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A FUNDAMENTAL APPROACH TO THE STICKING OF INSECT RESIDUES TO AIRCRAFT WINGS

by

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I. SURFACE ROUGHNESS

INTRODUCTION

Since the informal report summarizing our presentation in November 1983, significant progress has been made in preparation for the road testing experiments to be run this spring and summer, when insect populations are high. The tests will provide data on the effects of surface energy and surface roughness on insect adhesion. The purpose of this (section) is to report on the work which has been done in the Mechanical Engineering Department since November and to make some projections of what work will be done in the future. A description of the proposed testing scheme will be given as will a description of the road test apparatus. Also, surface preparation techniques which have been investigated will be discussed.

TESTING SCHEME

The proposed testing scheme is to expose prepared test surfaces to insect impacts. This will be accomplished by fixing specimens to an apparatus which will be mounted on the roof of a car. Two primary variables, surface energy and surface roughness, will be studied in detail. A third variable, angle of impact of the insect, will be considered by using specimens which are semicircular in shape to simulate a wing leading edge. Four polymers (with surface energies varying from 45 to 10 dynes/cm) and four surface roughness values, ranging from 0.2 to 1.0 μm R_a, will be used to prepare the test surfaces. Also, a control surface for each of the four roughness values will be included in the test. Thus, a minimum of 20 surfaces will be tested in a single run. However, there is sufficient space on the experimental apparatus for 38 specimens. The dependent variables of interest will be insect impact density and the height of the insect debris.

DESIGN OF ROAD TEST APPARATUS

An apparatus has been constructed for collecting insect impact data on polymer-coated surfaces of varying roughness. A sketch of the experimental set-up is shown in Figure 1. The apparatus will be mounted on a canoe rack on the roof of a car in order to perform road tests on the prepared specimens. Two factors influenced the apparatus design. (1) The effects of the car's flow field must be minimized or eliminated from the test specimens, (2) the test surfaces must resemble a wing leading edge to account for the various angles at which insects impact an aircraft wing.

To minimize the effect of the car's flow field in the test specimens the apparatus was designed to position the test surfaces approximately 2 feet above the roof of the car. To simulate wing leading edge geometry, the specimens will be of a semicircular shape. This configuration will facilitate the study of the effects of angle of impact on insect adhesion. To achieve the semicircular shape, the specimens material will be very thin aluminum or steel sheet. The thin sheets will be wrapped around a 4" O.D. aluminum tube which has been cut lengthwise along a diameter. The specimens will be attached to the tube using screws or by folding the ends of the specimens under the edges of the tube and clamping the tube securely to the channel section. A possible specimen mounting configuration is shown in Figure 2.

Calculations have indicated that a 0.016 in. thick aluminum plate can be bent around the 4 in. diameter tube without yielding. Thus, the specimens can be bead blasted to create the desired surface finish and coated with the polymer while flat, and then bent around the tube for the field tests. After the tests and the specimens are removed from the test apparatus, they will return to their flat shape for data analysis.

PREPARATION OF TEST SURFACES

In order to study the effects of surface roughness on insect adhesion, it is necessary to have a range of surface roughnesses on which to correlate experimental data. The range of surface roughness of interest is from 0.2 to 1.0 μm R_a. To achieve the desired surface roughness, a sand or glass bead blasting technique has been studied. The use of very fine (G10 grade) glass beads as the blasting agent has been found to give a more uniform surface and a lower surface roughness than was possible with sand.

Glass bead blasting experiments on steel plate have been conducted by varying the flow pressure and the time of exposure of the bead stream to the test surface. The results show that a satisfactory surface roughness range can be obtained. Figure 3 shows curves of surface roughness against time of exposure for different flow pressures of the glass bead stream. It would be more desirable to use a material with a lower elastic modulus, such as aluminum, so that specimens can be more easily bent into a semicircular shape and then straightened back after testing for easier analysis. However, glass bead blasting of 1100 Aluminum sheet has not been satisfactory. The minimum surface roughness was found to be about 2.0 μm R_a. In an attempt to alleviate this problem, a harder aluminum alloy sheet, namely 7075-T6, will be investigated to determine if the desired surface roughness range can be achieved. This study will be performed when the necessary materials have been received.

FUTURE WORK AND CONCLUSIONS

The experimental apparatus has been constructed and is ready for the test.

The final specimen configuration will be determined when the bead blasting tests on the 7075-T6 aluminum plate have been completed. A possible method for measuring the depth of field using an LVDT.

II. SURFACE ENERGY

INTRODUCTION

This project aims to study the effect of surface energy on the sticking of insects to aircraft wings. The approach taken was to determine the critical surface tensions of polymer films cast on ferrotype plates and using similar plates to collect bug residues in a road test. In the latter case, prepared plates were mounted on top of automobiles. The plates were then analyzed for bug identity and density, and by SEM (scanning electron microscopy), ESCA (electron spectroscopy for chemical analysis) and IRS (infrared spectroscopy). The purpose of the latter three analyses is twofold: first, to determine if the characteristics of the plates cast in the lab change when they are exposed to the road environment, and second, to see if there is a difference in the way insect residues stick to the plate as a function of the surface energy of the cast polymer film. Plates coated with Nyebar and polysulfone have been partially analyzed and the preliminary results are presented below.

EXPERIMENTAL

Polymer Film Preparation - Polysulfone pellets were obtained from Union Carbide. A 3% (w/v) solution was prepared by dissolving the pellets in chloroform and shaking for 1 hour. A 0.2% solution of Nybar was obtained from the W. F. Nye Co. Both polysulfone and Nyebar solutions were cast to a 5 mil thickness on ferrotype plates for both lab and road tests. The plates were air dried for 24-48 hours to evaporate the solvent completely. Prepared samples were kept in sealed containers and stored in a dessicator until ready for use.

