloud at a rate of approximately 125 pounds per minute. The sand boxes were refilled when no more than 40 percent had been used.

EROSION MATERIAL SELECTION AND SCREENING TESTS

Because the leading-edge erosion-protection material formed an integral part of the low-RCS composite rotor blade, the erosion material could not be metallic. Hence, a search was made for a nonmetallic material that would serve. It was to have a thickness between 0.025 and 0.040 inches and minimum dielectric constant. The tests that had been conducted previously clearly indicated that while elastomeric materials were good for protecting against a sandy environment they generally held up poorly in rain. So, the preliminary search was concentrated on finding elastomers that would perform well in rain.

A literature search and conversations with suppliers led to the selection of the materials listed in Table 1 as candidates for further screening. These materials were put through a rainfall screening test in the erosion test facility using a one-inch-per hour rain at a rotor tip speed of 850 feet per second.

Table 1 also indicates the length of time these materials survived. The first tests were plagued with poor bonding between the elastomer and blade. They were rebonded, and the tests rerun with the "A" designation. The two specimens selected were: (1) ultra-high molecular weight polyethylene (UHMWPE) and (5A) adhesive-backed polyurethane. These materials were in the 0.025-to-0.040-inch-thick range, which the tests reported in Figure 2[1] indicate is the best thickness range for long erosion life. Figures 3 and 4 show these selected specimens at the end of their test runs.

The survival time was determined by the first appearance of a hole through the erosion material. Figure 5 shows what happened to unprotected Kevlar, the basic material from which the MTS Blade was made. So, for complete protection, the life of the erosion material cannot be considered longer than that at which a hole first appears.

EROSION TEST STAND CALIBRATION

After the initial screening tests, the test stand was recalibrated to the requirements of MIL-STD-210. A special calibration stand allowed the droplets to fall 10 feet from a test orifice (the distance from the spray bar to the rotor plane in the test stand) to a point where they were photographed with a stroboscopic camera. The droplet population was measured from the photographs, and the calibration chart was established (Figure 6). A 0.024-inch-diameter orifice size and a 46-inch head height were chosen.

The sand was calibrated by passing random samples of Number 30 and Number 50 sand through a series of progressively finer screens. Figure 7 shows the grain size population. The desired mixture was determined to be a 4-to-1 ratio of Number 50 and Number 30 sand, Number 50 being the larger proportion.

EROSION TESTS

Ten test blades were prepared for each of the two candidate erosion materials. Four of each type were tested in sand until destruction, four of each type were tested in rain until destruction. The last two of each type were exposed to rain and to sand, each for half its expected life; one was exposed to rain first, the other to sand first.

1. Graham, T.L., "High Temperature Stable Subsonic Rain Erosion Resistant Fluoro-Elastomer Boot Material Development," USAFML Technical Report 74-9. U.S. Air Force Material Laboratory, Dayton, Ohio. May 1974.

The rain environment was 1.89 inches per hour of simulated rainfall with a rotor tip speed of 959 feet per second. The sand environment was 125 pounds of sand per minute blown up by a rotor downwash which simulated that of the AH-1G helicopter that is hovering with a rotor tip speed of 750 feet per second.

Figure 1 shows the sand and rain tests being conducted. Figures 8 through 17 are photographs showing the erosion characteristics. Table 2 shows the results of the tests, including the overall times to destruction.

The dimensional wear of the erosion material was measured at four spanwise stations with the micrometer tool shown in Figure 18. The blade stations for taking these measurements were:

- BS 54 (tip)
- BS 51
- BS 47
- BS 43

These stations can be seen clearly in the lower left photograph of Figure 9. One measurement was made at the leading edge, and two more were made at 45 degrees above and below the leading edge. Time histories of the dimensional wear of the erosion materials are plotted in Figures 19 through 39. It had been planned to also present a time history of the weight of the erosion material worn away, but this became impractical when it was discovered that in many cases the blade itself, beyond the ends of the erosion material, was being worn away faster than the anti-erosion material.

The wear characteristics were different for the two kinds of material. The polyurethane just slowly eroded away in either sand or rain. The UHMWPE behaved the same in rain, but in the sand environment it took on a peened appearance where the material formed into minute wavelets that eventually wore through. In some cases, the UHMWPE behaved as if it were being moved away from the leading edge and built up at the 45-degree points (see Figure 24, for example).

The polyurethane material surpassed the ultra-high molecular weight polyethylene by far in all aspects:

- Rain erosion life
- Sand erosion life

- Wear patterns
- Ease of installation and removal

A curious fact emerged from the rain-before-sand tests. These specimens were exposed to the rain environment for 50 percent of the life they had demonstrated in the single environment tests, and then they were exposed to the sand until they wore out. Both materials exhibited the characteristic that, when the rain test preceded the sand test, the erosion material lasted twice as long in the sand as would have been expected. This phenomenon did not occur when the specimens were exposed in the reverse order. The constraints of the contract did not permit evaluating this characteristic further, and no good reason for the phenomenon has been discovered.

ESTIMATED EROSION MATERIAL SERVICE LIFE

The mean time between unscheduled maintenance (MTBUM) was estimated for the two candidate erosion materials based on the data measured in the whirlstand erosion tests and on a correlation with OH-6A helicopter field experience. The average test times before the UHMWPE specimens were found to be unacceptable were 36.2 minutes in the sand environment and 13.2 minutes in rain environment. Under the same test environments and blade tip speeds, the average times for the polyurethane antierosion strip were 121.2 minutes in the sand environment, and 15.2 minutes in the rain environment.

The MTBUM and erosion test data for the hard anodized aluminum OH-6A blade was used for the correlation. Data from field experience with the OH-6A rotor operating in the erosion mode revealed a 750-hour MTBUM. Whirlstand erosion tests on this blade showed 54 minutes before rejection in the sand environment at a tip speed of 665 fps, and 216 minutes before rejection in 1.0 inches per hour rain environment at a tip speed of 850 fps. This data was converted to the conditions of the present test (750 fps tip speed in the sand and 959 fps tip speed in the 1.89 inch-per-hour rain) by making the following assumptions:

- The Unscheduled Maintenance Action Rate (reciprocal of MTBUM) varies directly and linearly with rain intensity.
- The Unscheduled Maintenance Action Rate varies directly with the square of the blade tip speed.

With these assumptions, the OH-6A erosion test data was adjusted to 42.5 minutes in the sand environment and 89.3 minutes in the rain. The reference OH-6A test results and the results from the present tests are summarized in Table 3.

The equation below was developed to estimate erosion material MTBUM for different percentages of time in sand or rain environments, based on the experience with the OH-6A rotor that showed a MTBUM of 750 hours for erosion-related blade removal:

$$\text{MTBUM} = \frac{LUV}{XY}\left[\frac{P(Y-X)+X}{P(V-U)+U}\right]$$

Here, L is the OH-6A MTBUM. X and Y are OH-6A blade test times before failure in sand and rain environments, respectively. U and V are the elastomeric material test times before failure in sand and rain environments, respectively. The rotor flies a certain percentage of the time in clear air with no erosion taking place, and the remainder is spent in a rain environment, a sand environment, or both: P is the fractional portion of this "remainder" time spent flying in the sand environment. Substituting the values for UHMWPE, the equation becomes:

$$\text{MTBUM} = 94.42\left[\frac{42.50 + 46.76\,P}{36.18 - 22.98\,P}\right]$$

and for polyurethane becomes:

$$\text{MTBUM} = 365.4\left[\frac{42.50 + 46.76\,P}{121.19 - 105.94\,P}\right]$$

These equations are plotted as functions of P in Figure 40.

The MTBUM assumes a flight environment of flight in clear air for an unspecified period of time plus flight in an erosive atmosphere of 80 percent sand and 20 percent rain of the remainder of the time. According to Figure 40, an AH-1G rotor flown in this environment would have MTBUM's of 421 hours with UHMWPE and 850 hours with polyurethane. These percentages are estimates based on frequent operations over unpaved terrain, including takeoffs, hover, downwash, low-altitude flying, and landings.

Whereas an all-metal blade such as that of the OH-6A would be scrapped at the end of its MTBUM erosion period, the use of the elastomeric erosion strip would allow the basic blade to be used indefinitely by stripping off the worn-out material and replacing it with new.

EROSION MATERIAL ATTACHMENT AND REMOVAL

The Dunlop polyurethane erosion material was easy to apply and remove. It comes from the manufacturer with an adhesive bonded onto it. The leading edge of the blade was sanded and then wiped with a clean cloth soaked in methylethylketone (MEK). The protective backing strip was removed from a six-foot-long strip of the polyurethane. The adhesive backing was activated by moistening with MEK. The strip was laid along the leading edge and worked down against the blade surface using gloved hands. Care was taken to work out all air bubbles, and final contact was assured by using a "rubber stitcher" (essentially a narrow-faced, fine-toothed gear wheel on a handle) to roll the strip down. Additional six-foot strips were laid end to end to cover the full length of the leading edge. The six-foot length was determined to be the longest length that could be handled practically and completely rolled down before the adhesive set up. Small polyurethane doublers were bonded on to cover the butt joints between the long polyurethane strips. In comparison, the UHMWPE required flame treating, a special adhesive, and vacuum bagging to bond it in place, and on several occasions during the model tests, the bond softened and allowed the plastic strip to creep toward the tip of the blade.

The removal of the erosion strip was very easy. A corner was pried up with a knife blade, and then, a brush dipped in MEK was used to wet the exposed adhesive. As the corner of the polyurethane was slowly pulled away from the blade, more MEK was brushed on to soften the adhesive. On the other hand, removal of the UHMWPE required that the strip be pulled off without the aid of a solvent, and the resulting rough surface had to be sanded smooth.

The ease of using the polyurethane material makes it very attractive for field service. By replacing worn strips before the underlying blade is exposed to an erosive environment, the service life of the blade can be greatly extended.

CONCLUSION AND RECOMMENDATION

This investigation has led to the selection of a polyurethane material that protects the composite MTS main rotor blade from sand and rain erosion while not interfering with the RCS properties of the blade. Further research is recommended to develop polyurethane's full potential as an anti-erosion material.

TABLE 1. SCREENING TEST SUMMARY[(a)]

Screening Test Series	Specimen Number	Description of Material	Dielectric Strength 10^6 volt/meter	Total Test Time - Minutes[(c)]
Preliminary	1 [(b)]	Ultra High Molecular Weight Polyethylene (UHMWPE), 0.040" thick. American Hoechst flame treated and formed. Bonded to leading edge with Uralane 5747 polyurethane adhesive and 181 fiberglass scrim cloth.	18.9	64.5
	2	Thermoset Polyurethane Boot by BJB Enterprise, Huntington Beach, 0.030" + 0.005". Bonded with Uralane 5747 polyurethane adhesive and 181 fiberglass scrim cloth.	20.8	13.0
	3	Goodyear Aerospace Co., Polyurethane Erosion Strips	20.8	
		(A) DZ90D41, 0.040" thick		2.0
		(B) 82C06, 0.030" thick		10.0
	4	Not tested	-	-
	5	Viton B Rubber Sheets 0.030" ± 0.10", bonded to 181 fiberglass, which is in turn bonded to the leading edge with Uralane 5747 adhesive.	19.7	12.5
	6	FEP Film 0.005" thick, backed by Viton, bonded to 181 fiberglass, which is in turn bonded to the leading edge with Uralane 5747 adhesive.	19.7	41.5
Final	1A	Ultra High Molecular Weight Polyethylene (UHMWPE), 0.040" thick, American Hoechst, flame treated and formed. Bonded to leading edge with Uralane 5747 polyurethane adhesive under vacuum.	18.9	45.6
	2A	Thermoset Polyurethane Sheet, by BJB Enterprise, Huntington Beach, 0.030" ± 0.005" thick. Bonded with Uralane 4747 polyurethane adhesive.	20.8	15.0
	3A	Thermoset Polyurethane Coating, BJB Enterprise, sprayed directly on leading edge of blade.	20.8	36.3
	4A	Silicone Sheet, 0.020" thick, with Kevlar cloth backing, bonded to leading edge with Uralane 4747 adhesive, supplied by Silicone Products Co., Monrovia.	21.6	2.1
	5A [(b)]	Two specimens, Dunlop Ltd., Rubber Div., England, adhesive-backed Polyurethane Sheet, 0.025" thick bonded directly to leading edge with MEK activated adhesive backing.	20.8	75.0 (Vacuum Bond) 108.6 (Pressure Bond)
	6A	Two specimens, Viton B rubber sheets, 0.030" ±0.010", bonded to 181 fiberglass, which are in turn bonded to leading edge with Uralane 4747 adhesive, under vacuum.	19.7	36.3 36.3
	7A	0.020" thic[illegible]xy-impregnated Kevlar fiber, applied to leading e[illegible] of blade with Uralane 4747 adhesive and cured as recommended by the vendor.	37.8	11.1

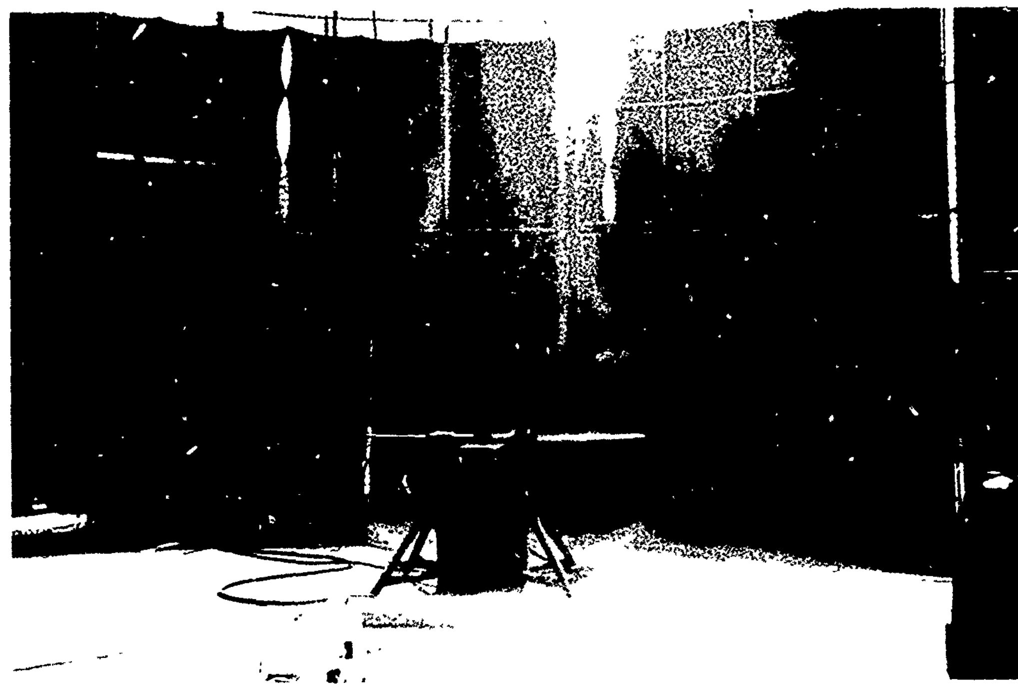
(a) All tests in 1-inch-per-hour rain at 850-fps rotor tip speed
(b) Materials selected for final testing
(c) Tests continued until destruction of strips

TABLE 2. EROSION TEST SUMMARY				
Material	Specimen	Figure	Type of Test	Total Test Time - Minutes[d]
Polyurethane	7	8	Sand[a]	117
	8	8		117
	9	9		74
	20	9		176
UHMWPE[c]	1	10	Sand	44
	4	10		44
	5	11		18
	6	11		20
	3	11		54
Polyurethane	4'	12	Rain[b]	11
	11	12		20
	17	13		15
	10'	13		15
UHMWPE	2	14	Rain	15
	3'	14		15
	5'	15		10
	6'	15		15
	18	15		10
Polyurethane	12	16	7.5 minutes in rain followed by 203 minutes in sand[d]	
	11'	16	60.5 minutes in sand followed by 4.5 minutes in rain[d]	
UHMWPE	1'	17	7.5 minutes in rain followed by 44.5 minutes in sand[d]	
	8'	17	22.5 minutes in sand followed by 4.5 minutes in rain[d]	

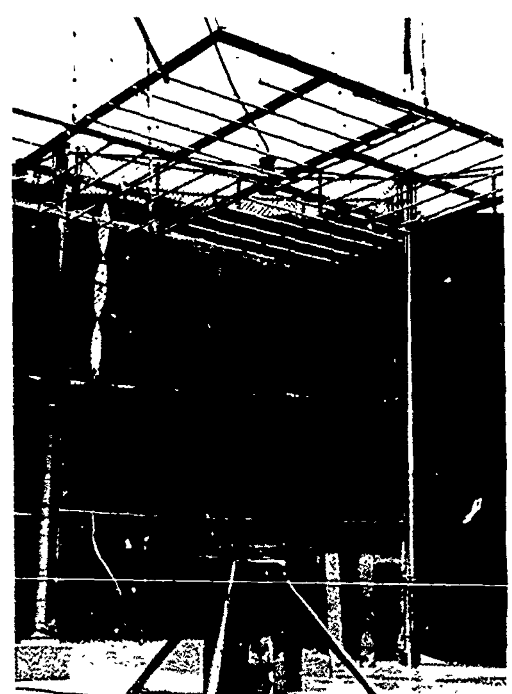
(a) Rain environment: 1.89 inches per hour and 959 fps tip speed
(b) Sand environment: 125 pounds per minute and 750 fps tip speed
(c) Ultra-High Molecular Weight Polyethylene
(d) Tests continued until destruction of strips

TABLE 3. AVERAGE TEST ENDURANCE FOR EROSION MATERIAL			
Environment	OH-6A* (Hard Anodized)	Polyurethane	UHMWPE
Sand (minutes)	42.5	121.2	36.2
Rain (minutes)	89.3	15.2	13.2

*Converted to present test conditions; see page 14.



Sand Test Configuration



Rain Test Configuration

Figure 1. Erosion Test Facility

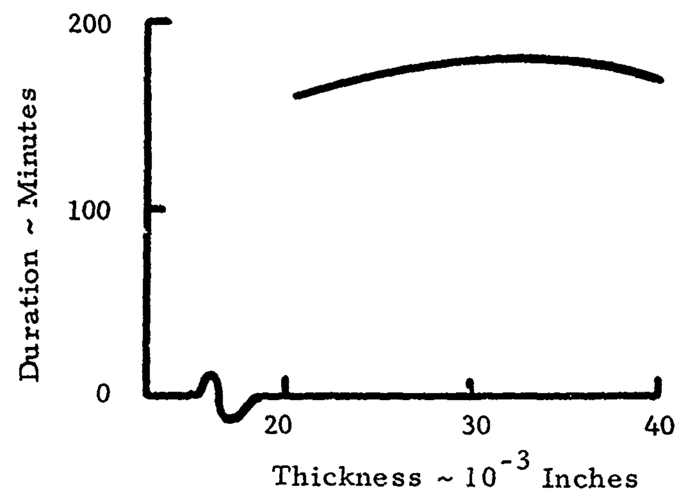


Figure 2. Effect of Thickness of Viton Fluoroelastomeric on Erosion Material Effectiveness[1]

1. Graham, T. L., "High Temperature Stable Subsonic Rain Erosion Resistant Fluoroelastomer Boot Material Development," USAFML Technical Report 74-9, U.S. Air Force Material Laboratory, Dayton, Ohio. May 1974.