Contact Angles - Contact angles were measured on the polymer coated plates using a series of ethanol/water solutions. The surface tensions of the solution were determined by the capillary rise method as described by Daniels et al. (1). To measure the contact angle, the sample was placed in an environmental chamber which was saturated with the vapor of the liquid being used. Droplets of approximately 5-6 mm in diameter were deposited on the substrate and the contact angle was measured using a Rame Hart 100-00 contact angle goniometer. Five replications were done for each sample and an average was taken.

Road Test - To collect bug residues, ferrotype plates were mounted on top of automobiles for 6-12 hour trips. For each trip, a polymer coated and an uncoated plate were mounted with the uncoated plate serving as the control for that trip. Test conditions for the different trips are given in Table I.

Bug Density - Bug density on the plate was determined by random sampling. A grid with squares measuring 13 x 13 cm was laid over the plate. The squares were assigned numbers according to row and column. A random number table was then used to determine which squares should be chosen for counting. Ten boxes were chosen and the bug debris counted under a microscope. The debris were classified as (i) bug parts, (ii) whole bugs, (iii) bug splats, (iv) bug parts and splats and (v) whole bugs and splats. The densities were calculated by dividing the number of bugs by the total area measured (1690 cm^2).

ESCA, IR - Samples of unexposed polymer coated plates and samples taken from different areas of the bug plates were analyzed by ESCA and IR. ESCA analysis was done using a Kratos XSAM electron spectrometer. Reflectance infrared spectra were obtained using a Perkin-Elmer 283B spectrophotometer.

SEM - Different areas on the bug plates were chosen for SEM analysis. These samples were sputter coated with gold for 35 seconds before SEM photomicrographs were taken using a JEOL microscope.

RESULTS

Contact Angles - The values for the surface tensions of the ethanol/water solutions and contact angles for Nyebar and polysulfone coated plates are listed in Table II. For each polymer, the contact angle decreased as the surface tension of the solution decreased. The critical surface tension of the polymer coating was determined by plotting cosine of the contact angle (θ) versus surface tension (γ_{liq}) as shown in Figure 4. The best straight line through the data points was determined by linear regression. Values for the critical surface tension are the values of surface tension corresponding to cos θ equal to 1 obtained by extrapolation. These values are listed in Table III and are in good agreement with values on similar systems reported in the literature.

Bug Identity - Dr. John Eaton of the Department of Entomology at Virginia Tech identified the bugs according to class, order and family. The results are given in Table IV. It can be noted that for the different trips and the two polymer coatings 95% of the bugs belong to the order Diptera. These insects measure no more than 5 mm and are thus considered small.

Bug Density - Results for bug counts and densities are shown in Tables V and VI respectively. Only the numbers for bug parts and for splats are given as they comprise the bulk of the debris. The total of these two types of bug residues show that there is less debris on the polymer coated plates than on the uncoated ones. This is not an unexpected result since the polymer films have lower surface energy than the bare ferrotype plates.

ESCA - ESCA results are given in Tables VII-X for the uncoated and coated plates both unexposed and exposed. Table VII gives the atomic percentages and the binding energies of the elements detected in the samples analyzed. Note the appearance of nitrogen in samples where bug debris is present. This indicates that nitrogen, presumably from residual amino acids in the bug, can be used as a tag element for bug residues.

Tables VIII-X list the C/O ratios for the ferrotype plates, polysulfone coated plates and Nyebar coated plates respectively. These values show that although there is carbon contamination from road exposure, the oxygen percentages also change so that the C/O ratios do not vary appreciably. A change in the ratio should be at least two times to be considered significant.

The three samples all have elements the concentration of which would be expected to remain constant if significant contamination does not occur. For the ferrotype plate, the element is chromium; for polysulfone, sulfur; and, for Nyebar, fluorine. The ratio of C/Cr, C/S and C/F can thus serve as gauges for contamination. Values of these ratios listed in Tables VIII-X support the results above which indicate that contamination was not significant even on plates exposed to road conditions. This conclusion is all the more surprising since the effective sampling depth of ESCA is only 5 nm.

IR - Analysis by IR has been completed for polysulfone. Figure 5 is a spectrum of freshly cast polysulfone coated plate. Fig. 6 is the spectrum of a sample taken from a polysulfone coated plate that was tested on the road.

A comparison of the two spectra shows that there is no qualitative change in the polymer film after exposure to road conditions. Again, the IR results are consistent with the ESCA results in that no significant contamination of the polysulfone coated plates has occurred. The structure and peak assignments for this polymer are given in Table V.

SEM - SEM is being used to determine if differences in surface energy of the polymer films will show up as differences in the way bug splats and residues wet the surface. SEM photomicrographs of typical debris are given in Figures 7 and 8. Figure 7 shows representative areas on polysulfone coated plates and Figure 8 shows examples of bug residues on Nyebar coated plates. The bug debris appears to wet the polysulfone coated plates better than the Nyebar.

SUMMARY

A detailed analysis of uncoated and polymer coated metal substrates has been made before and following collision with insects. Critical surface tensions of unexposed Nyebar and polysulfone coatings were 10. and 33. dynes/cm, respectively as determined from contact angles. 95% of insect residues collected belong to order Diptera. Significantly less insect debris was detected on the coated plates compared to the uncoated plates. Coated and uncoated plates before and after exposure to insect collisions were analyzed by SEM/ESCA/IRS. Wetting of the polymer coating by insect residues was gauged qualitatively from SEM. Minimal contamination at the 5 nm level of both uncoated and coated plates occurs even after hours of exposure to road conditions as determined by ESCA analysis. The presence of nitrogen detected by ESCA on exposed plates is unequivocal evidence for insect residues left on plates.

LITERATURE CITED

(1) Daniels, F., J. H. Matthews and J. W. Williams, Experimental Physical Chemistry, McGraw-Hill, Inc., New York (1941).

(2) Kang, Yoonok, Characterization of Polymeric Membranes: Sulfonated Polysulfones, Ph.D. Dissertation, VPI & SU (1981).