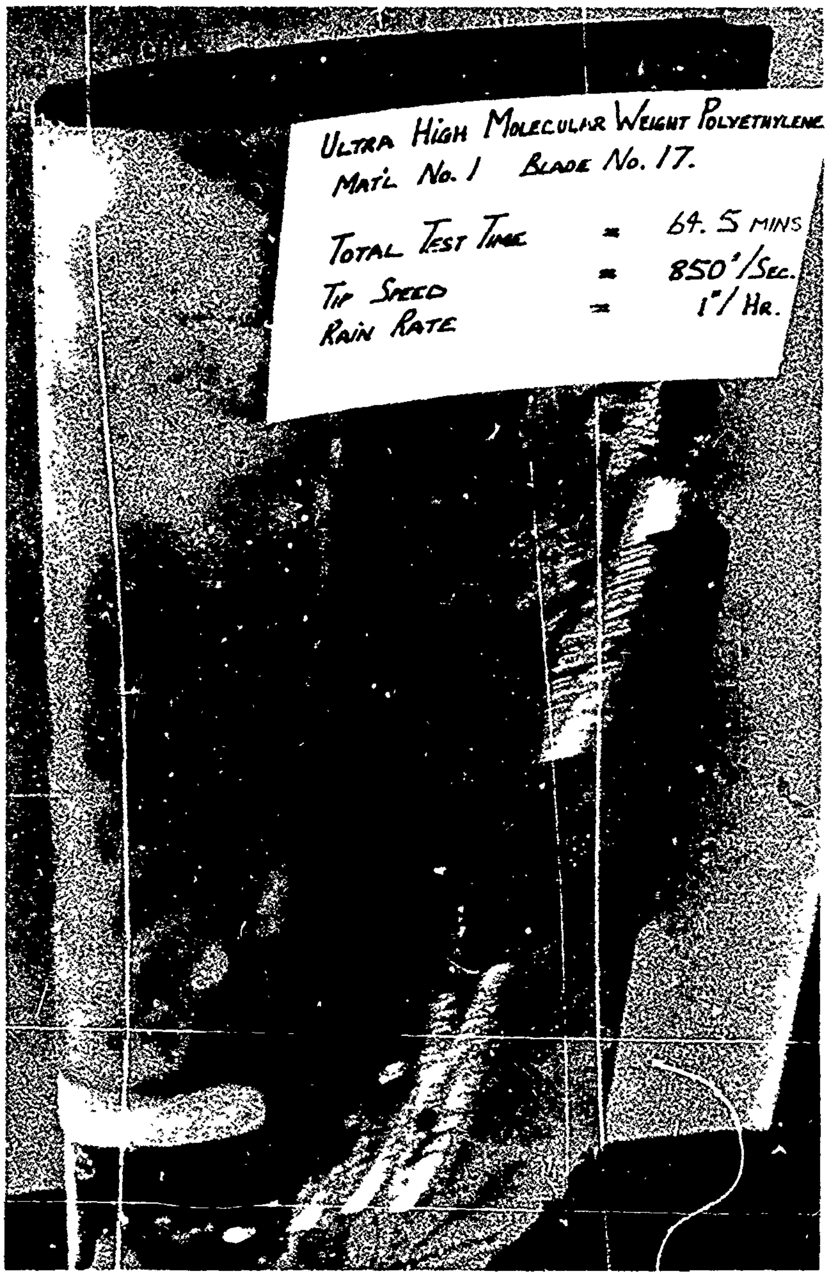


Figure 3. Ultra-High Molecular Weight Polyethylene Erosion Material (American Hoechst)

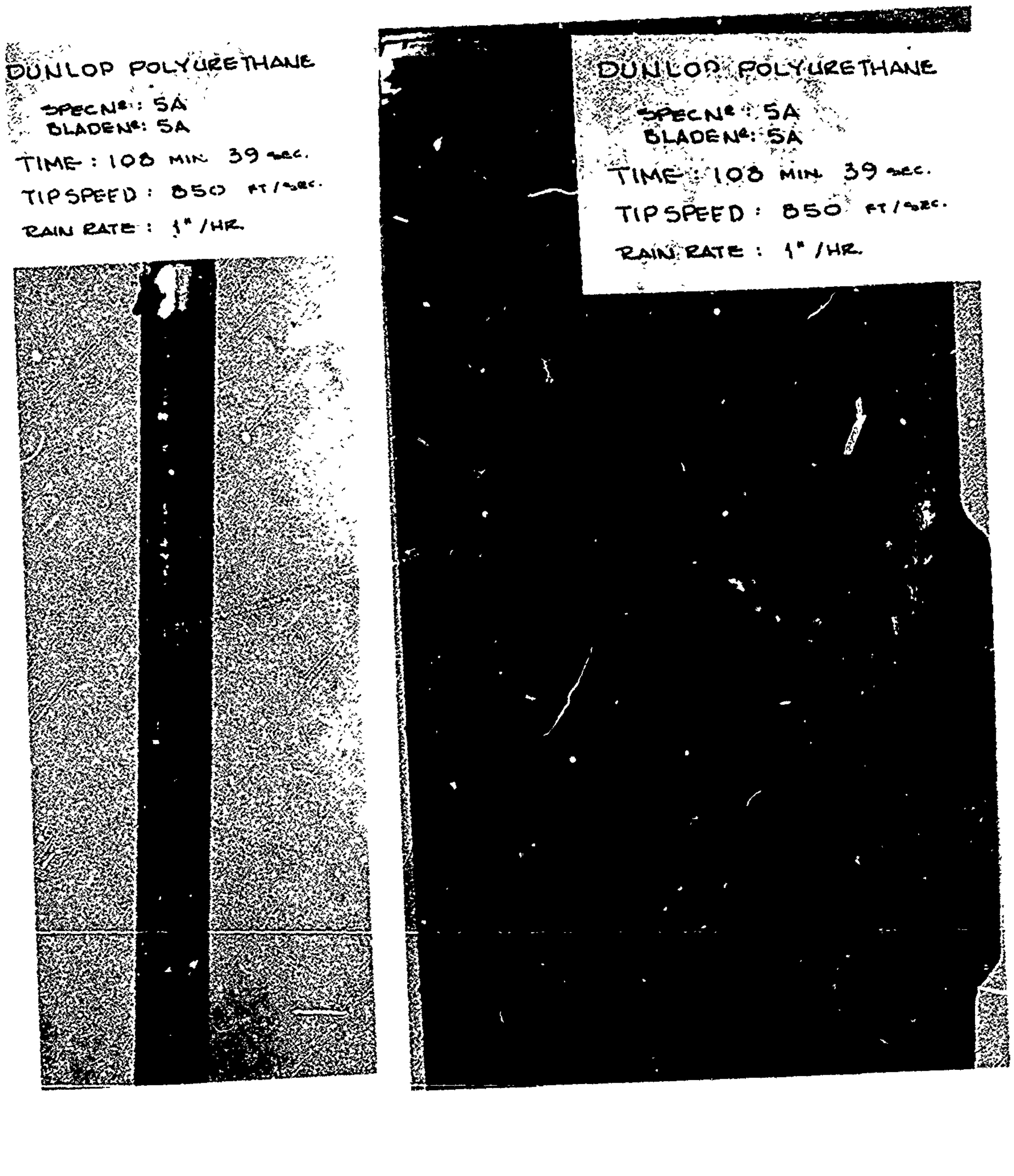


Figure 4. Polyurethane Erosion Material
(Dunlop Ltd.)

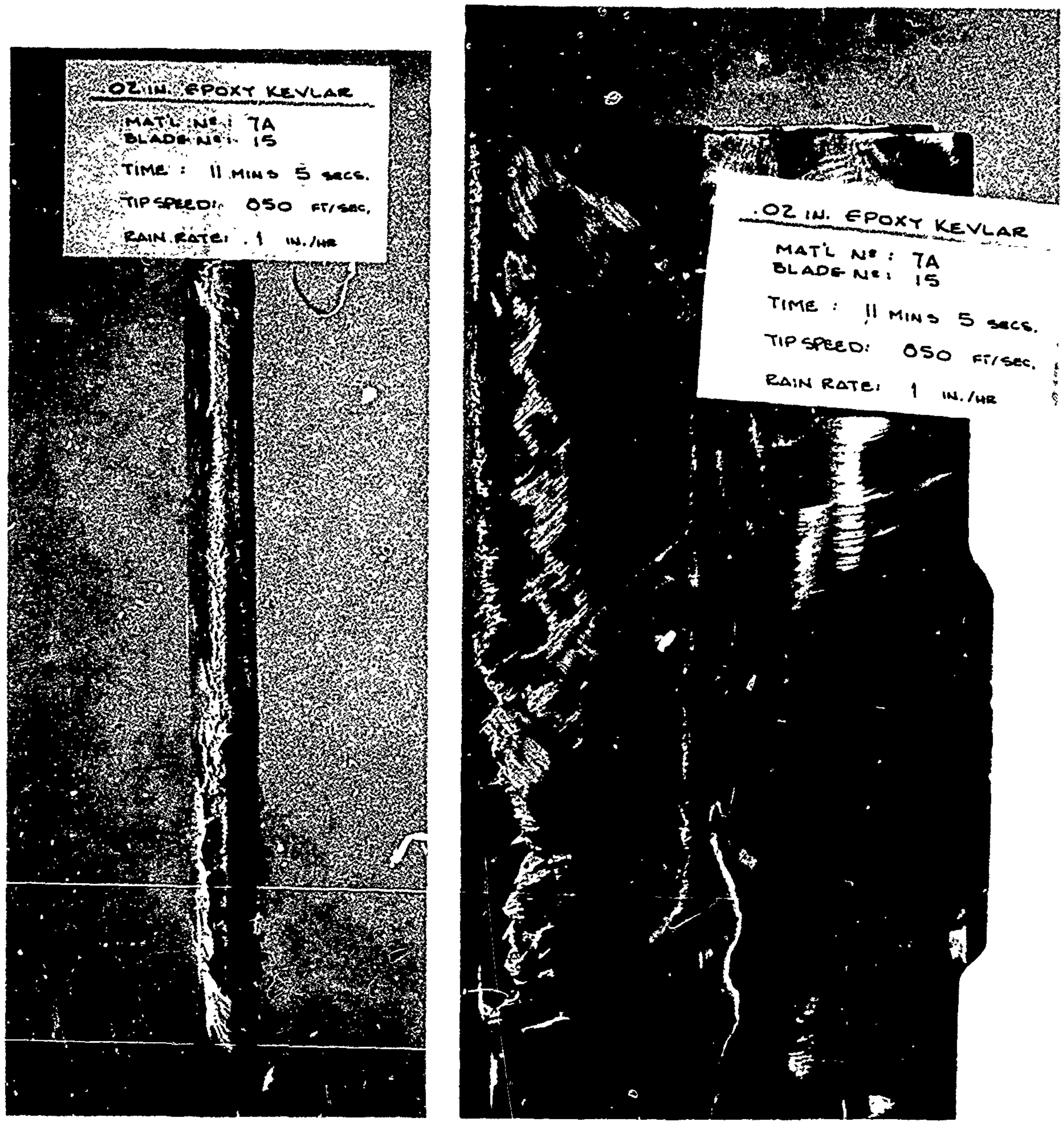


Figure 5. Kevlar/Epoxy - Bare Blade Reference

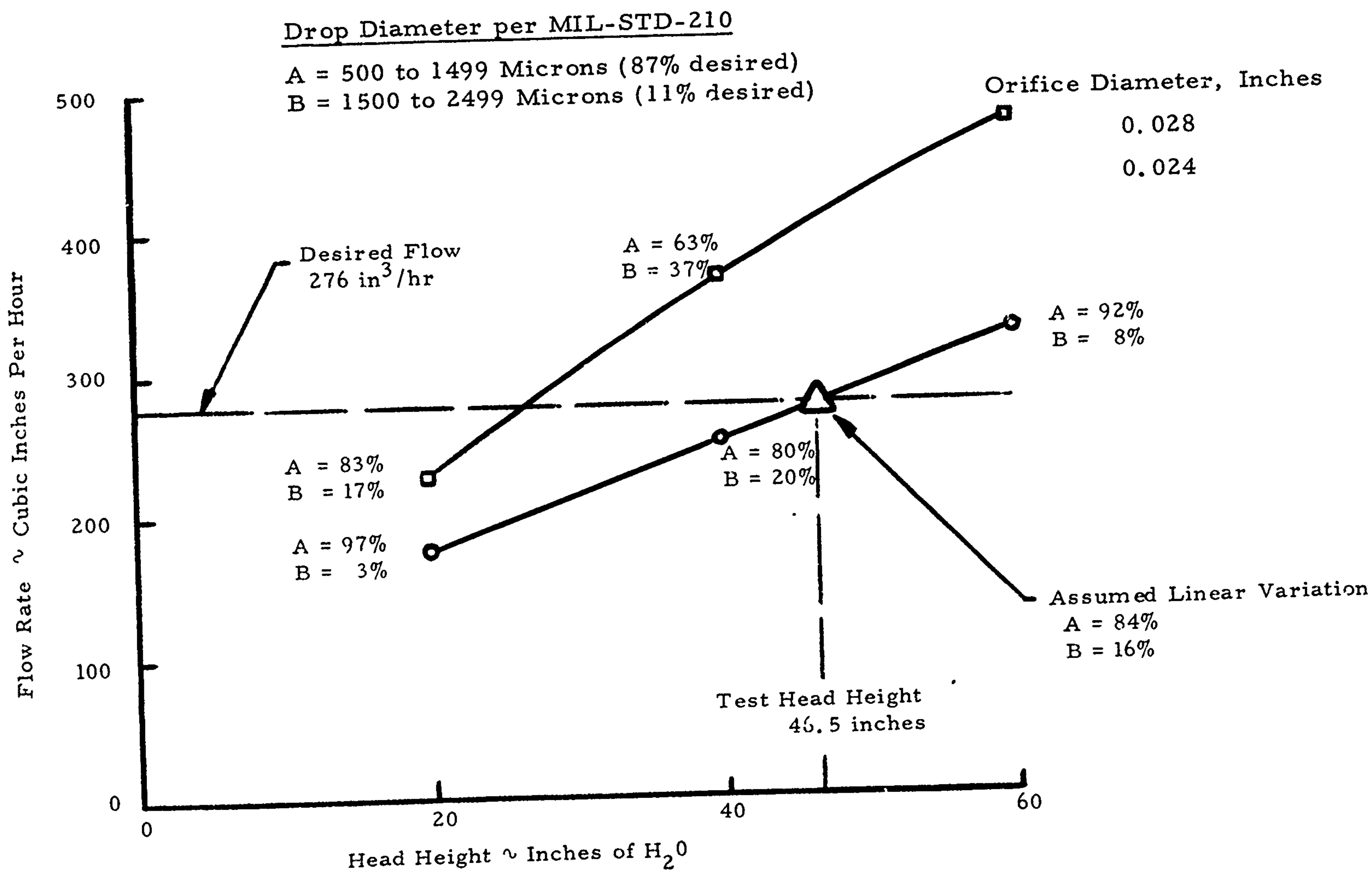


Figure 6. Rain Droplet Size Calibration

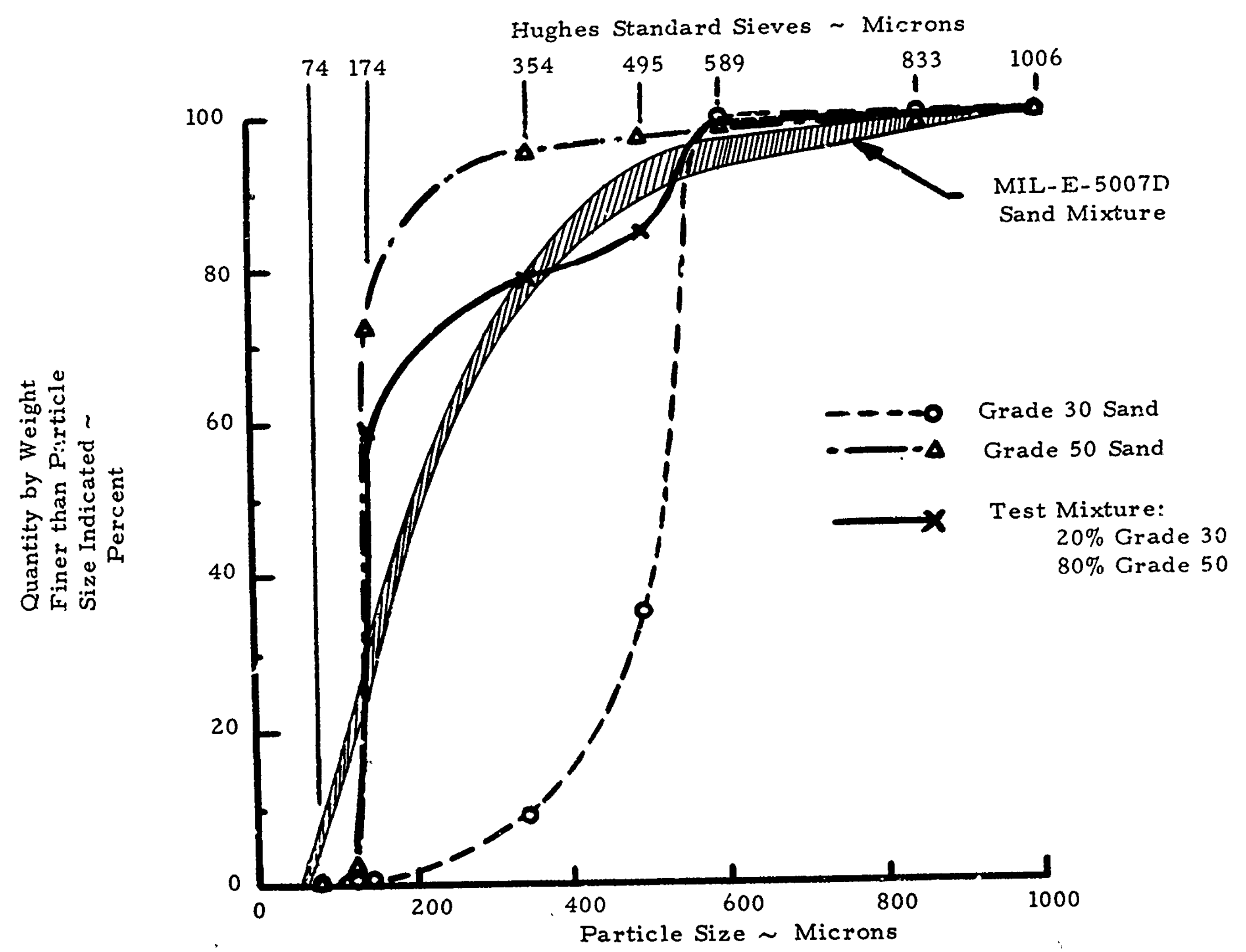
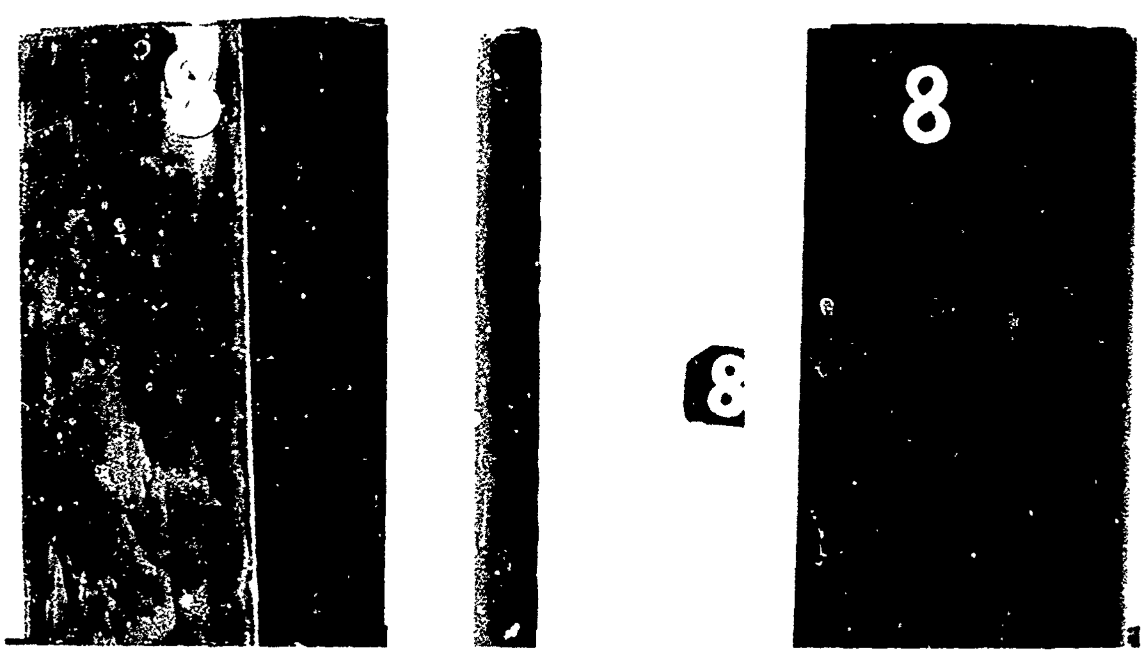


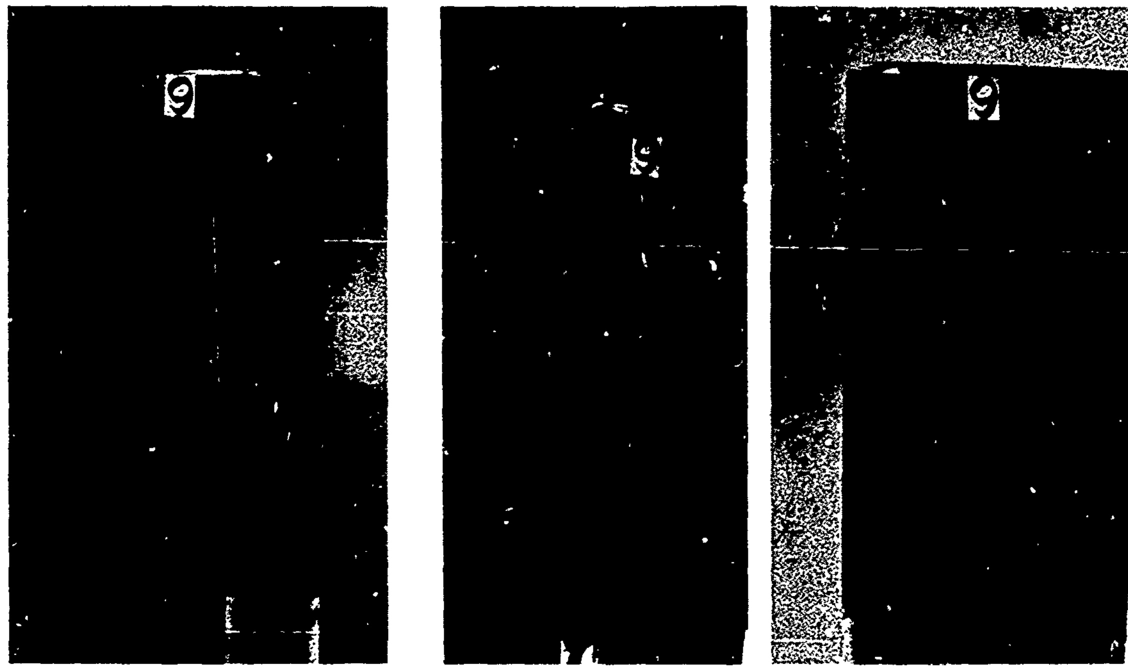
Figure 7. Sand Particle Size Calibration