TABLE I

ROAD TEST CONDITIONS

Polymer coating	Conditions
1. Polysulfone	22 July 1983: No rain Blacksburg to Naxera Leave: 5:30 PM Arrive: 12:00 AM JPW car
2. Nyebar I	12 August 1983: No rain Blacksburg to Naxera Leave: 1:30 PM Arrive: 6:30 PM JAF car
3. Nylon	09 September 1983: No rain Blacksburg to Naxera Leave: 4:30 PM Arrive: 11:30 PM JPW car
4. Nyebar II	10 September 1983: No rain, cool, damp Blacksburg to Bethany Beach, DE (via Eastern shore) Leave: 5:30 PM Arrive: 5:20 AM HFW car

TABLE II

CONTACT ANGLES OF LIQUIDS ON POLYMER COATINGS

$EtOH/H_2O$	Surface Tension (dyne/cm)	Nyebar		PSF	
		Right	Left	Right	Left
H_2O	71.8	112.8	113.6	85.2	86.0
10/90	55.4	108.7	107.4	78.5	79.6
30/70	53.3	93.2	93.6	66.8	66.4
50/50	45.1	86.0	86.0	57.3	56.6
60/40	42.8	82.9	83.1	43.8	43.8
70/30	42.9	78.5	78.5	36.1	35.9

TABLE III

CRITICAL SURFACE TENSIONS OF POLYMER COATINGS

Polymer	γ_c (dyne/cm)
Polysulfone	33.2
Nyebar	10.0

TABLE IV

BUG IDENTIFICATION ON EXPOSED PLATES

CLASS INSECTA

DISTRIBUTION ORDER PLATE	4% HOMOPTERA	< 1% HEMIPTERA	< 1% TRICHOPTERA	95% DIPTERA	< 1% EPHMEROPTERA	< 1% LEPIDOPTERA
1. PSF	Aphidae Alerdidae			Chironomidae Cecidomidae Chlicoides Chloropidae		
2. PSF Control	Aphidae Cicadelldae		Hydroptilidae	Maseidae Chironomidae Cecidomiidae Colicidae Tipalidae Chloropidae	Heptageniidae	
3. Nyebar I	Aphidae			99% Simuliidae Cecidomiidae Chironomidae Mycetophilidae Ceratopogonidae		
4. Nyebar I Control	Aphidae	Miridae				
5. Nylon				100% Ceratp]pgpmodae Simuliidae Chironomidae		
6. Nylon Control				Ceratopogonidae		
7. Nyebar II				Cecidomiidae Cullicoides Chironomidae		
8. Nyebar II Control				Cecidomiidae Culicoides Psychodidae		

TABLE V

BUG COUNT ON EXPOSED PLATES

	Plate	Bug parts	Splat	Total
1.	PSF	91	22	113
2.	PSF Control	73	81	154
3.	NYEBAR I	40	21	61
4.	NYEBAR I CONTROL	71	35	106
5.	NYLON	41	8	49
6.	NYLON CONTROL	86	25	111
7.	NYEBAR II	30	21	51
8.	NYEBAR II CONTROL	78	18	96

TABLE VI

BUG DENSITY ON EXPOSED PLATES

	Plate	Bug part density (#/cm^2)	Splat density (#/cm^2)	Total density(#/cm^2)
1.	PSF	0.054	0.013	0.069
2.	PSF CONTROL	0.043	0.048	0.091
3.	NYEBAR I	0.024	0.012	0.036
4.	NYEBAR I CONTROL	0.042	0.021	0.063
5.	NYLON	0.024	0.0047	0.0287
6.	NYLON CONTROL	0.051	0.015	0.066
7.	NYEBAR II	0.018	0.012	0.030
8.	NYEBAR II CONTROL	0.046	0.011	0.057

TABLE VII

ESCA ANALYSIS OF COATED AND EXPOSED PLATES

Sample	Photopeak											
	C 1s		O 1s		N 1s		Cr 2p3		S 2p		F 1s	
	A.P.	BE(eV)	A.P.	BE(eV)	A.P.	BE(eV)	A.P.	BE(eV)	A.P.	BE(eV)	A.P.	BE(eV)
CLEAN FERROTYPE	67.7	284.5	27.6	530.9	-	-	3.21	576.6	1.5	167.4	-	-
NBII C1 (NBS)*	76.9	284.5	21.2	531.7	-	-	1.92	577.4	-	-	-	-
NBII C2 (BS)	75.0	284.5	20.3	531.5	1.81	399.4	1.62	576.9	1.23	168.3	-	-
PSF C1 (BS)**	70.7	284.5	22.2	531.8	2.01	399.4	2.85	576.8	0.92	168.3	-	-
PSF C2 (BS)	73.0	284.5	21.6	531.7	1.72	399.9	2.99	577.2	0.69	168.4	-	-
PSF C3 (NBS)	71.4	284.5	24.3	531.7	-	-	3.30	577.6	1.04	168.9	-	-
CLEAN NYEBAR	57.0	284.5	9.8	533.2	-	-	-	-	-	-	33.0	689.8
NBII 1 (NBS)	63.2	284.5	11.6	532.1	-	-	-	-	0.23	168.8	25.0	688.9
NBII 2 (NBS)	56.0	284.5	11.1	532.6	-	-	-	-	-	-	32.9	689.2
NBII 3 (BS)	62.1	284.5	11.1	532.0	-	-	-	-	-	-	26.8	690.4
CLEAN PSF	83.7	284.5	13.5	532.3	-	-	-	-	2.2	167.2	-	-
PSF 1 (NBS)	89.1	284.5	9.7	532.1	-	-	-	-	1.24	167.6	-	-
PSF 2 (NBS)	86.3	284.5	12.9	531.9	-	-	-	-	0.78	167.2	-	-
PSF 3 (BS)	86.3	284.5	13.1	532.0	-	-	-	-	0.57	167.9	-	-