Specimen No. 7, 117

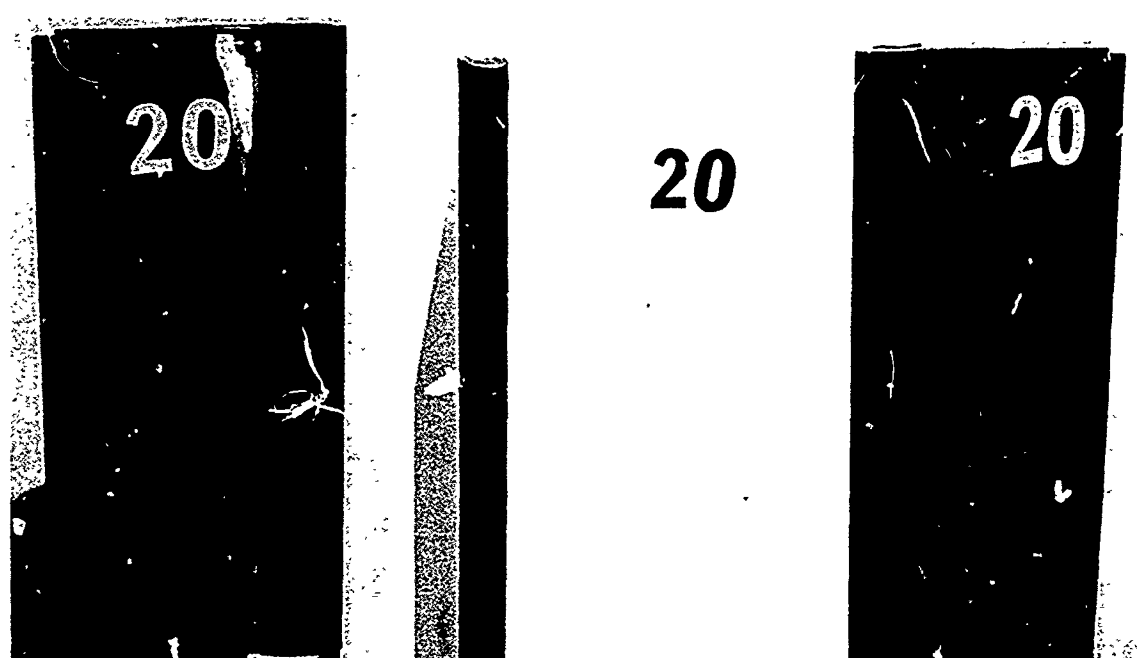


Specimen No. 8, 117 Minutes

Figure 8. Polyurethane Sand Erosion Test

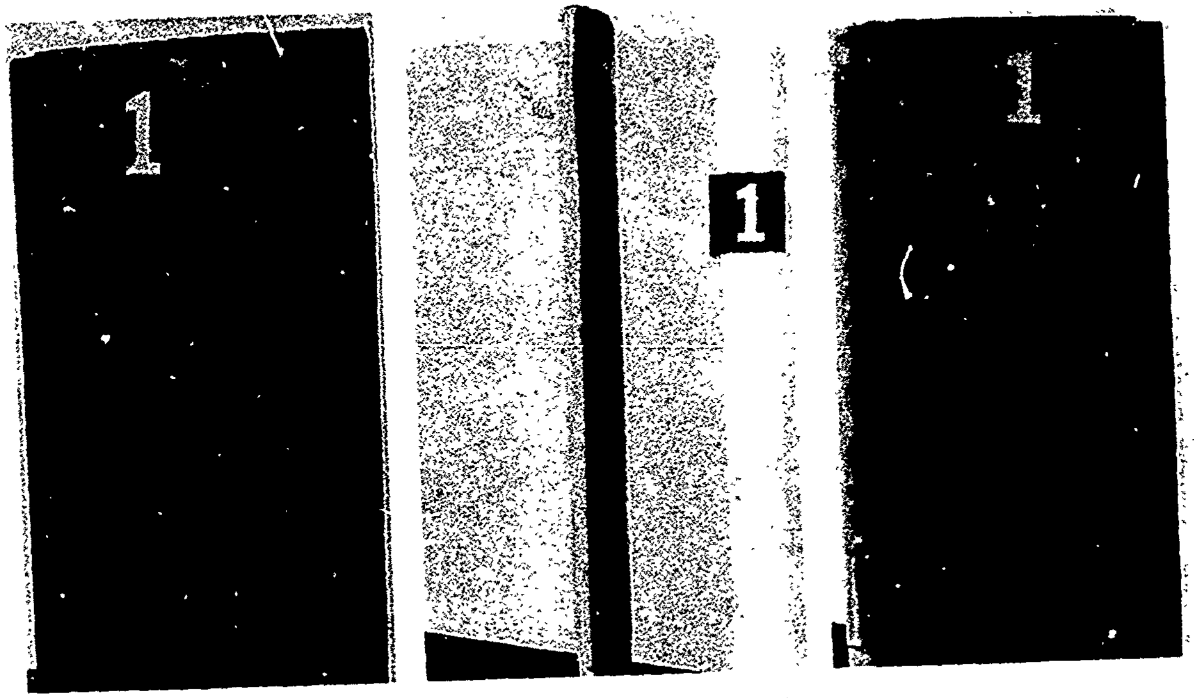


Specimen No. 9, 74 Minutes

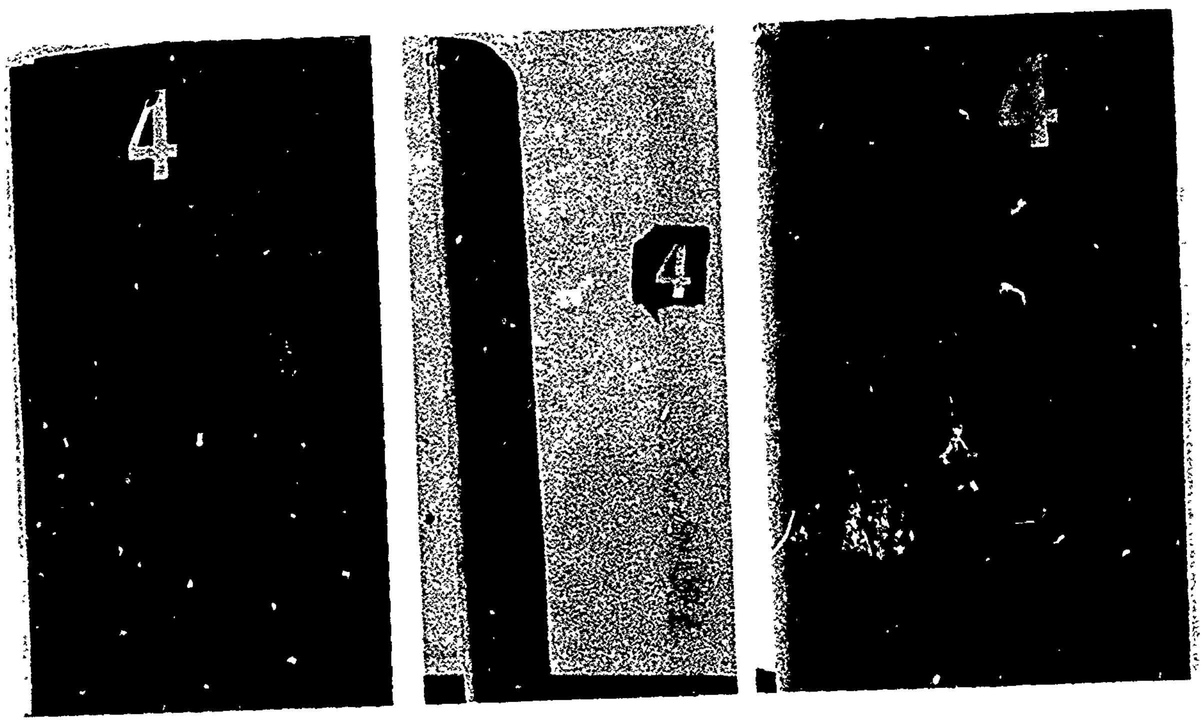


Specimen No. 20, 176 Minutes

Figure 9. Polyurethane Sand Erosion Test

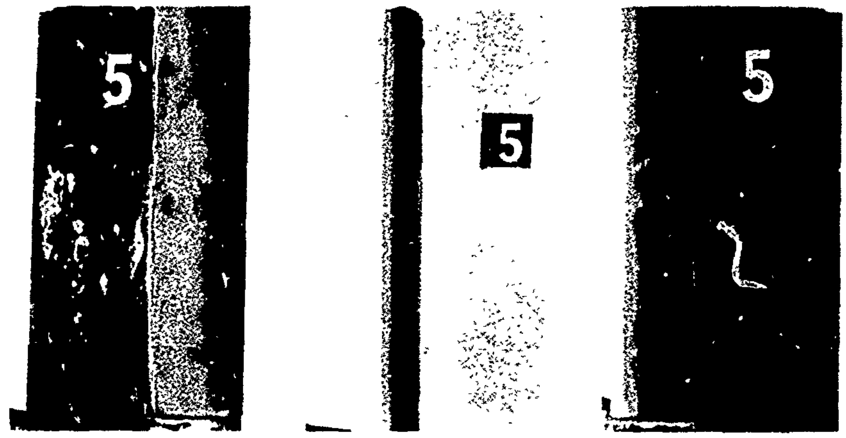


Specimen No. 1, 44 Minutes



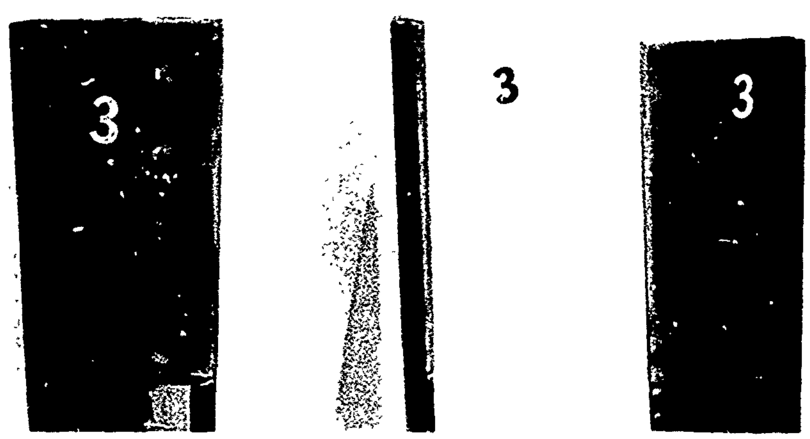
Specimen No. 4, 44 Minutes

Figure 10. UHWPE Sand Erosion Test



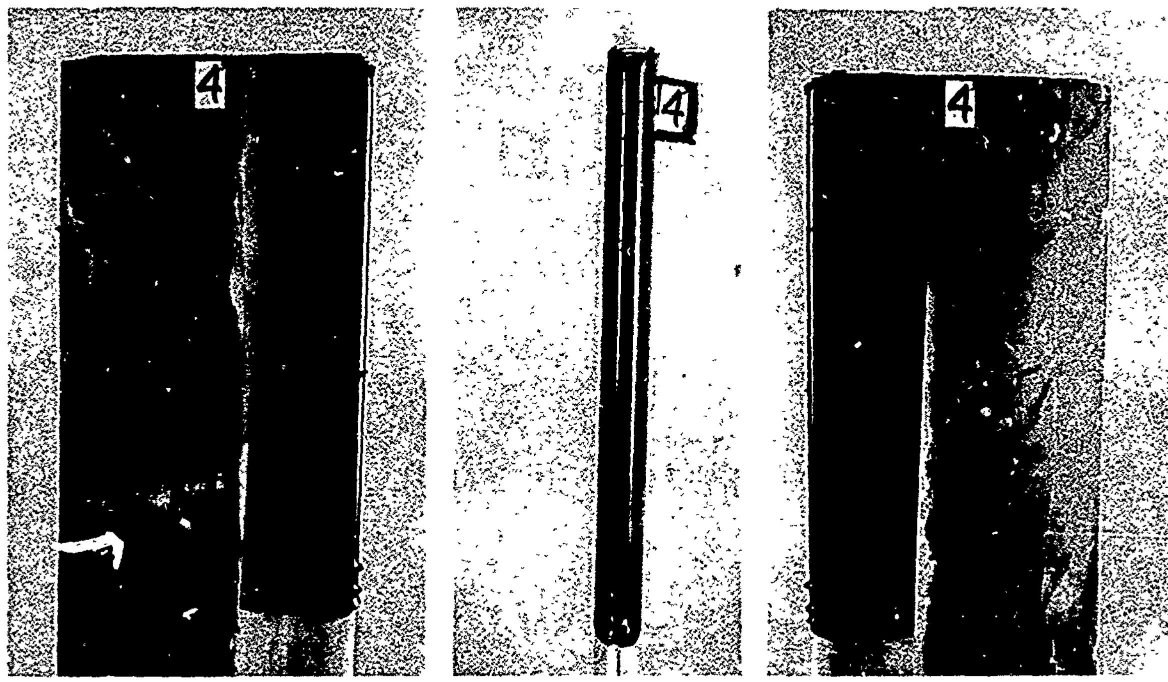
Specimen No. 5, 18 Minutes

Specimen No. 6, 20 Minutes

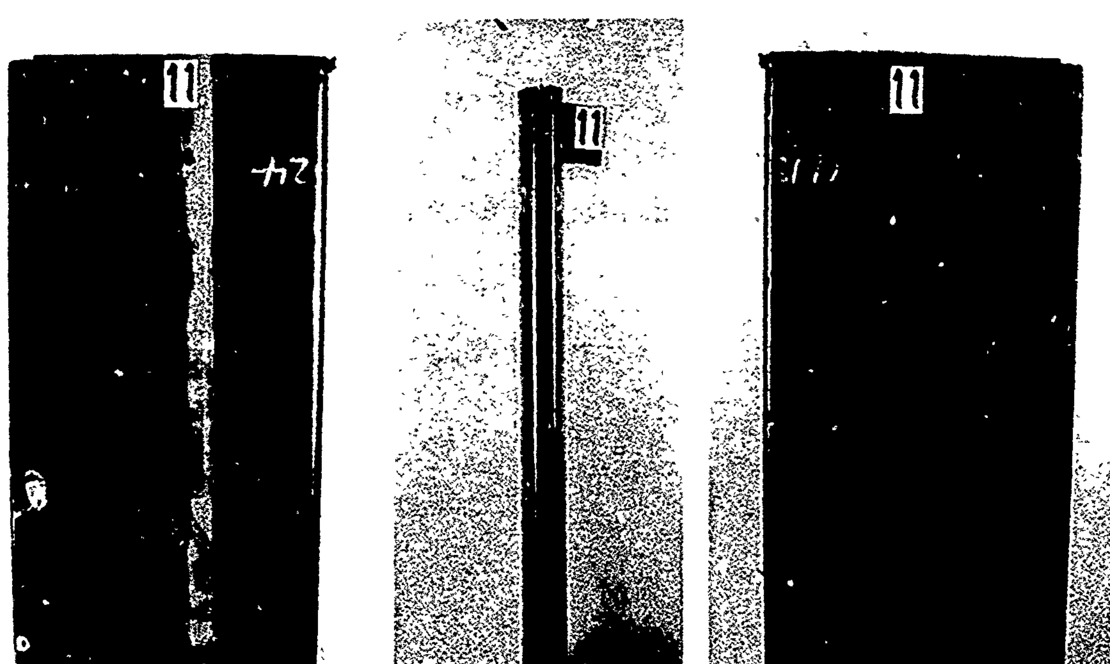


Specimen No. 3, 54 Minutes

Figure 11. UHMWPE Sand Erosion Test



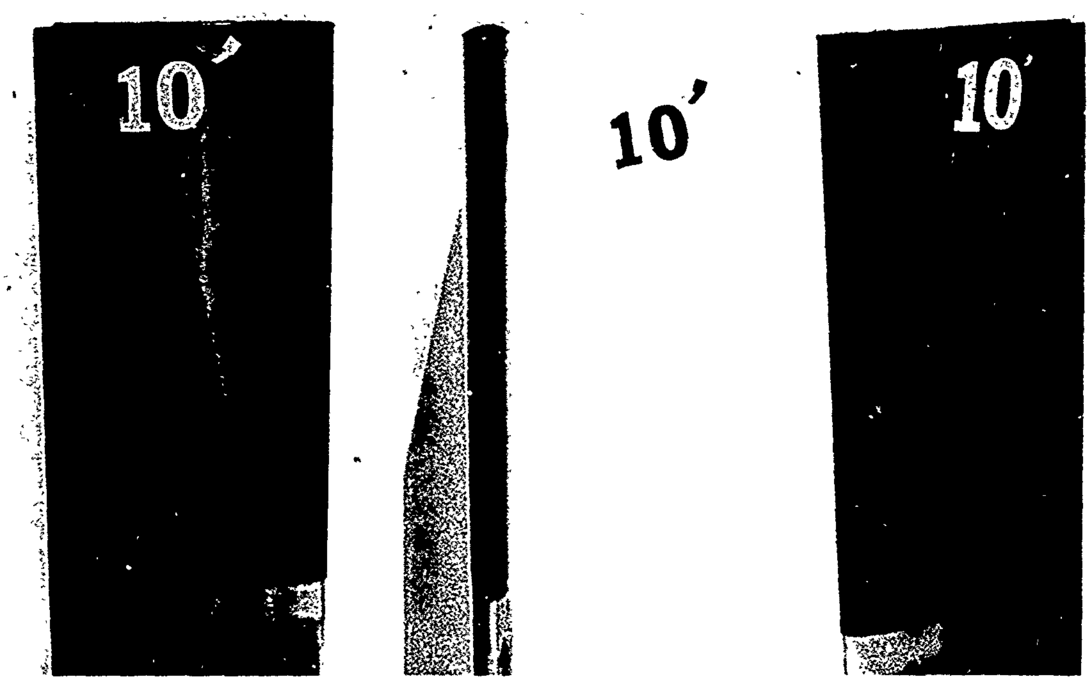
Specimen No. 4, 11 Minutes



Specimen No. 11, 20 Minutes

Figure 12. Polyurethane Rain Erosion Test

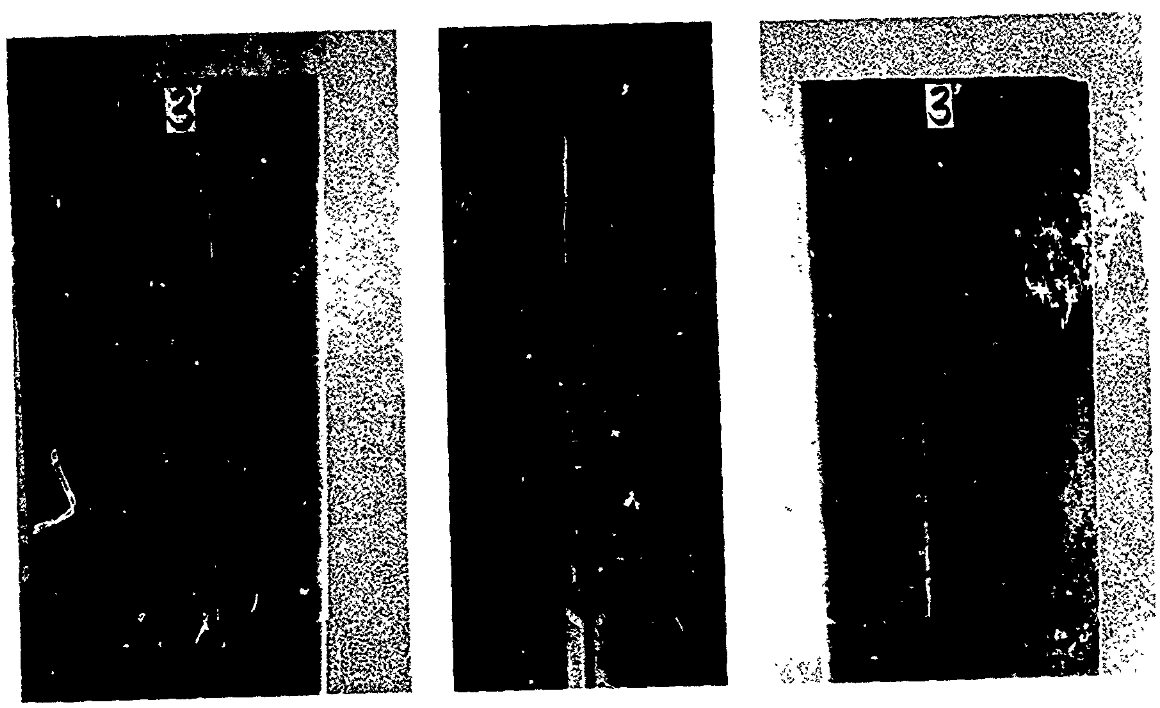
Specimen No. 17, 15 Minutes



Specimen No. 10, 15 Minutes

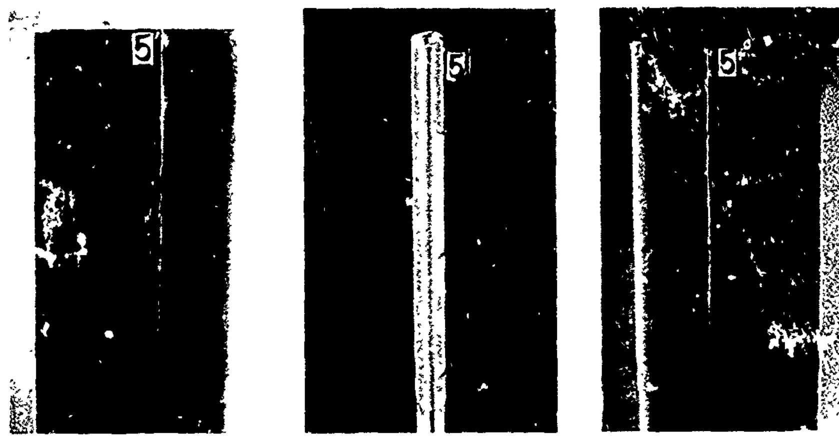
Figure 13. Polyurethane Rain Erosion Test