*NYEBAR II CONTROL 1 (NO BUG SPLAT) **POLYSULFONE CONTROL 1 (BUG SPLAT)

TABLE VIII

ESCA ATOMIC RATIOS FOR FERROTYPE PLATES

Sample	C/O	C/Cr
FERROTYPE PLATE	2.4	21.1
NBII C1	3.6	40.1
NBII C2	3.7	46.3
PSF C1	3.2	24.8
PSF C2	3.4	24.4
PSF C3	2.9	21.6

TABLE IX

ESCA ATOMIC RATIOS FOR POLYSUYLFONE COATED PLATES

Sample	C/O	C/Cr
POLYSULFONE	6.2	38.0
PSF 1	9.2	71.9
PSF 2	6.7	110.6
PSF 3	6.6	150.9

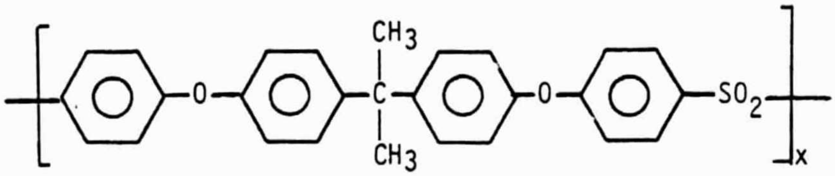
TABLE X

ESCA ATOMIC RATIOS FOR NYEBAR COATED PLATES

Sample	C/O	C/Cr
NYEBAR	5.8	1.7
NBII 1	5.5	2.5
NBII 2	5.1	1.7
NBII 3	5.6	2.3

TABLE XI (2)

IR PEAK ASSIGNMENTS FOR POLYSULFONE COATED PLATE



Wave number (cm^{-1})	Assighment
3000	AROMATIC C-H STRETCHING VIBRATIONS
1590, 1510, 1490	AROMATIC C=C STRETCH
1410	ASYMMETRIC C-H BENDING DEFORMATION OF CH_3
1330	ASYMMETRIC O=S=O STRETCHING
1300	ASYMMETRIC O-S-O STRETCH
1250	ASYMMETRIC C-O-C STRETCHING OF ARYL ETHER
1180	ASYMMETRIC O=S=O STRETCH
1150	SYMMETRIC O=S=O STRETCH
1080	AROMATIC RING VIBRATIONS
1020	SYMMETRIC O=S=O STRETCH
700-560	C-S STRETCHING VIBRATIONS

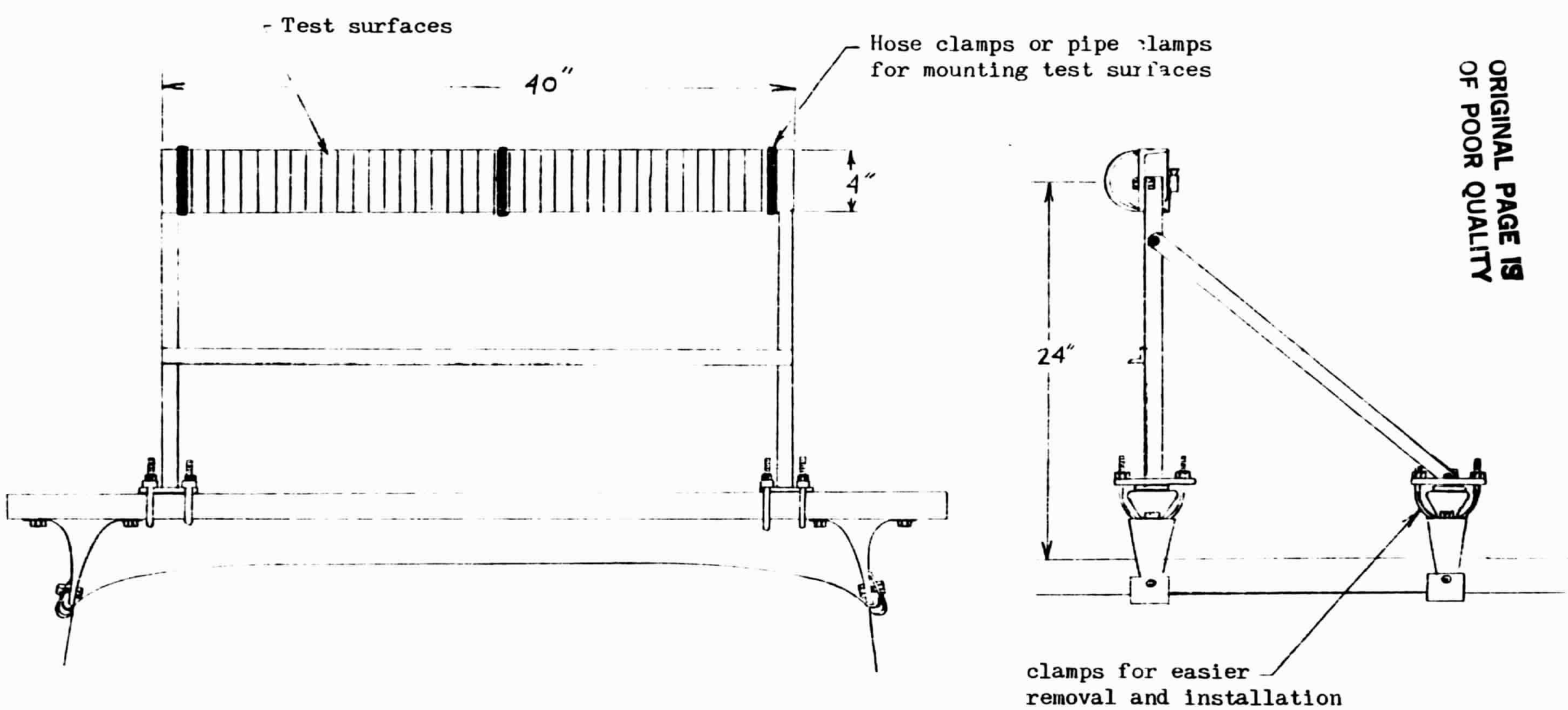


Figure 1. Front and side views of the experimental set-up. The frame is of welded aluminum construction for light weight.