Specimen No. 2, 15 Minutes

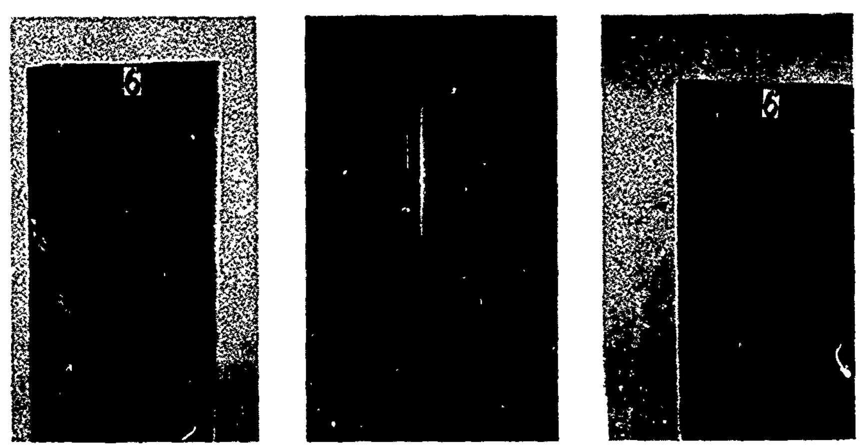


Specimen No. 3', 15 Minutes

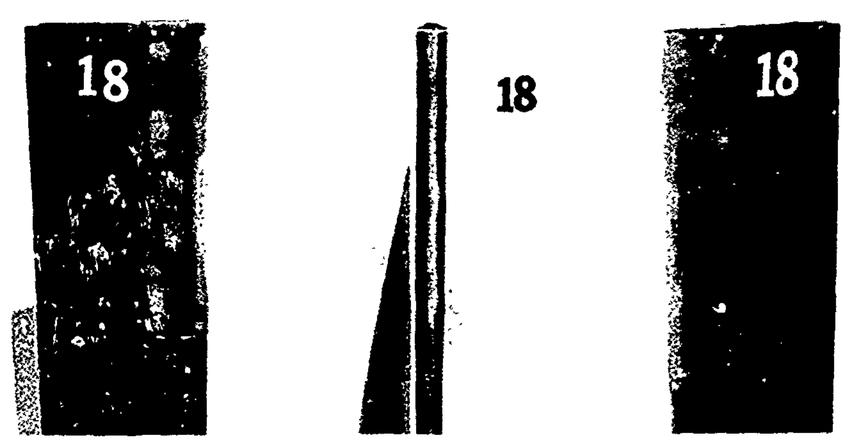
Figure 14. UHMWPE Rain Erosion Test



Specimen No. 5', 10 Minutes

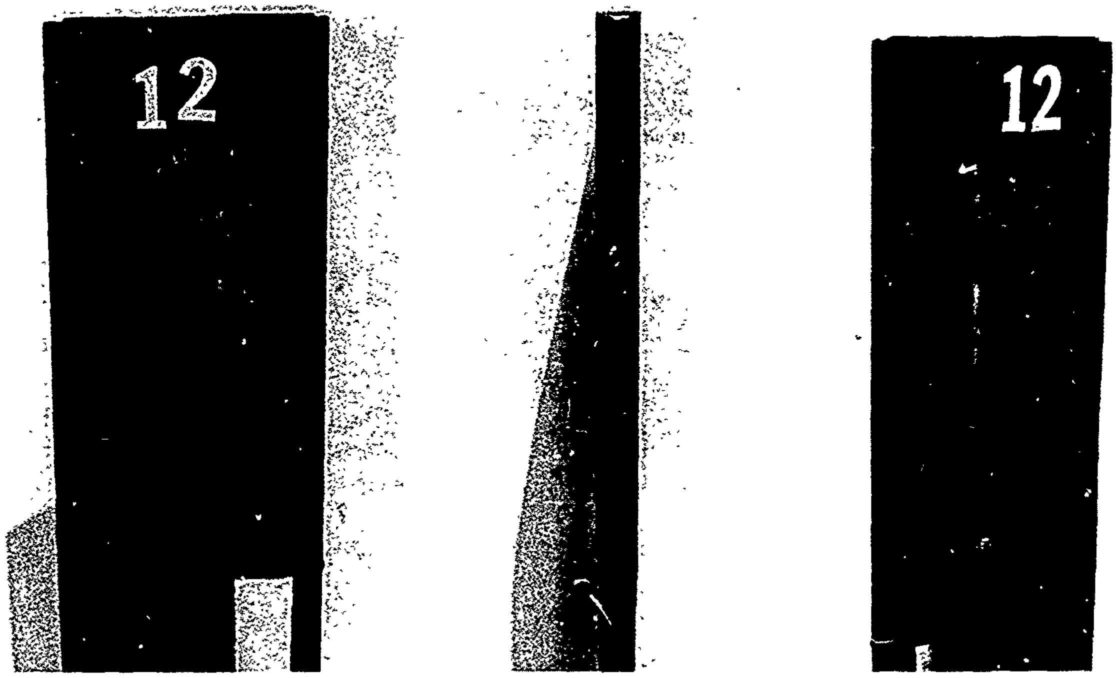


Specimen No. 6', 15 Minutes

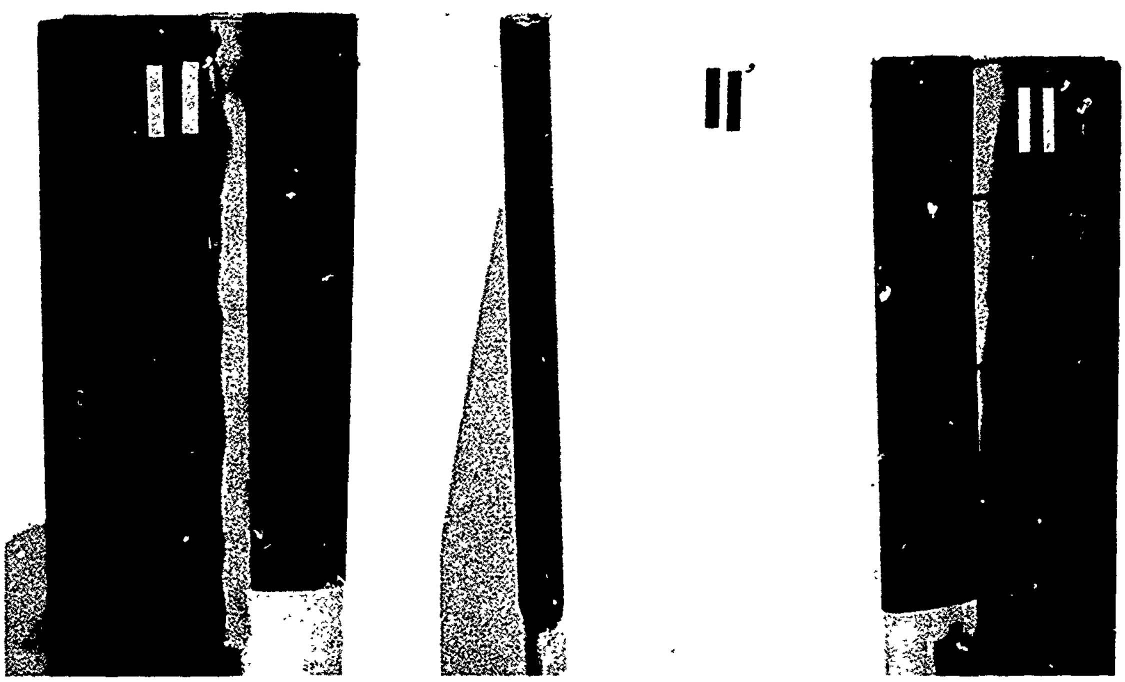


Specimen No. 18, 10 Minutes

Figure 15. UHMWPE Rain Erosion Test

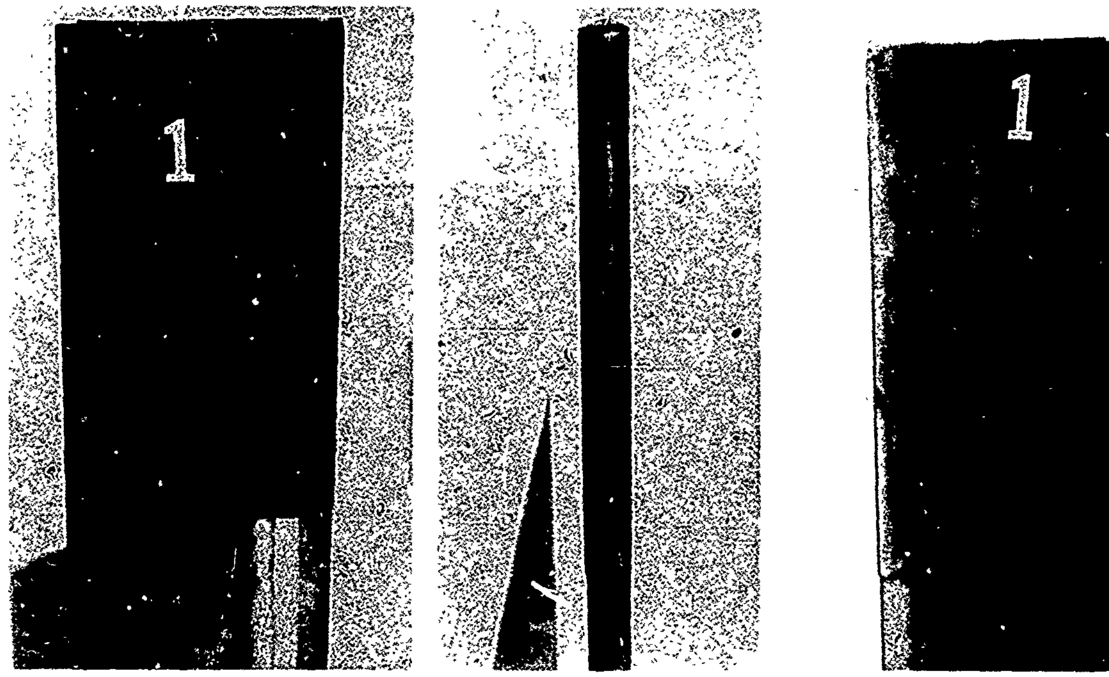


Specimen No. 12 - 7.5 Minutes in Rain before 203 Minutes in Sand

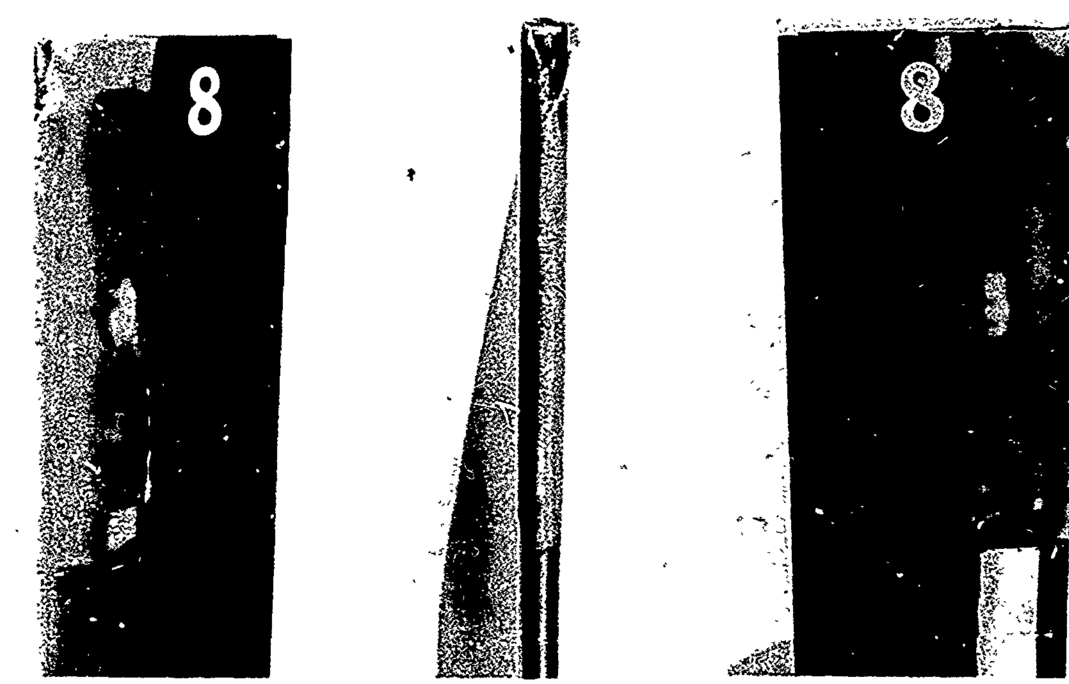


Specimen No. 11 - 60.5 Minutes in Sand before 4.5 Minutes in Rain

Figure 16. Polyurethane Erosion Test



Specimen No. 1 - 7.5 Minutes in Rain Before 44.5 Minutes in Sand



Specimen No. 8 - 22.5 Minutes in Sand Before 4.5 Minutes in Rain

Figure 17. UHMWPE Erosion Test

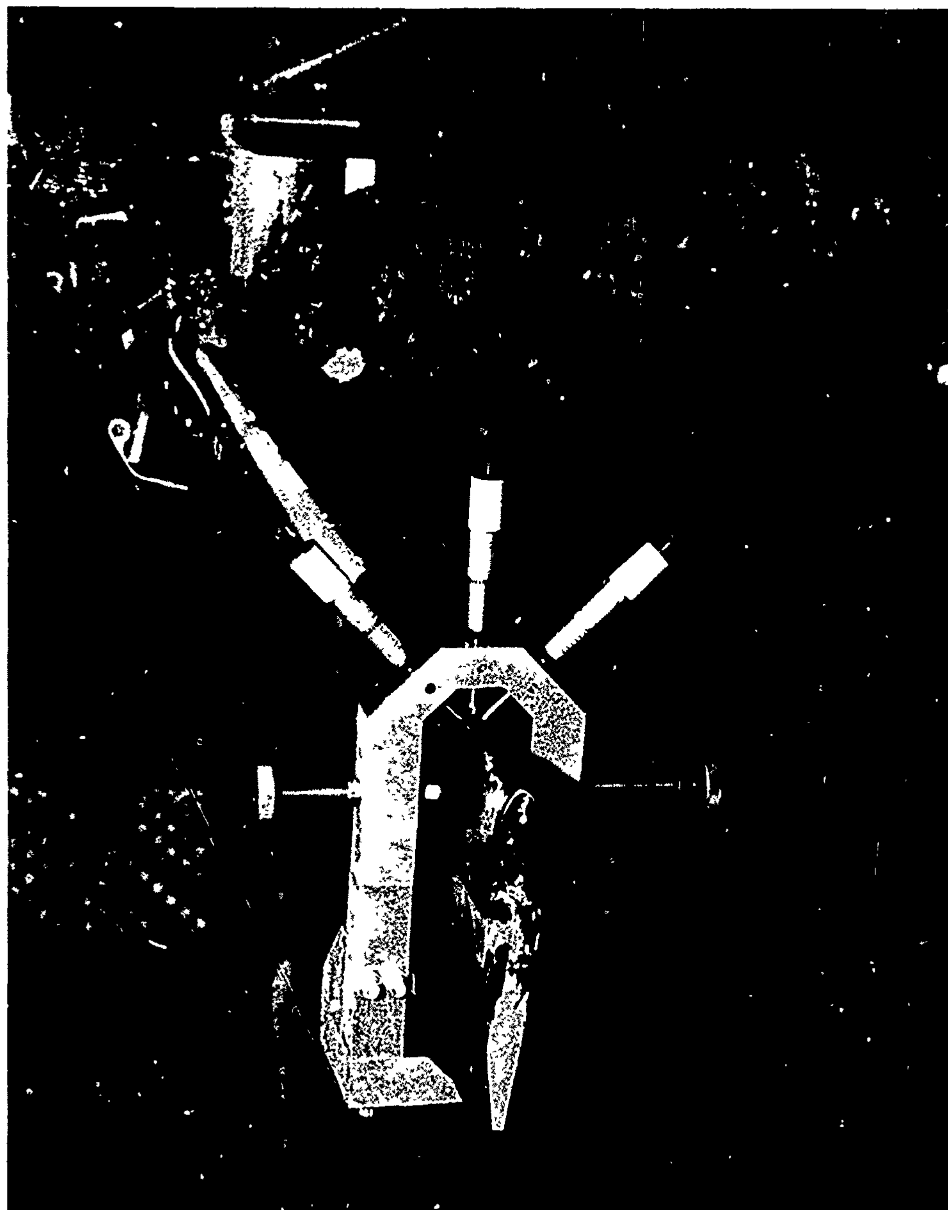


Figure 18. Micrometer Tool for Measuring Wear

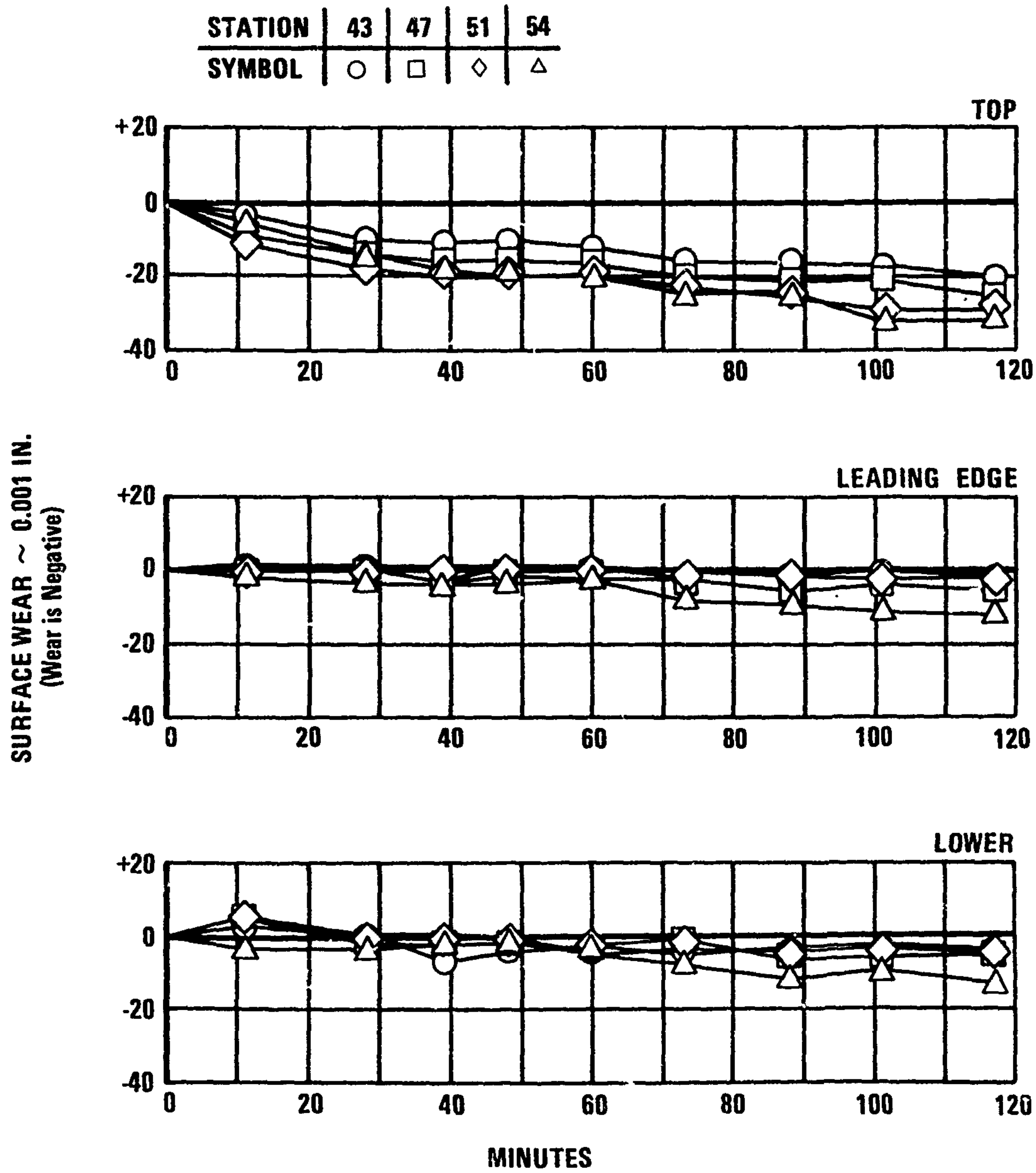


Figure 19. Sand Erosion Test - Polyurethane (Specimen No. 7)

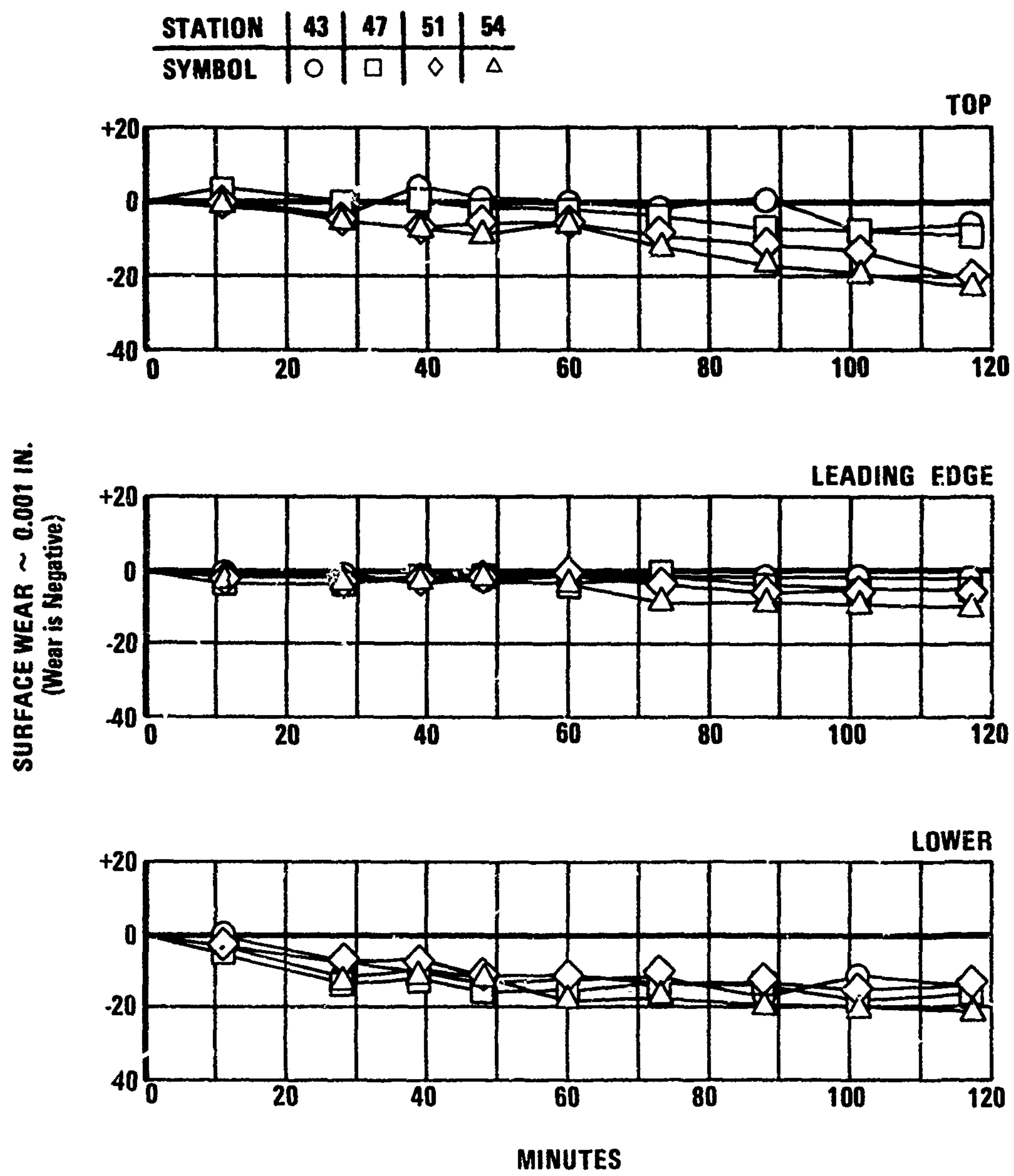


Figure 20. Sand Erosion Test - Polyurethane (Specimen No. 8)

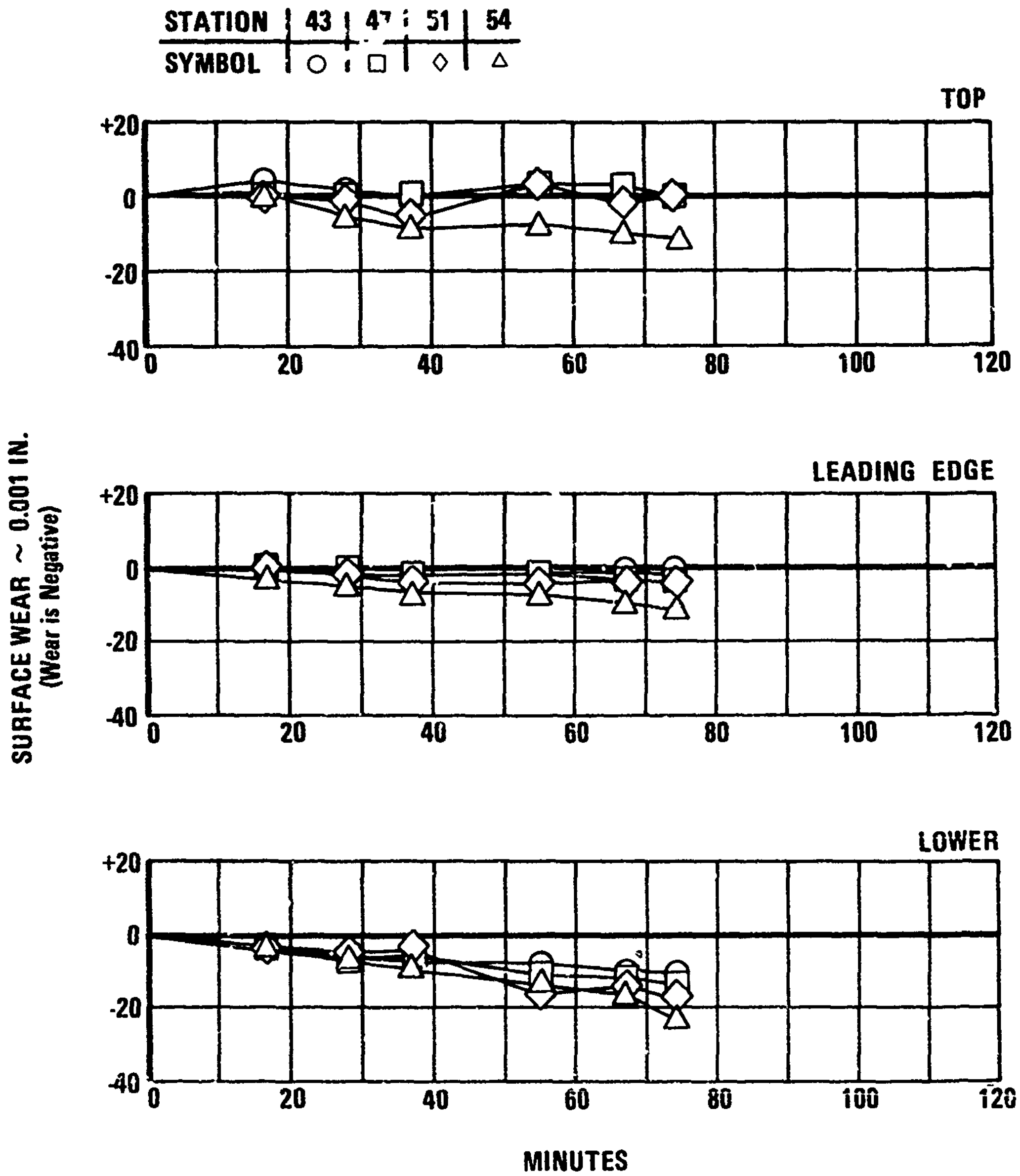


Figure 21. Sand Erosion Test - Polyurethane (Specimen No. 9)

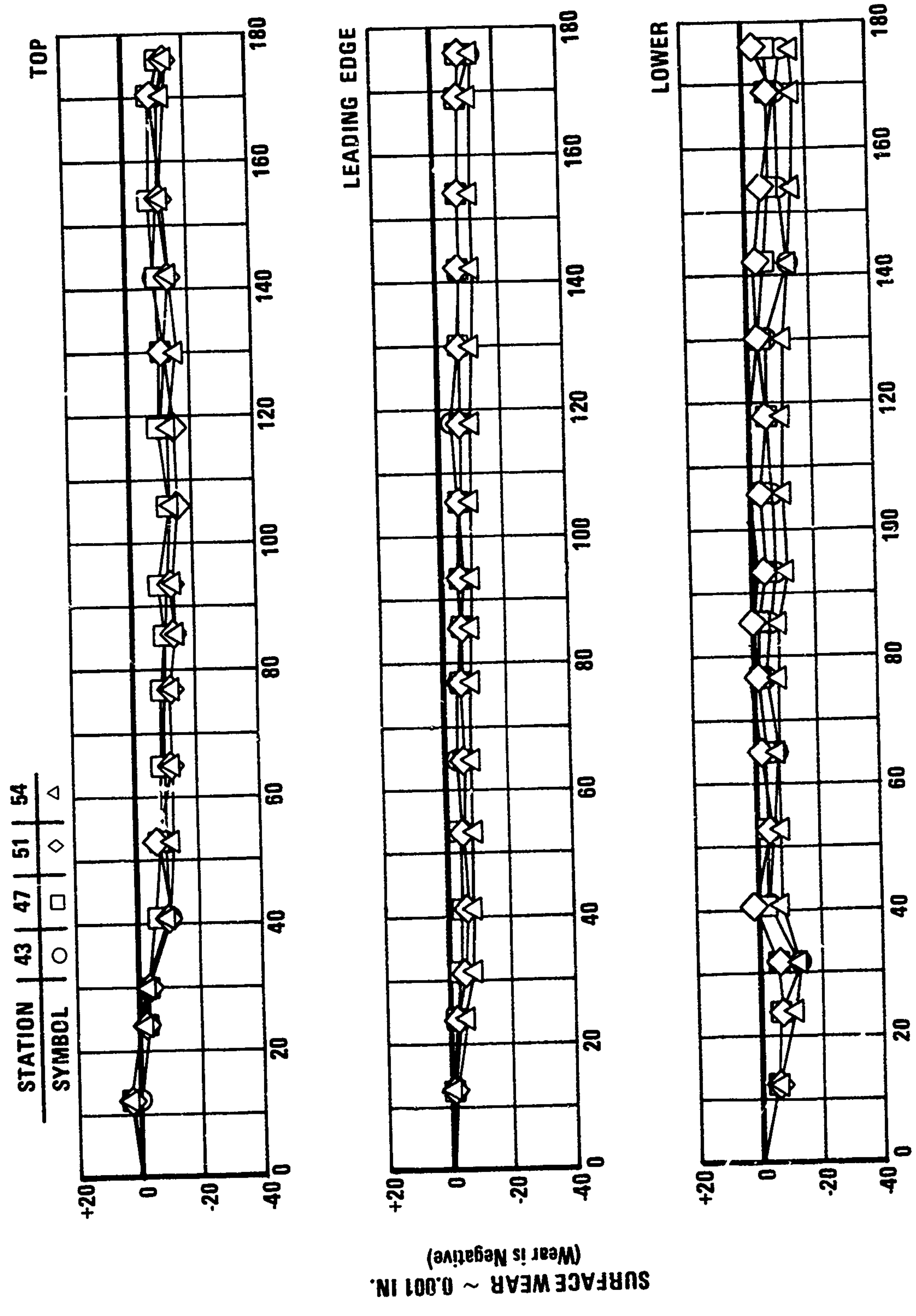


Figure 22. Sand Erosion Test - Polyurethane (Specimen No. 20)

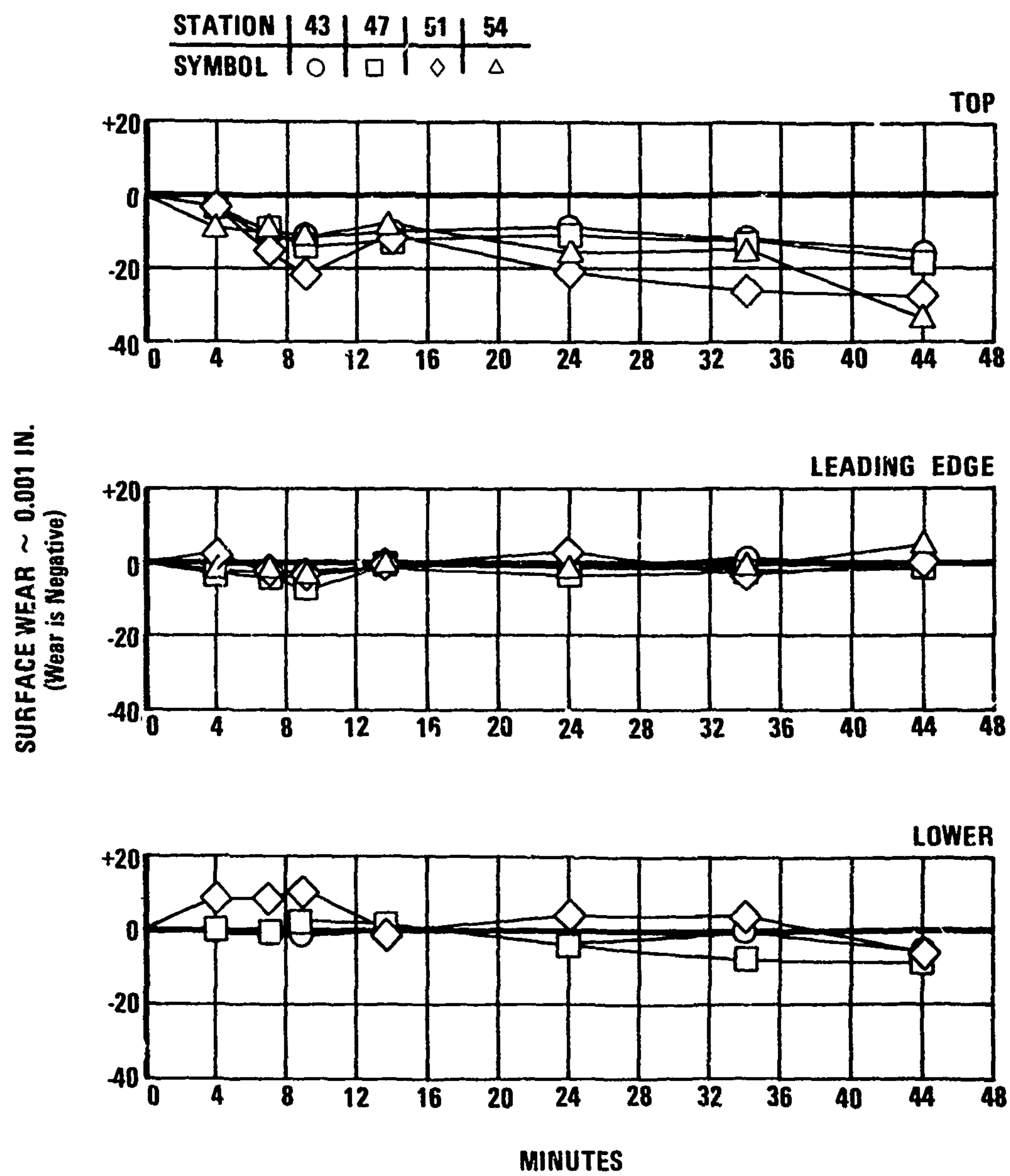


Figure 23. Sand Erosion Test - UHMWPE (Specimen No. 1)

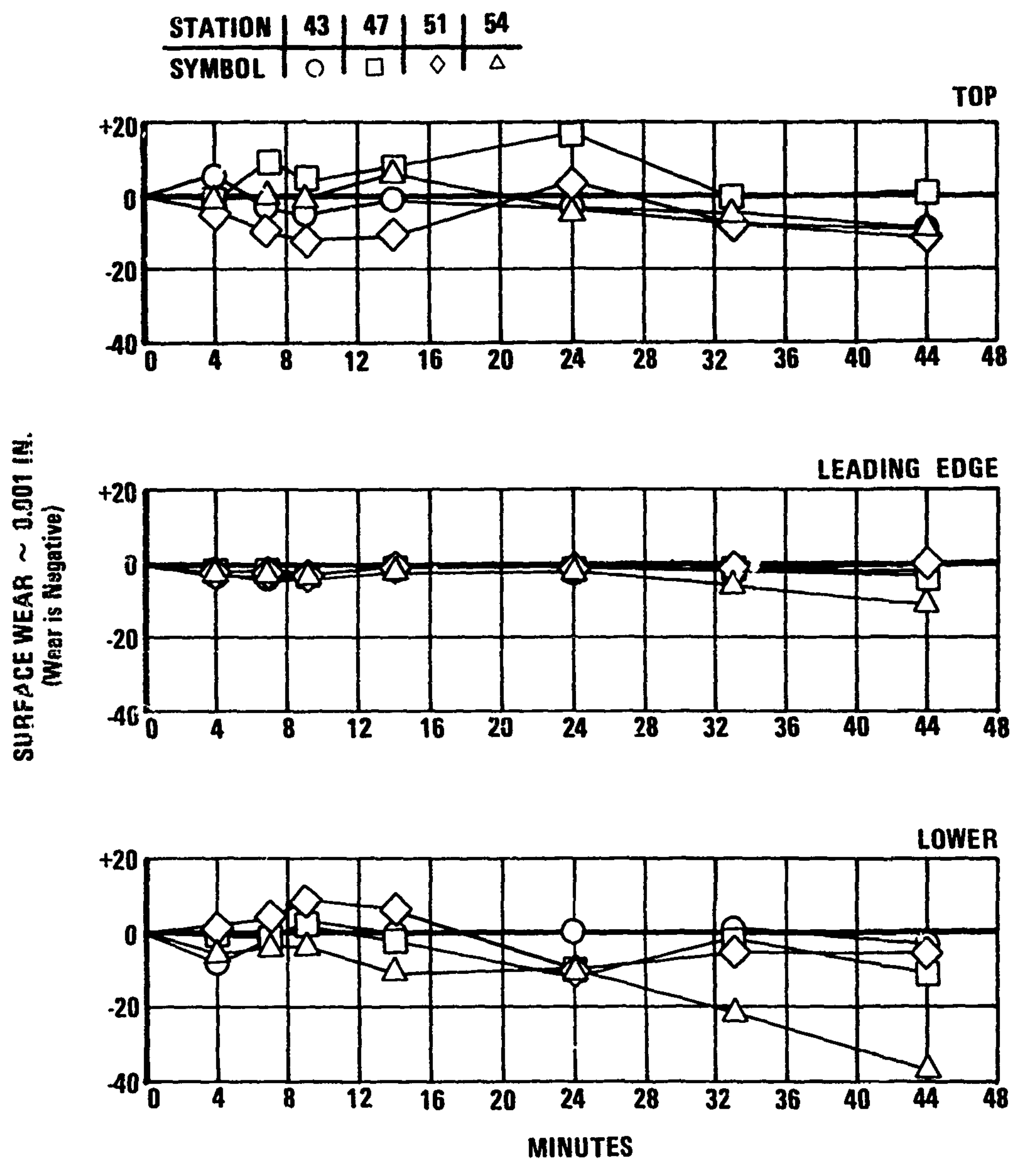


Figure 24. Sand Erosion Test - UHMWPE (Specimen No. 4)