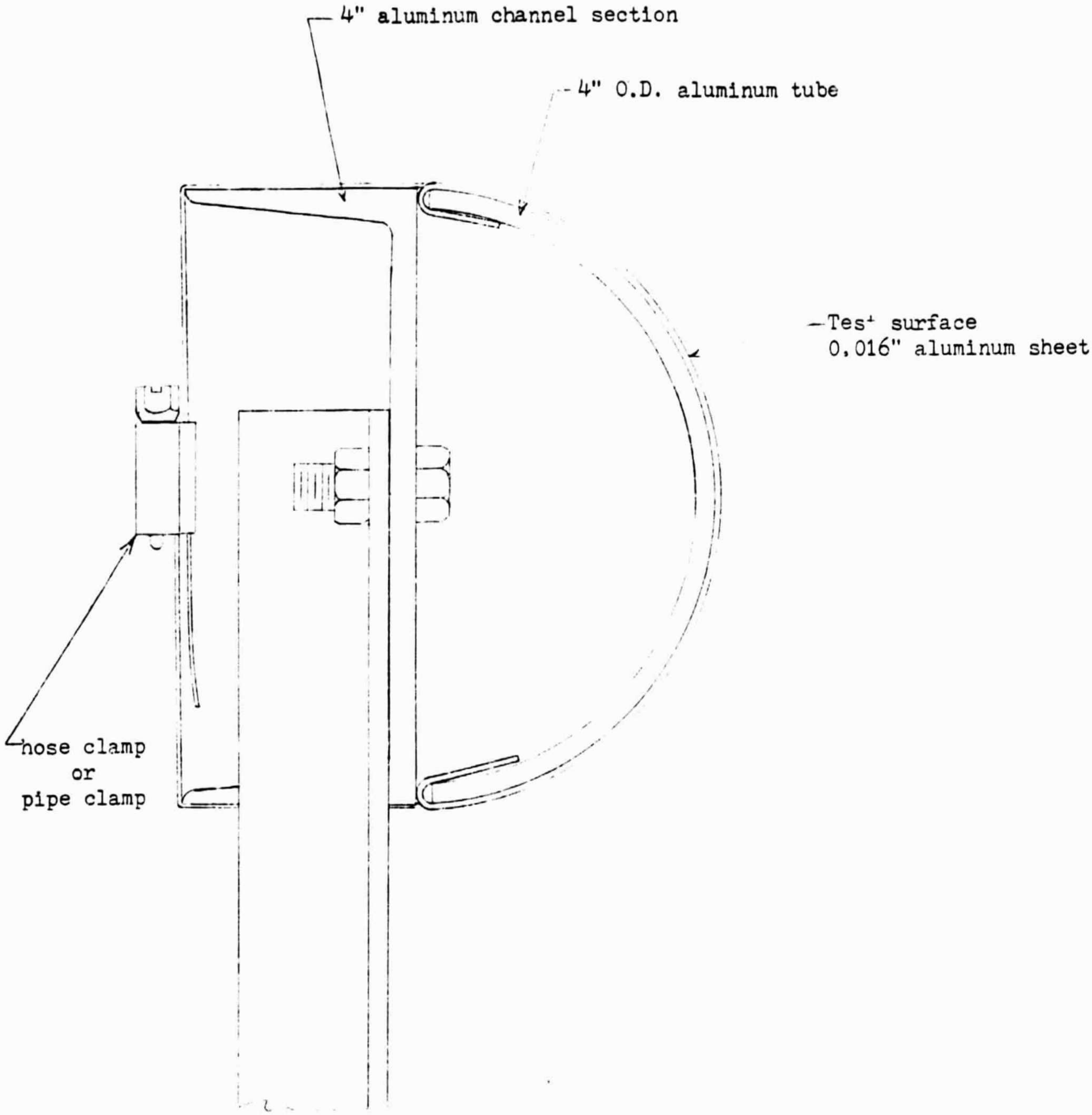


Figure 2. Possible specimen mounting configuration, side view.