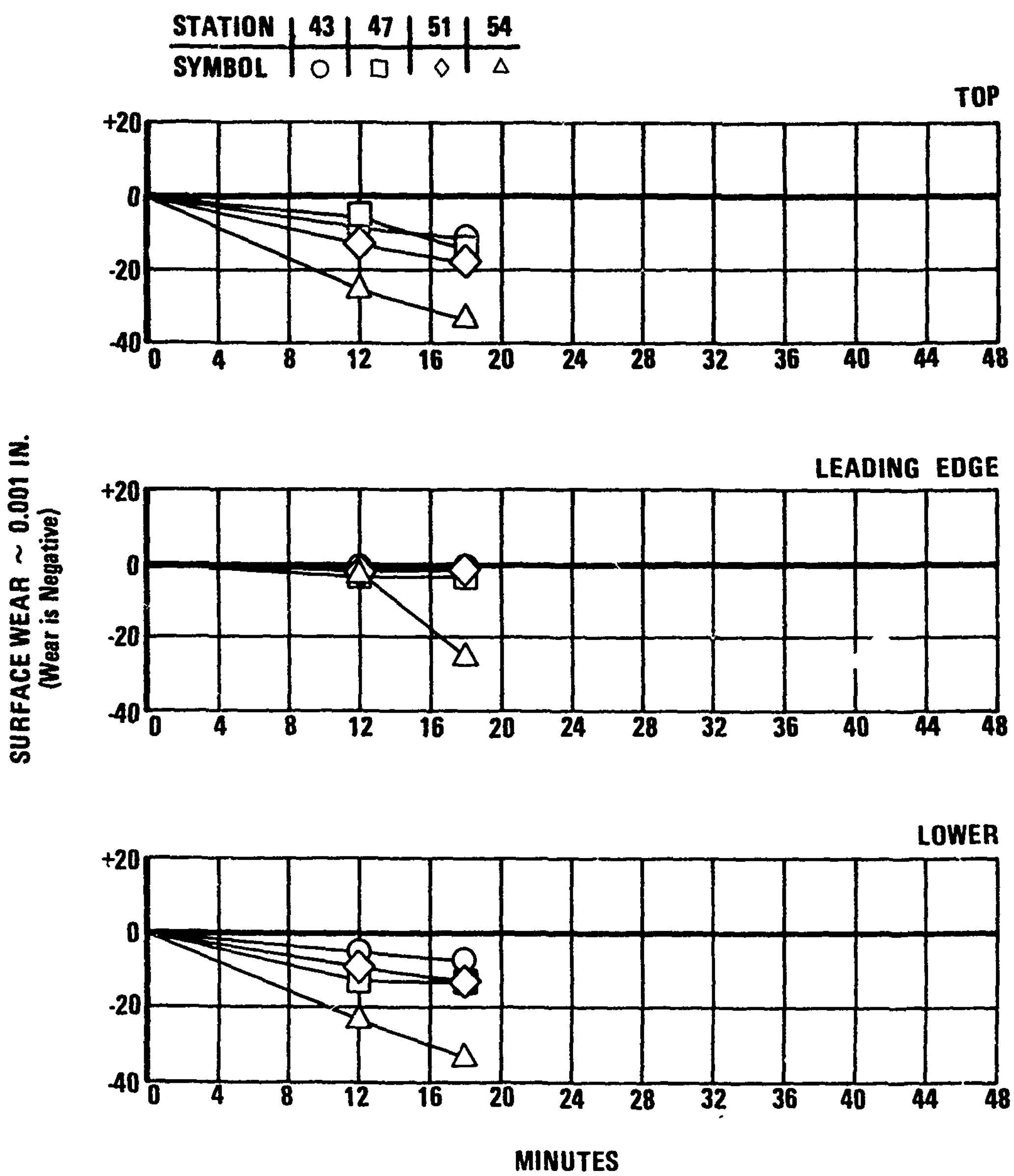


Figure 25. Sand Erosion Test - UHMWPE (Specimen No. 5)

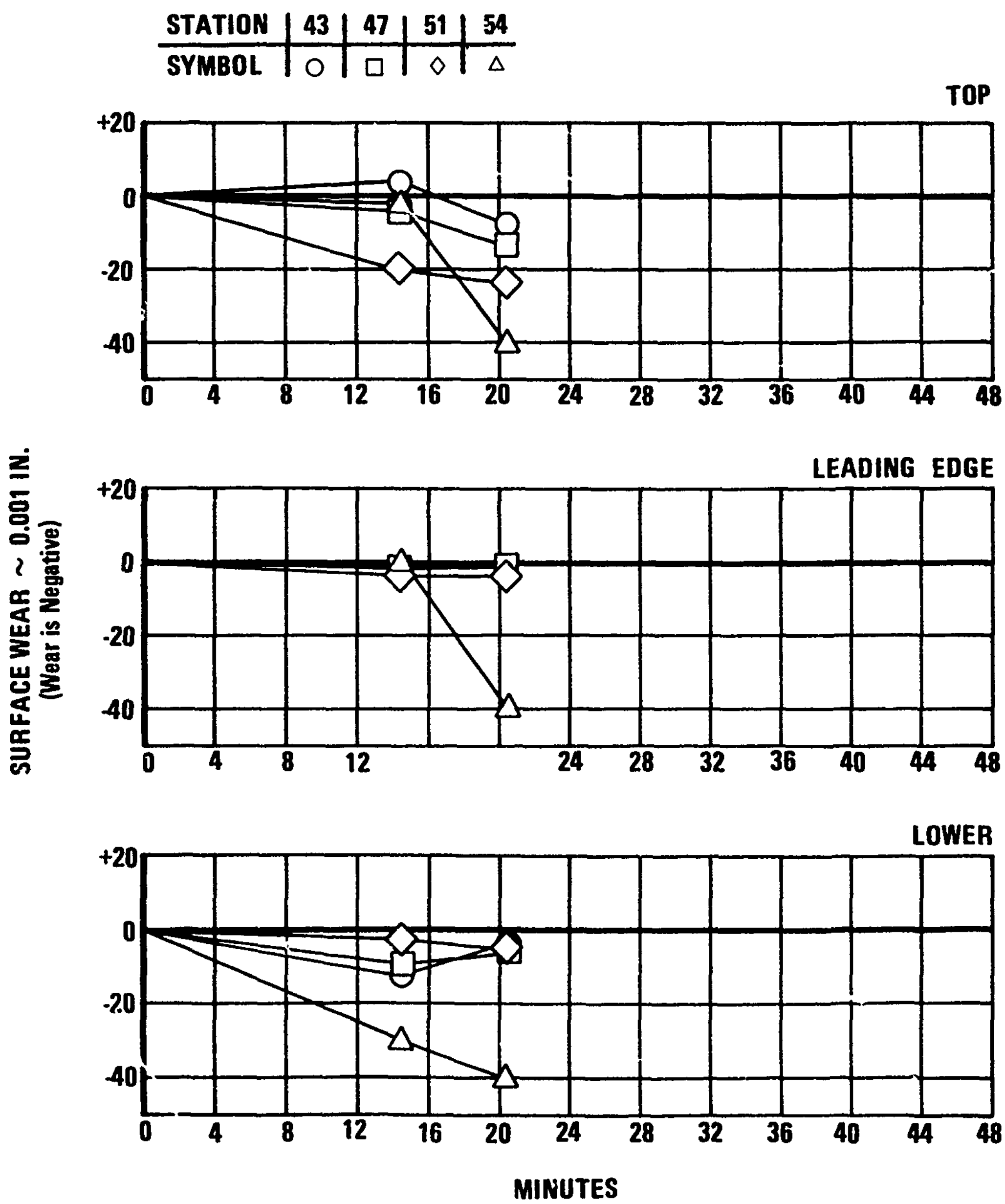


Figure 26. Sand Erosion Test - UHMWPE (Specimen No. 6)

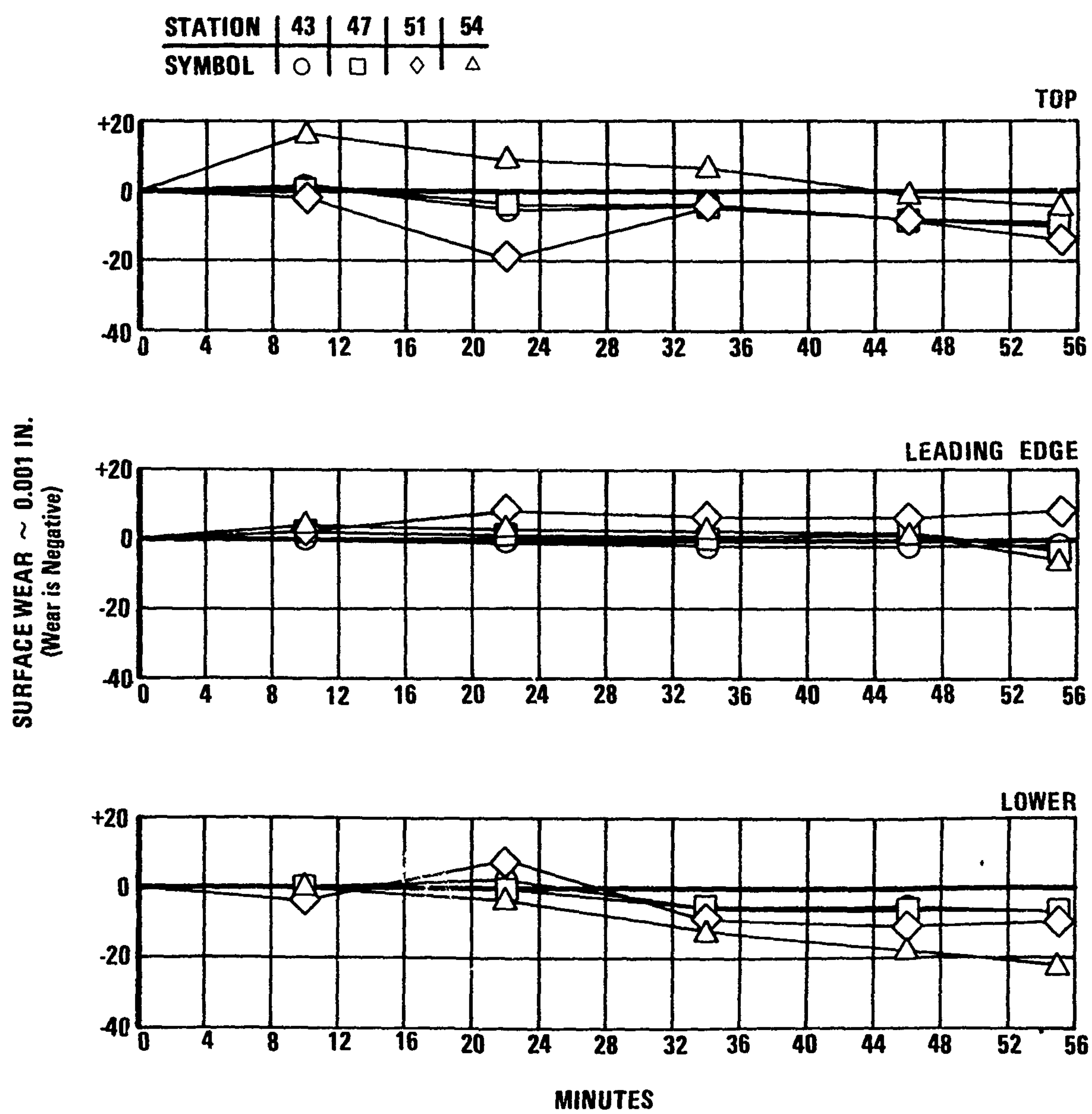


Figure 27. Sand Erosion Test - UHMWPE (Specimen No. 3)

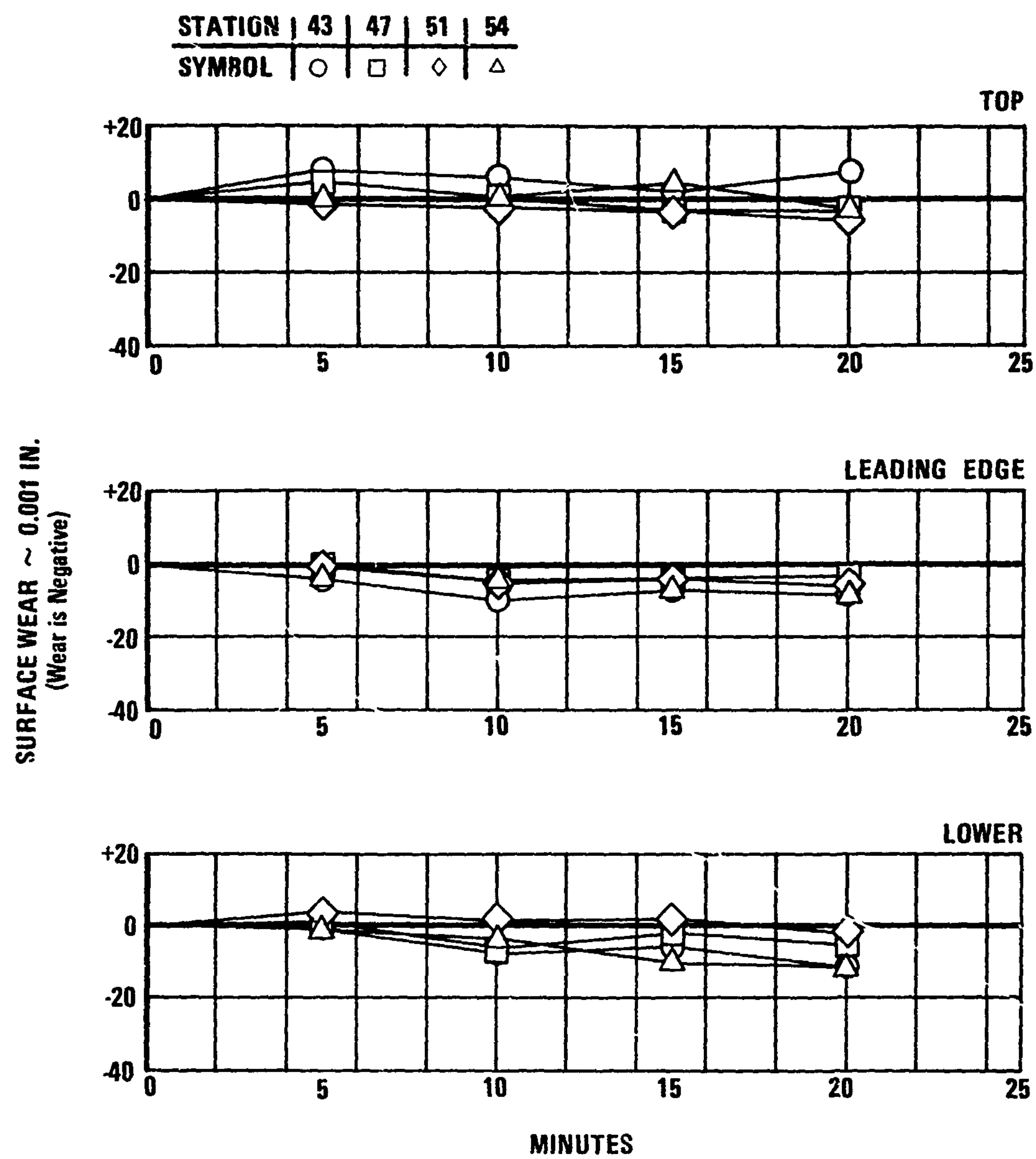


Figure 28. Rain Erosion Test - Polyurethane (Specimen No. 11)

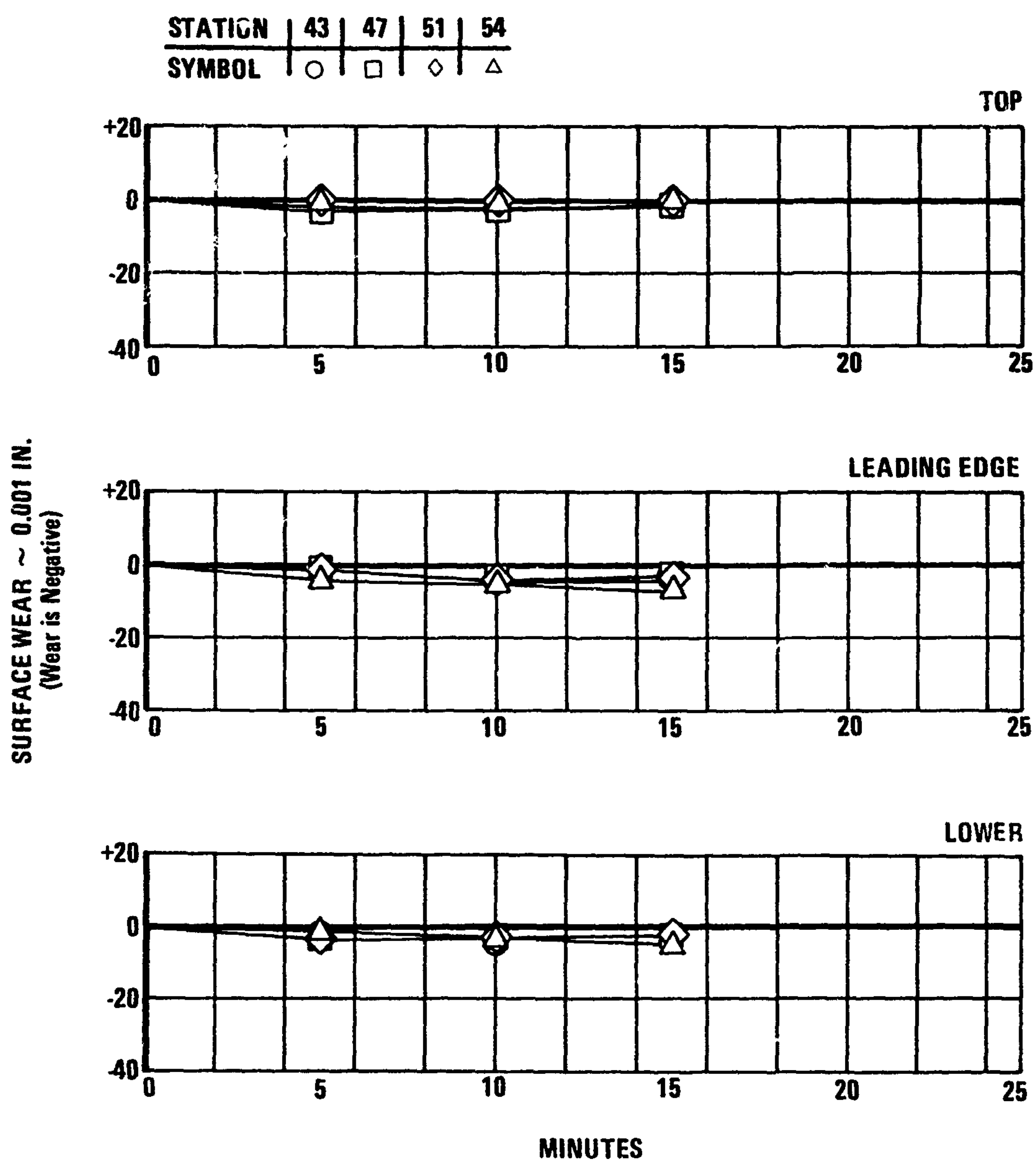


Figure 29. Rain Erosion Test - Polyurethane (Specimen No. 17)