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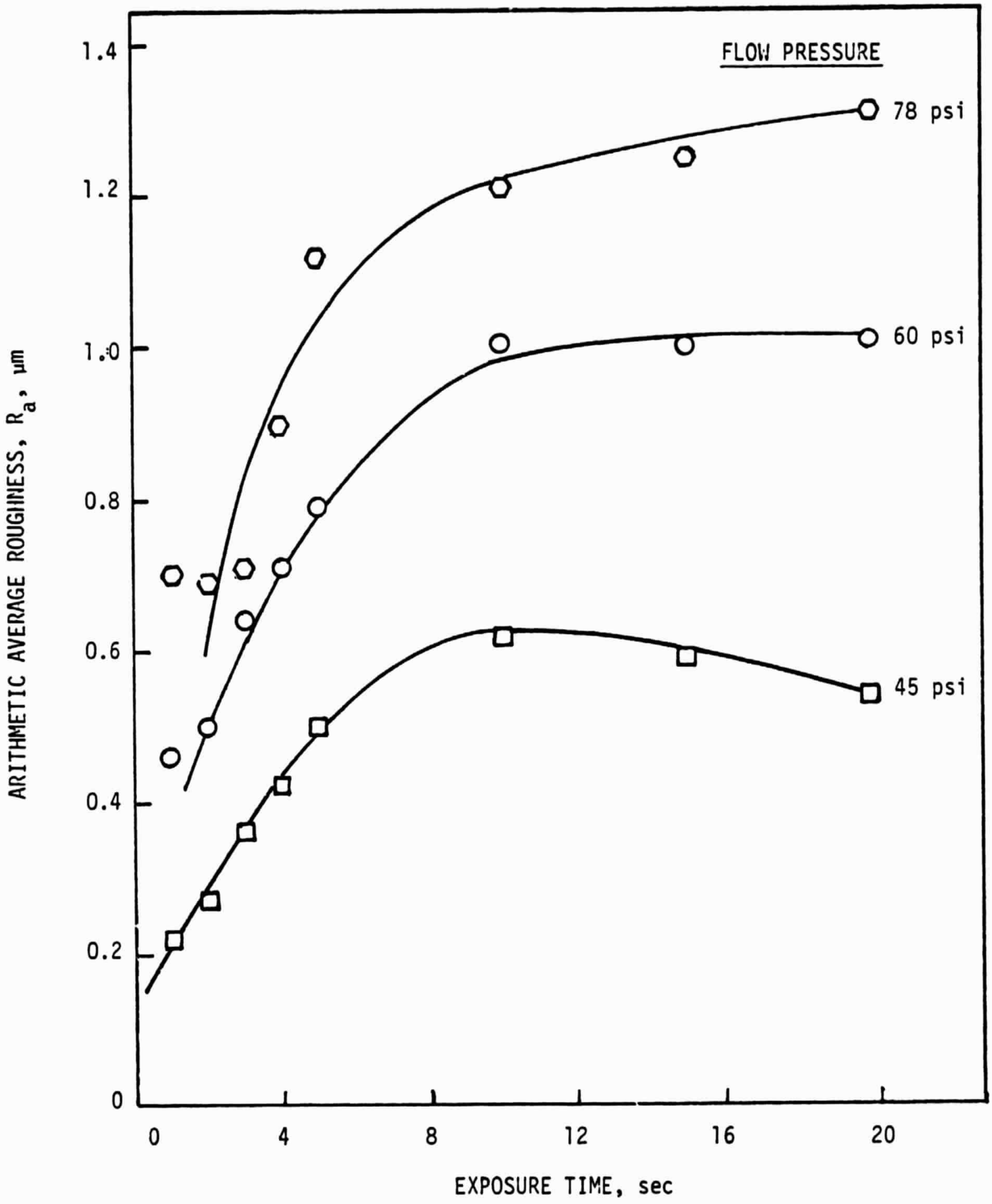

Figure 3. Results of glass bead blasting experiments on steel plate showing the effects of flow pressure and time of exposure of the bead stream on the surface roughness.

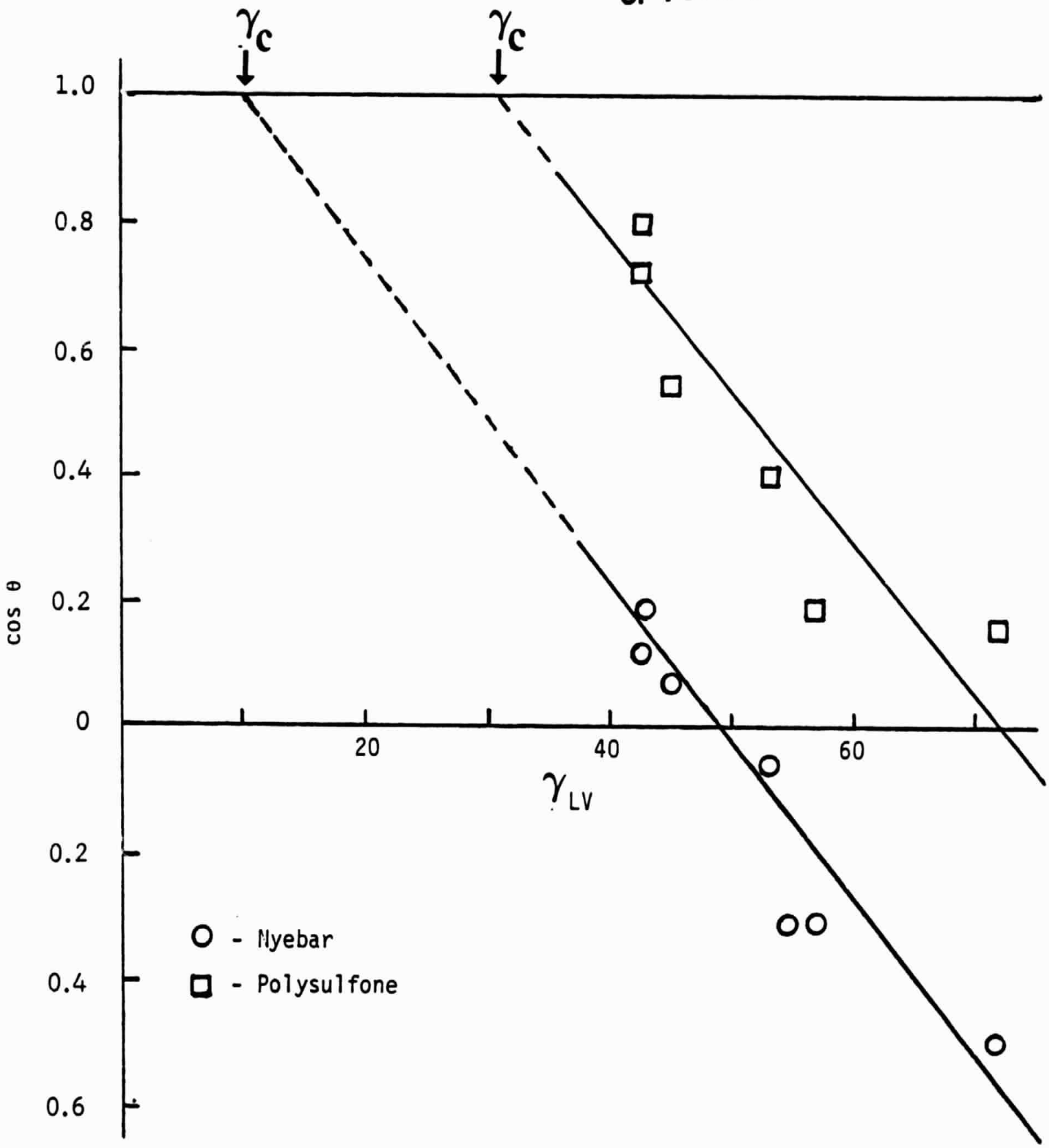

Figure 4. Determination of critical surface tension of polymer coatings.

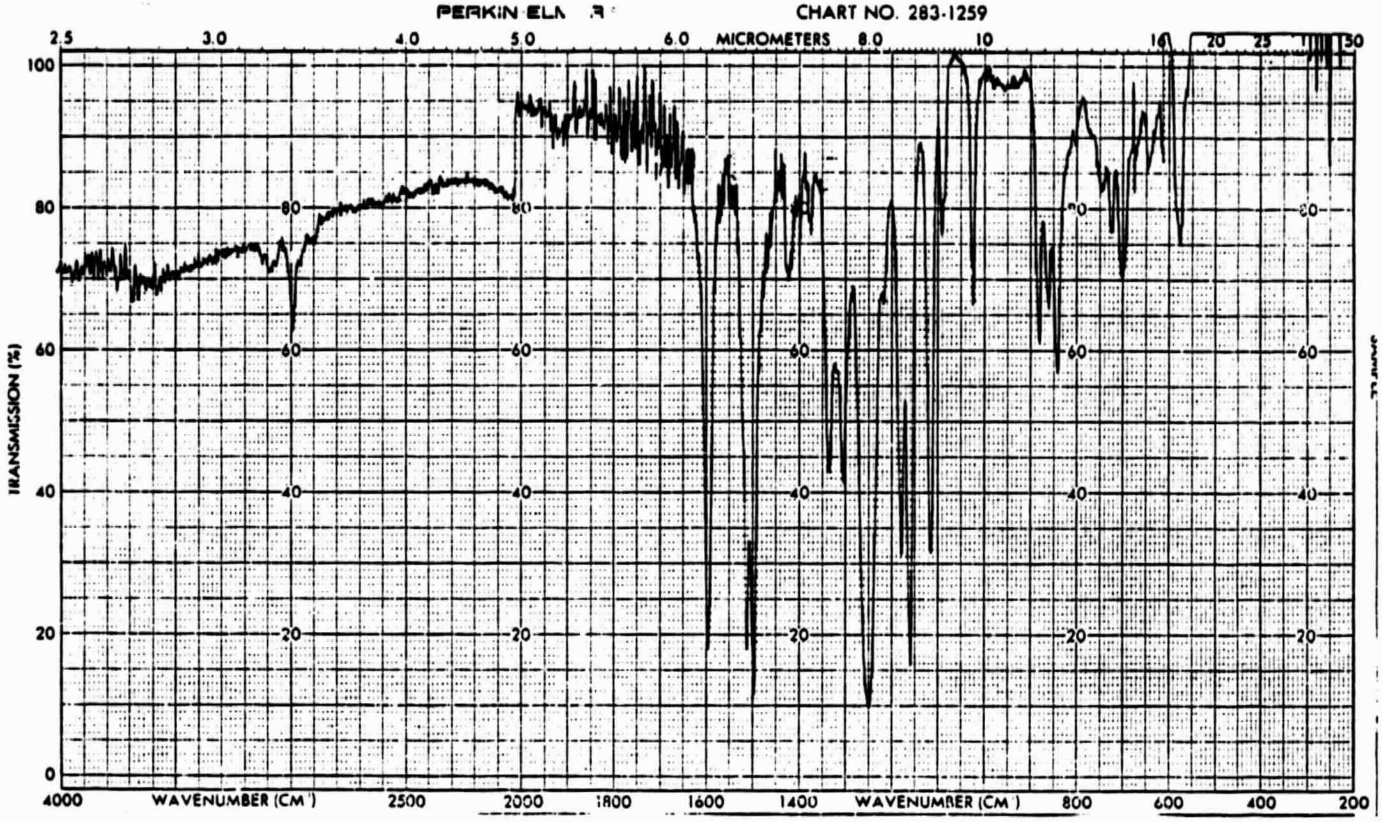

Figure 5. IR spectrum of polysulfone film.