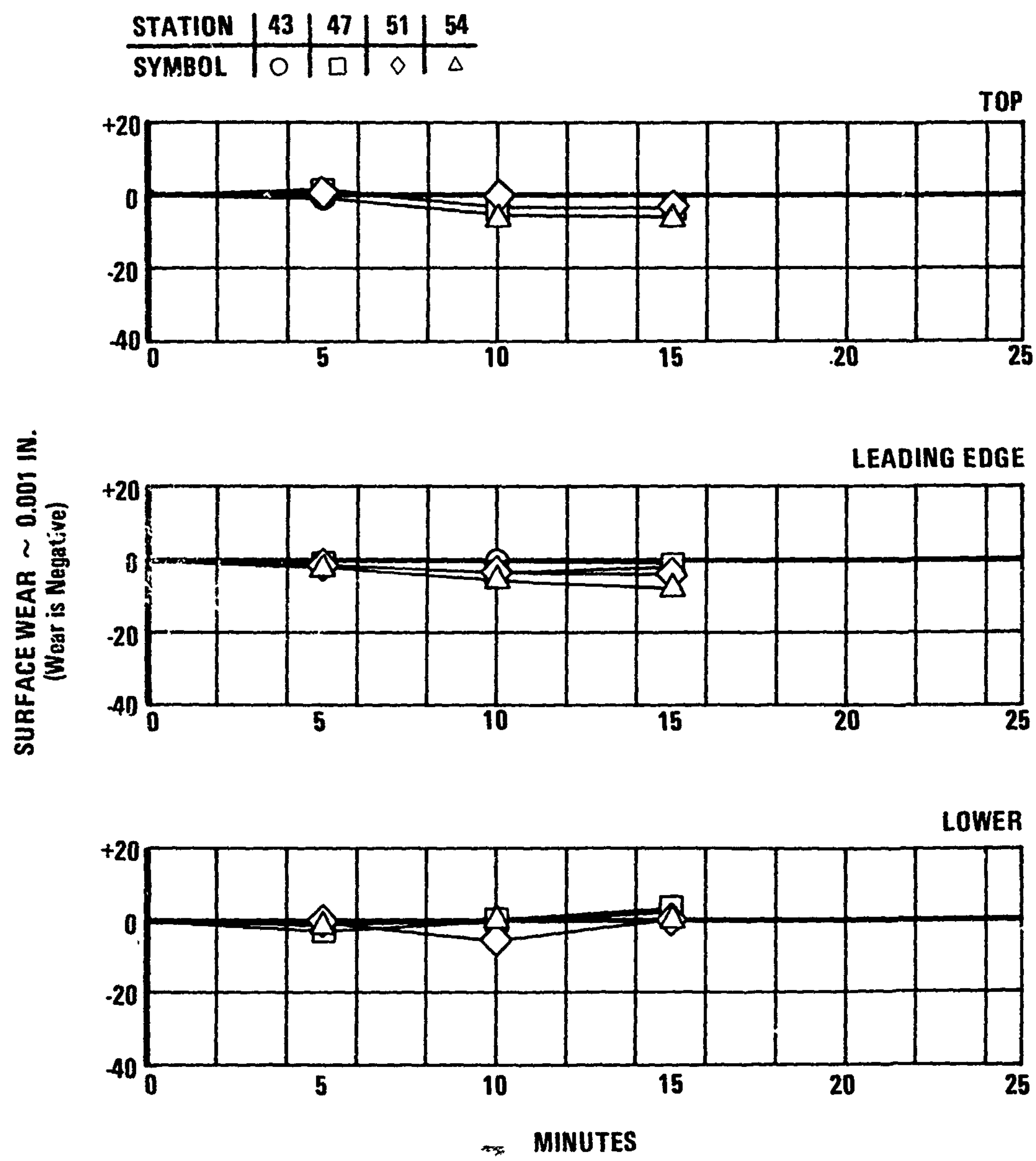


Figure 30. Rain Erosion Test - Polyurethane (Specimen No. 10')

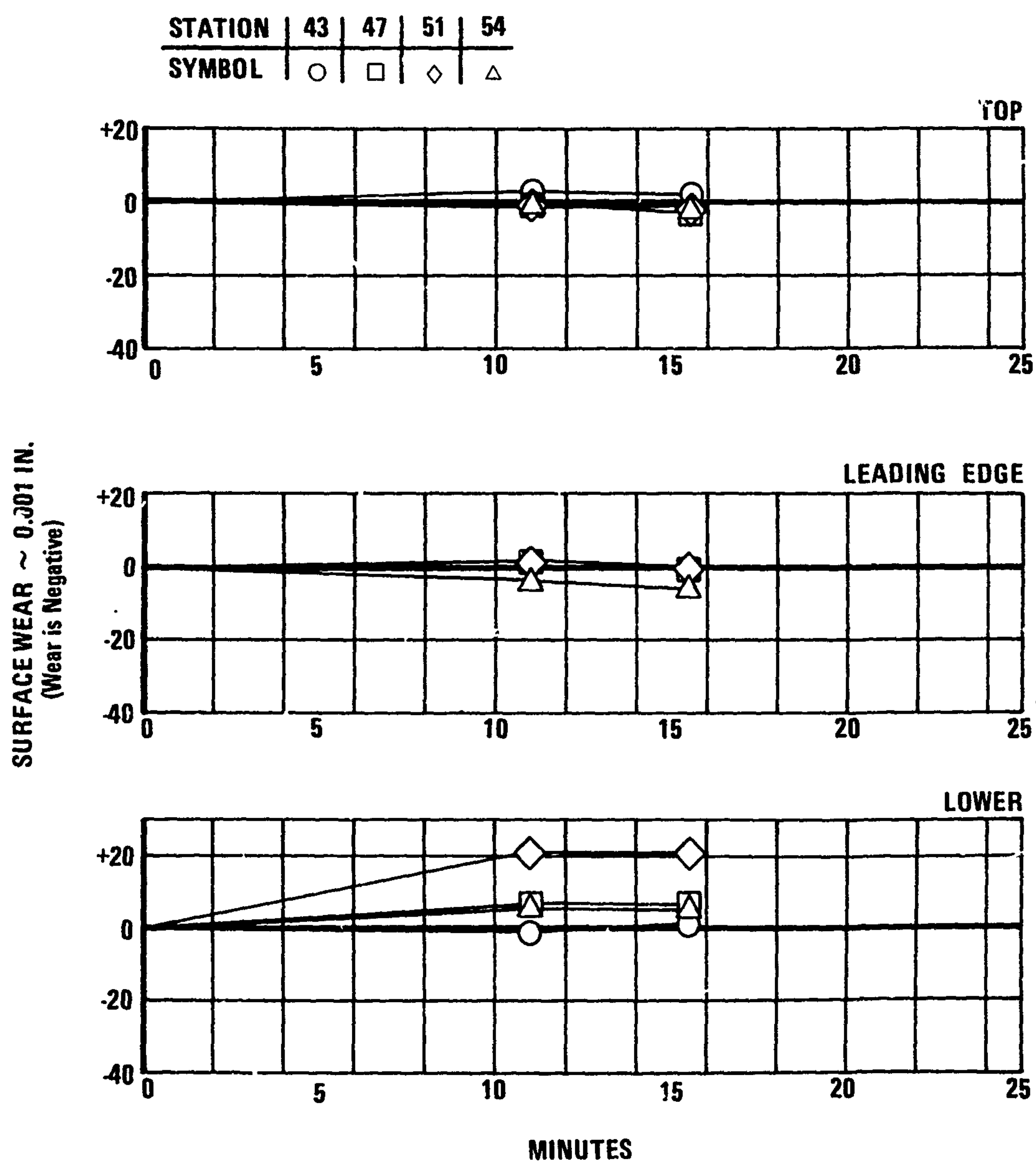


Figure 31. Rain Erosion Test - UHMWPE (Specimen No. 2)

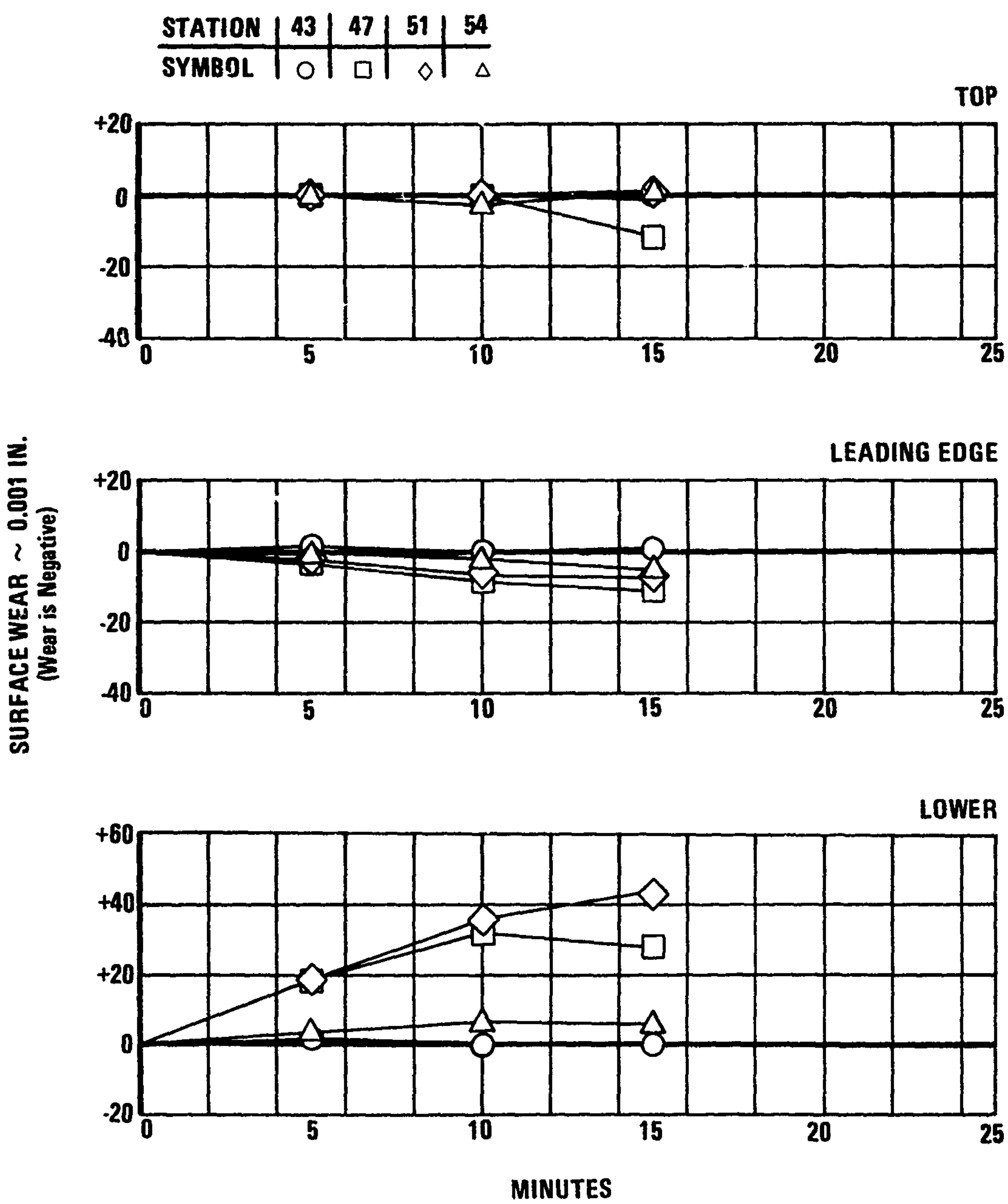


Figure 32. Rain Erosion Test - UHMWPE (Specimen No. 3')

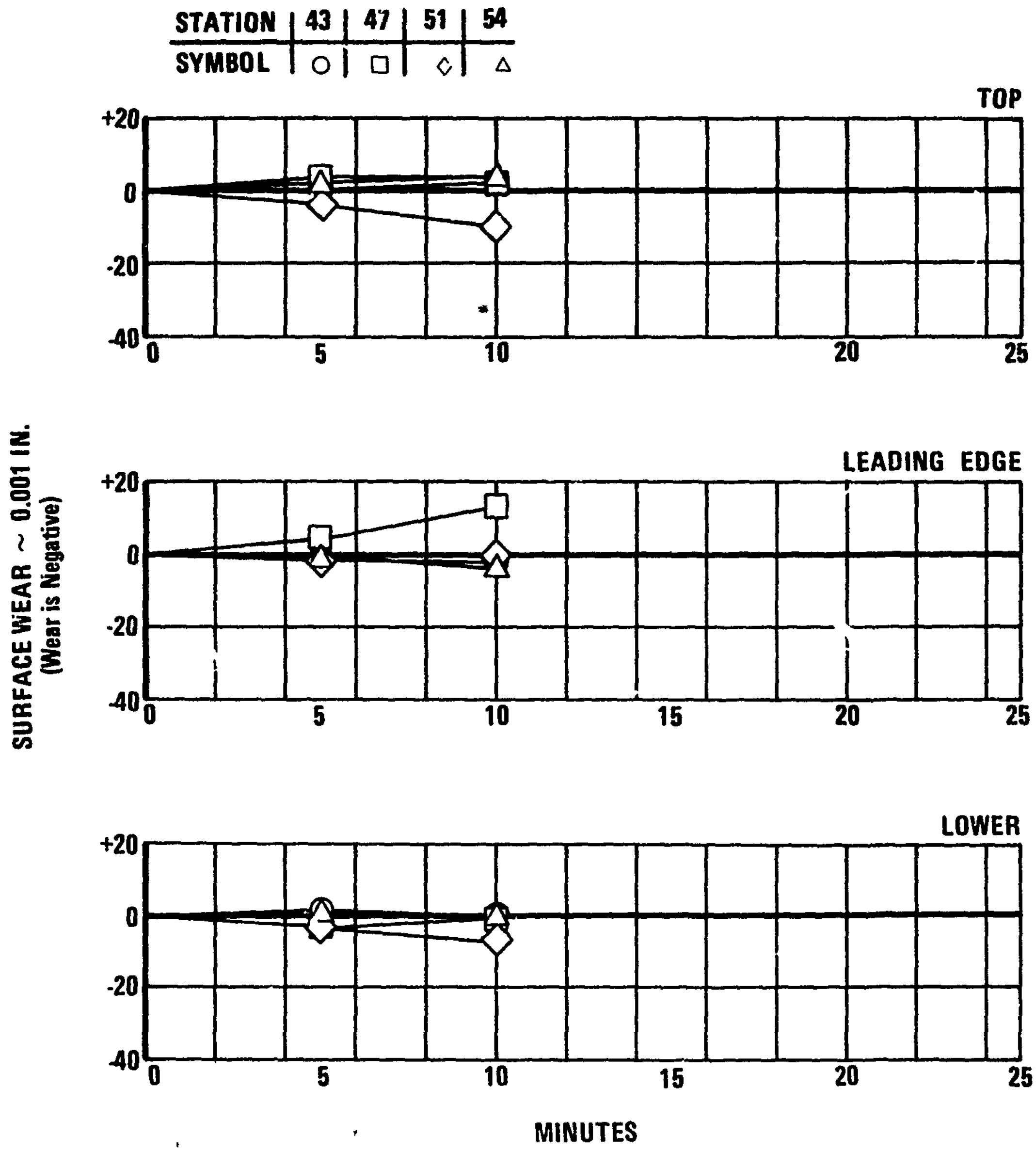


Figure 33. Rain Erosion Test - UHMWPE (Specimen No. 5')

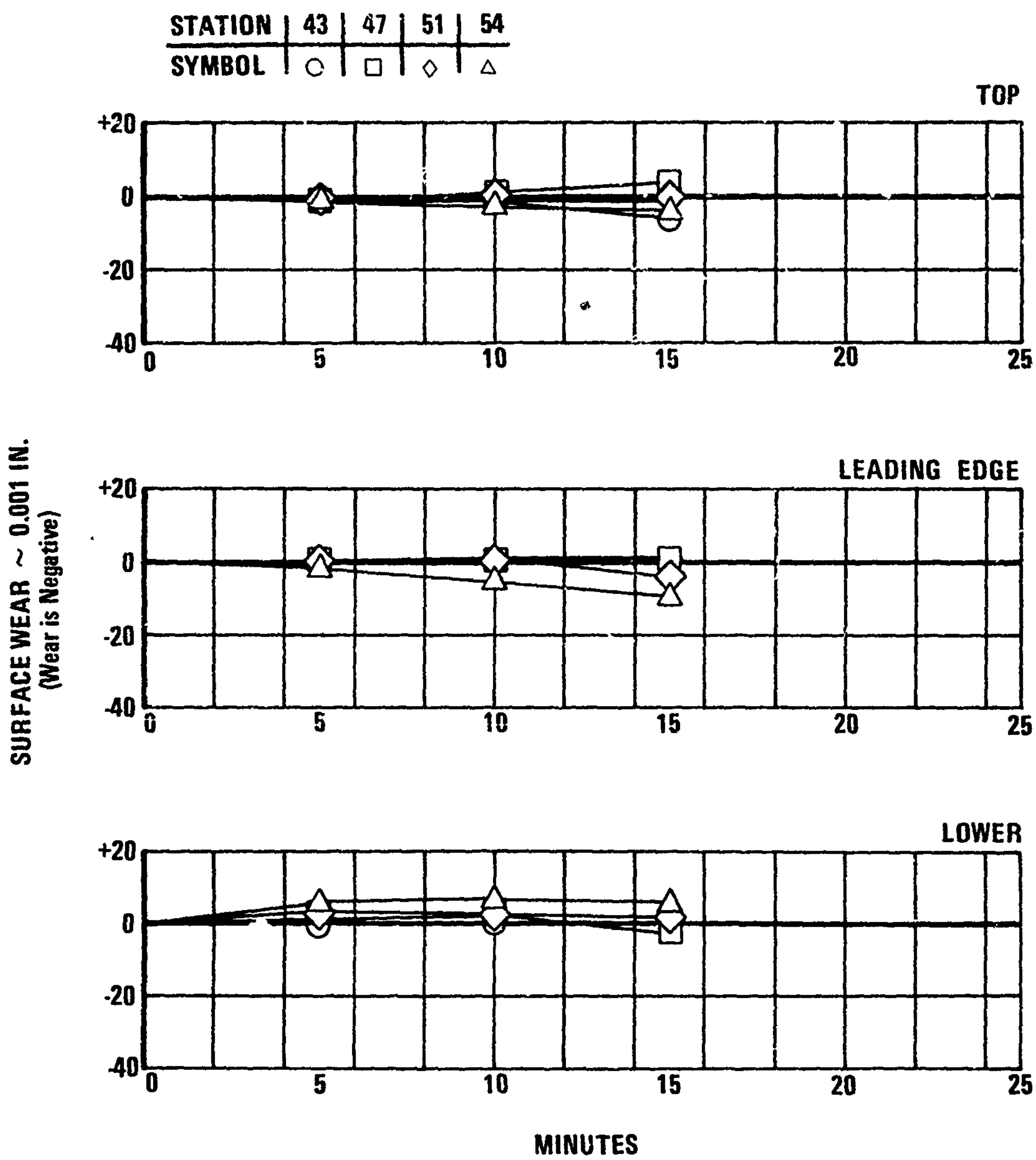


Figure 34. Rain Erosion Test - UHMWPE (Specimen No. 6')

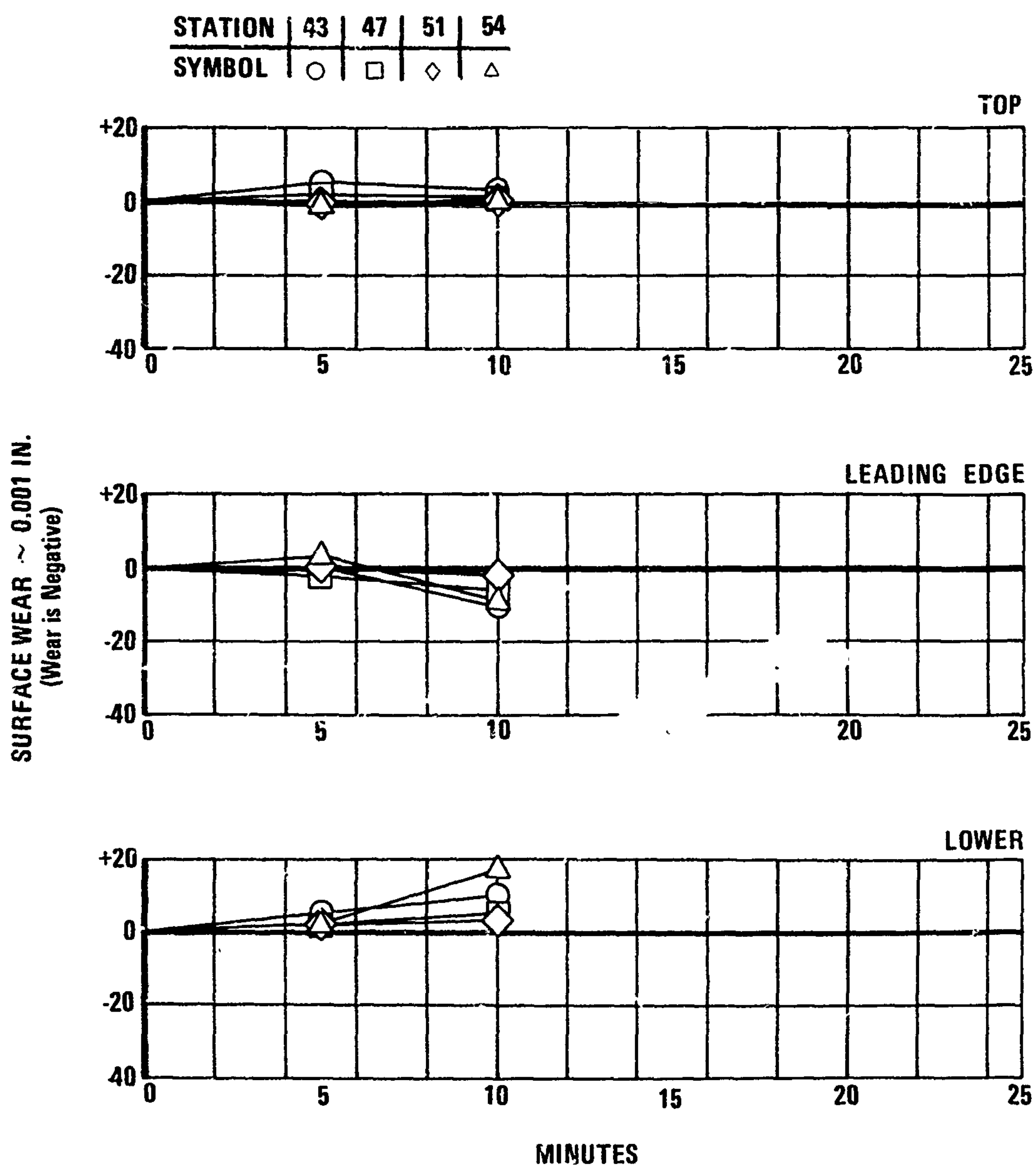


Figure 35. Rain Erosion Test - UHMWPE (Specimen No. 18)