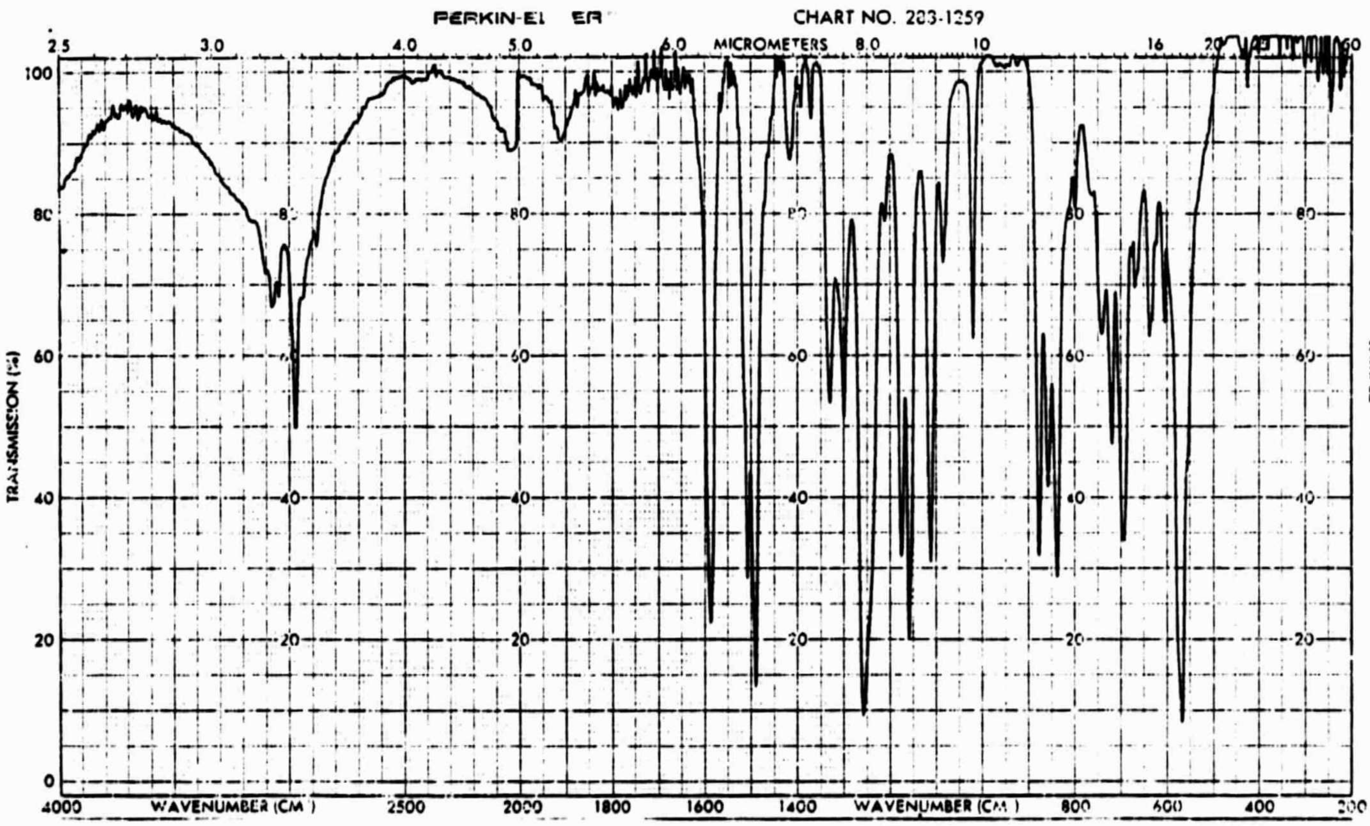

Figure 6. Infrared spectrum of exposed polysulfone film.

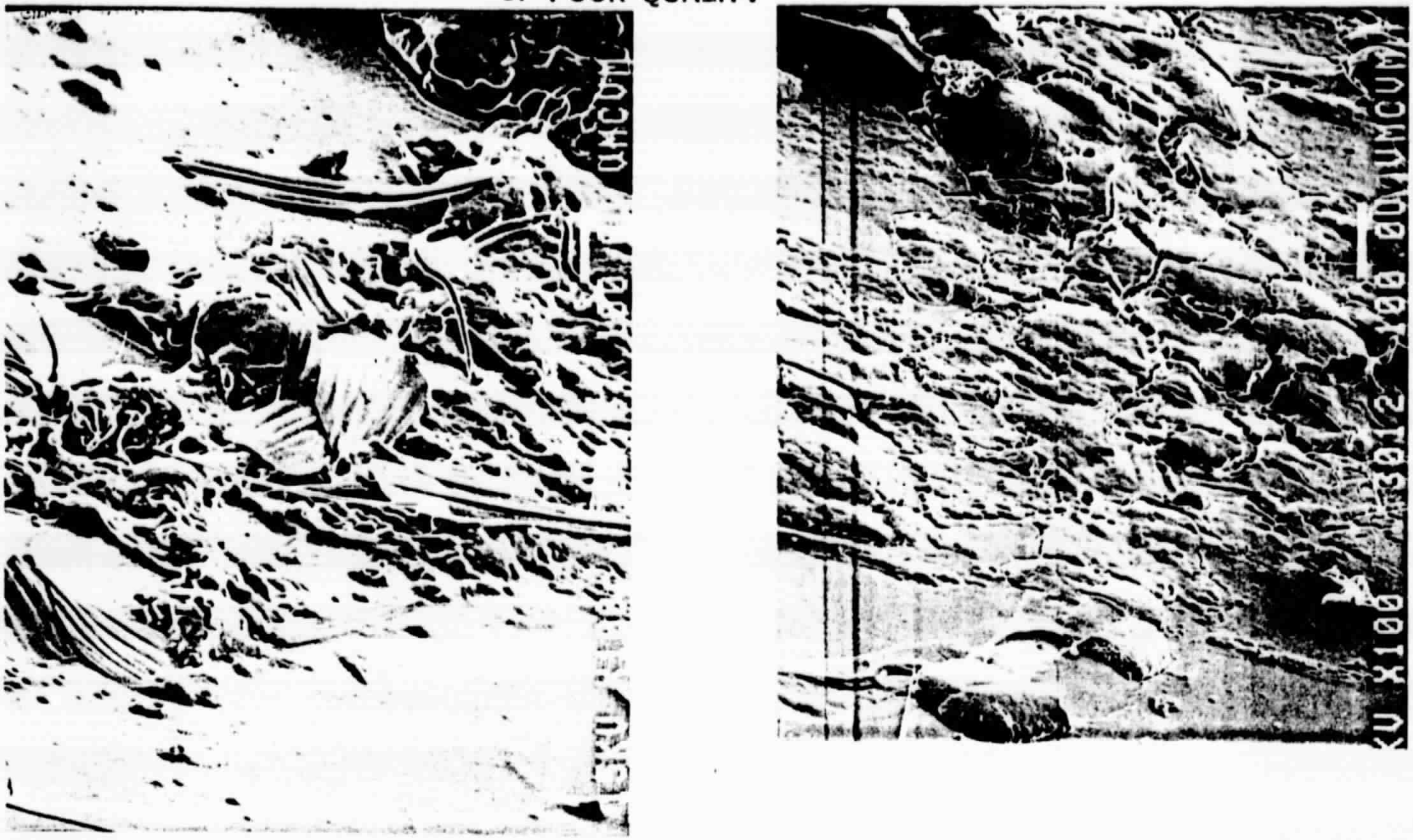

Figure 7. SEM photomicrographs of exposed polysulfone film.

Figure 8. SEM photomicrographs of exposed Nyebar film.