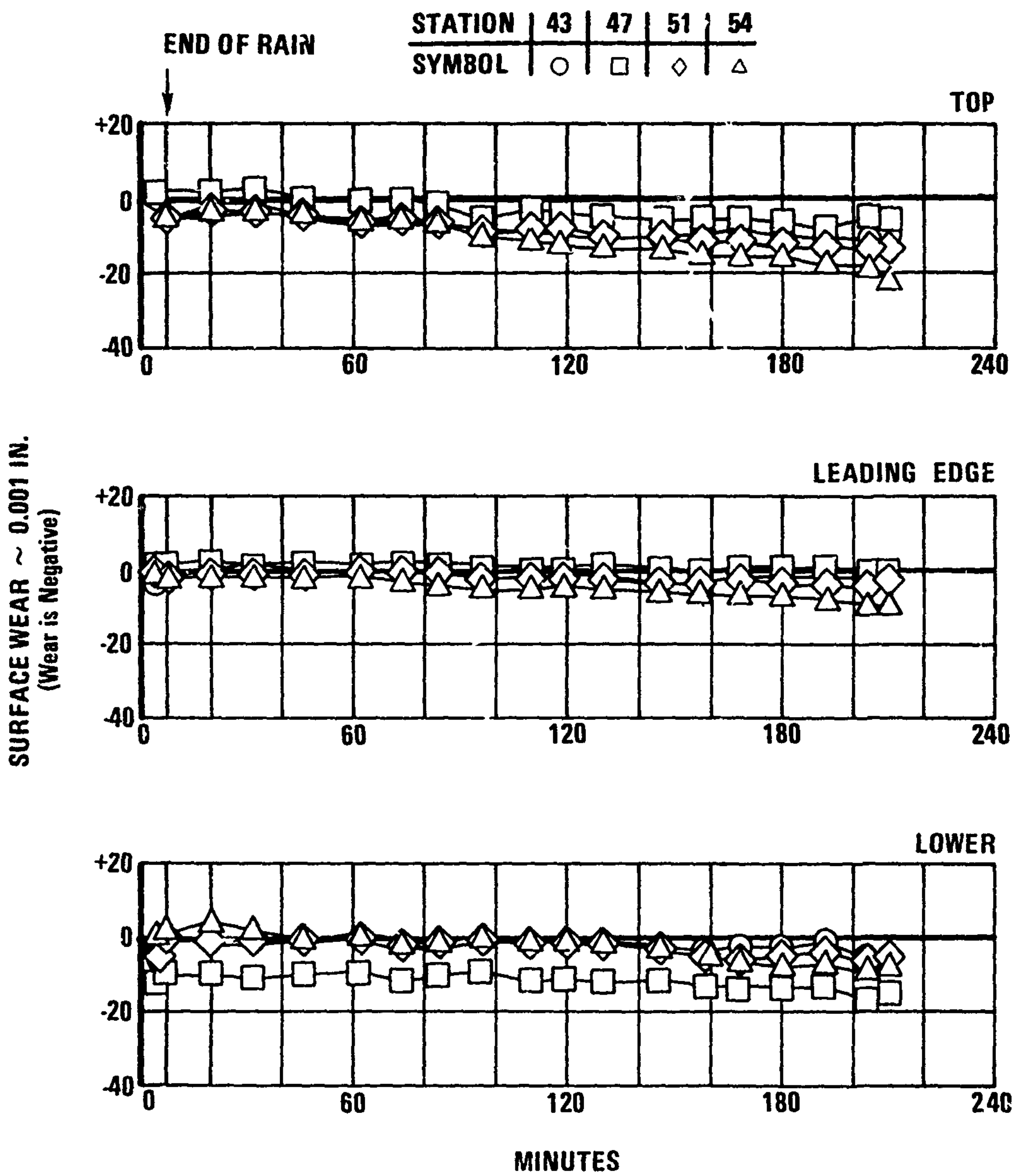


Figure 36. One-Half Life Rain, Remainder Sand Erosion Test - Polyurethane (Specimen No. 12)

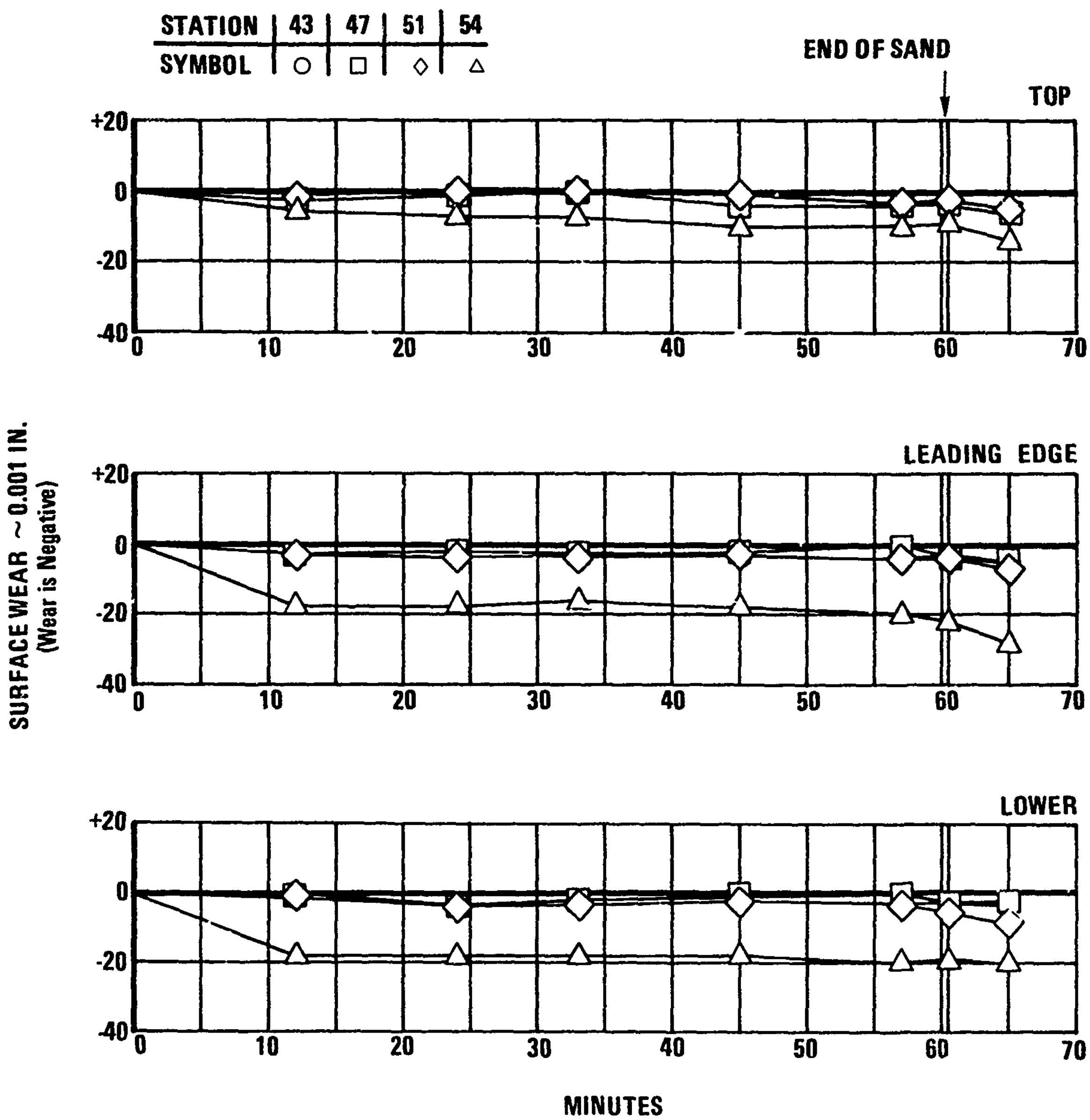


Figure 37. One-Half Life Sand, Remainder Rain Erosion Test - Polyurethane (Specimen No. 11')

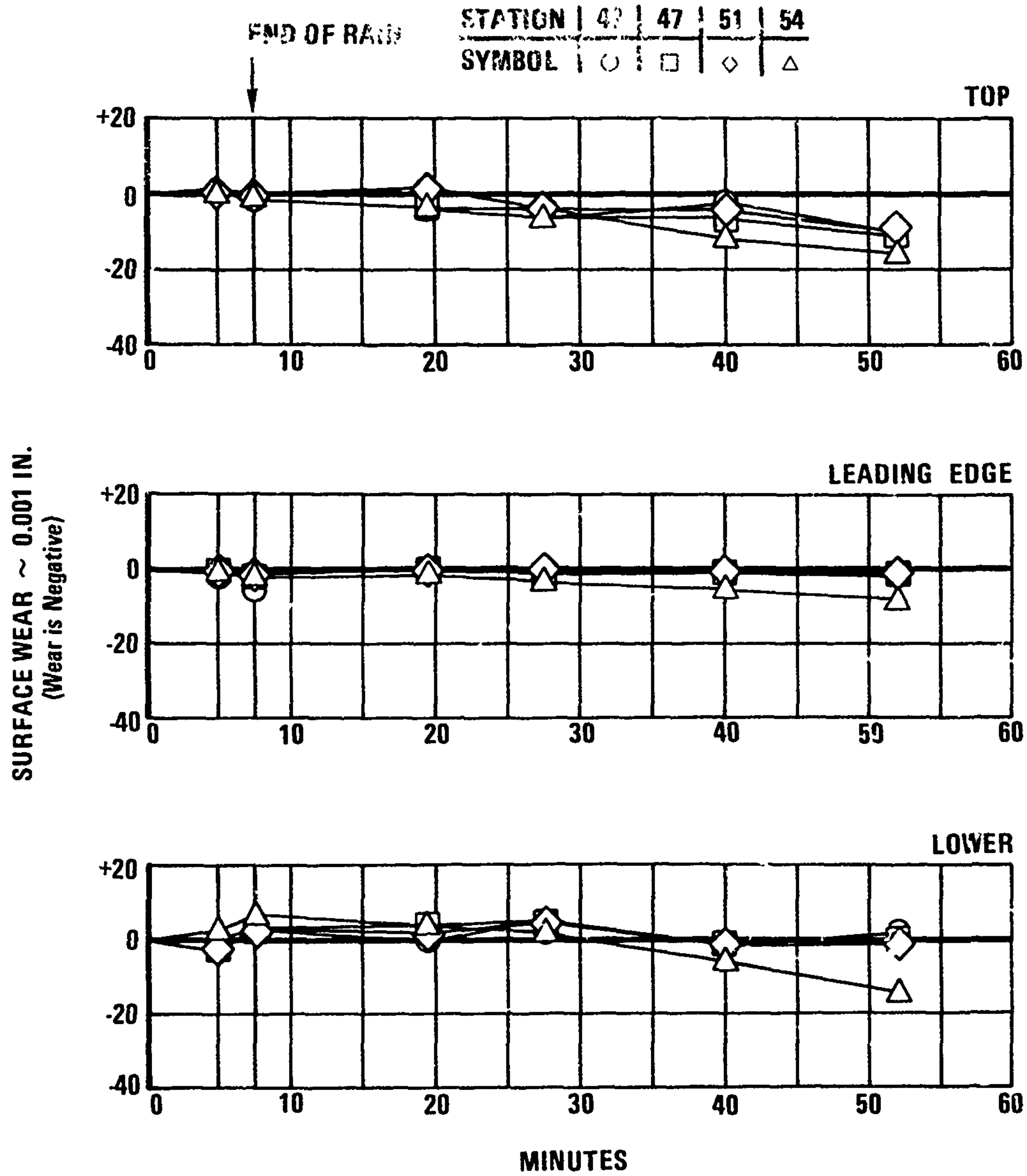


Figure 38. One-Half Life Rain, Remainder Sand Erosion Test - UHMWPE (Specimen No. 1')

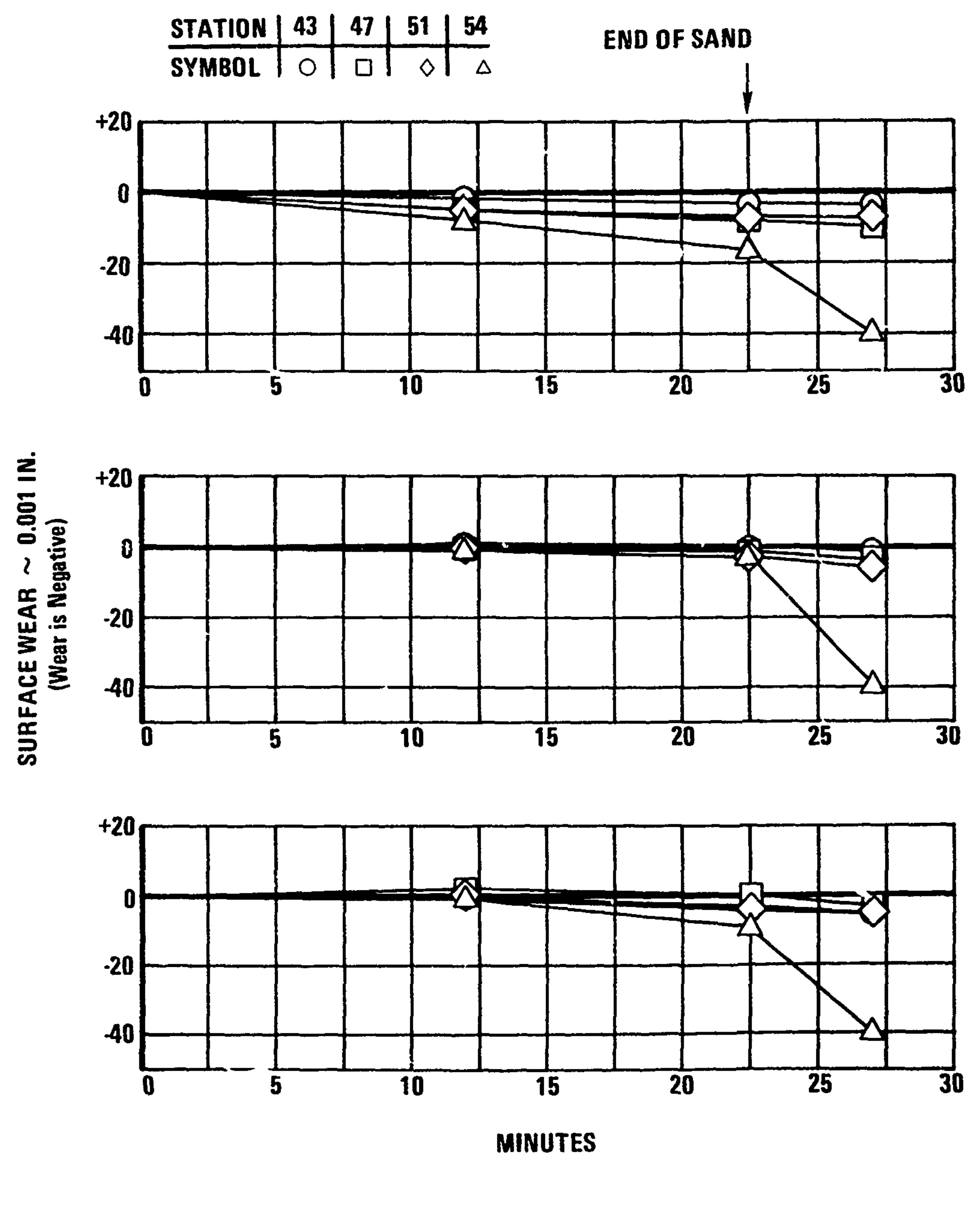


Figure 39. One-Half Life Sand, Remainder Rain Erosion Test - UHMWPE (Specimen No. 8')

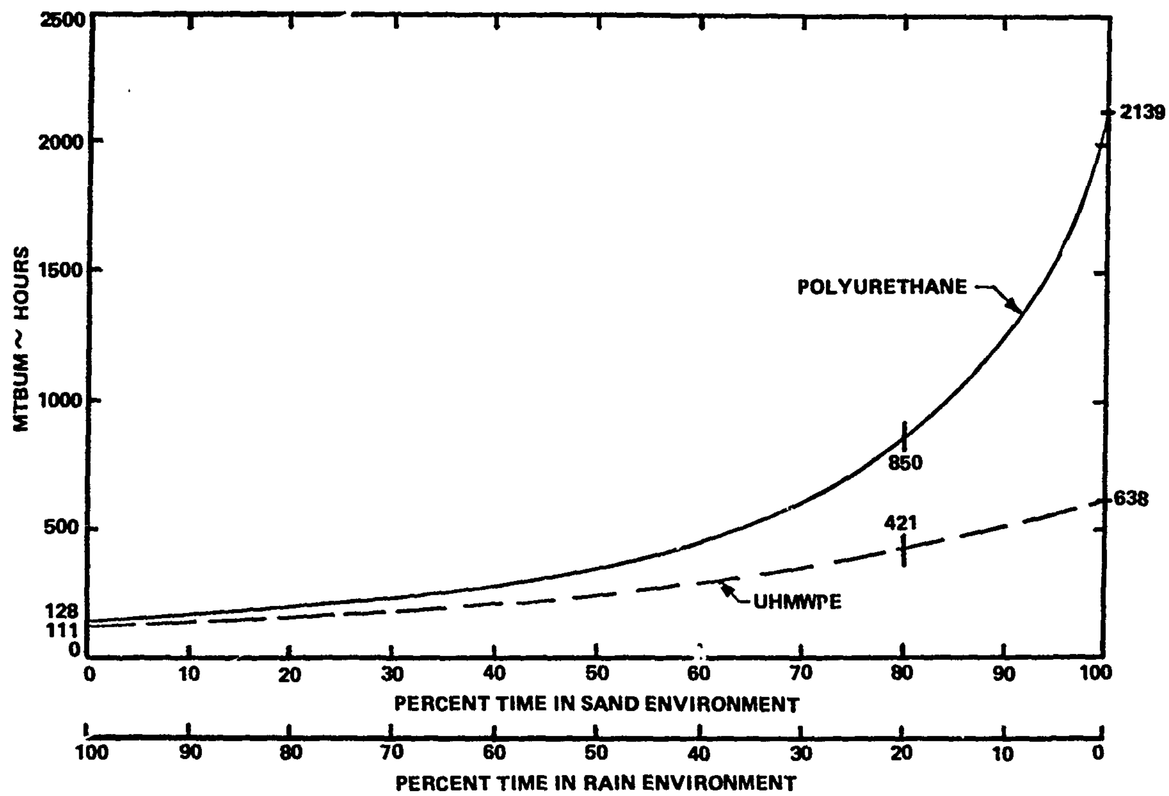


Figure 40. Anti-Erosion Material MTBUM in Sand and Rain Environments

SYMBOLS

GHz	frequency, gigahertz
RAM	radar absorbing material
RCS	radar cross section
MTS	multi-tubular spar
UHMWPE	ultra-high molecular weight polyethylene
L	Mean time between unscheduled maintenance (hours) for OH-6A main rotor blade with respect to erosion damage
MTBUM	Mean time between unscheduled maintenance (hours)
P	fraction of time rotor is exposed to a sand environment (as opposed to a rain environment)
U	elastomeric erosion material time until failure in a sand environment
V	elastomeric erosion material time until failure in a rain environment
X	OH-6A helicopter rotor time until failure in a sand environment
Y	OH-6A helicopter rotor time until failure in a rain environment
Kevlar-49	DuPont Corporation aramid filament
S-Glass	Ferro Corporation glass filament
t	erosion material thickness (inches)

REFERENCES

1. Graham, T. L., "High Temperature Stable Subsonic Rain Erosion Resistant Fluoroelastomer Boot Material Development," USAFML Technical Report 74-9, U. S. Air Force Material Laboratory, Dayton, Ohio. May 1974.