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EVALUATION OF POLYMER EMULSIONS TO SERVE AS SOIL TREATMENTS FOR DUST CONTROL

[illegible]

March 1971

Sponsored by U. S. Army Materiel Command

Conducted for U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

Under Contract No. DACA-39-70-C-[illegible]

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13. ABSTRACT

This report describes research work conducted to develop an improved polyvinyl acetate (PVA) polymer emulsion. Various manufacturers were contacted for information, recommendations, and samples of basic PVA systems. Some systems were modified with various additives. Tests were conducted on both modified and unmodified samples. These tests included determination of physical properties with particular emphasis placed on toughness. Environmental tests included exposure to ultraviolet light and water spray, soil bacteria, and fungi and heat aging. Modifications studied included viscosity, plasticizers, and fungicides. The above data were analyzed and six of the most promising formulations were submitted to the U. S. Army Engineer Waterways Experiment Station (WES) for evaluation. Laboratory screening tests and weathering tests were performed on these materials at the WES. The WES completed evaluation of the formulations and requested that procurement specifications for formulation 034001B be prepared. Procurement specifications were prepared using analysis of the 034001B test data. The specifications contain both physical and chemical properties of this material.

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FOREWORD

The work described in this report was performed under contract DACA-39-70-C-0012, entitled "Evaluation of Polymer Emulsions to Serve as Soil Treatments for Dust Control," dated 20 October 1969, between the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, and The Western Company, Research Division. The research was sponsored by the U.S. Army Materiel Command under research and development project 1G664717DH01-12, "Combat Engineer Equipment (Dust Control Material)."

The purpose of this research is to develop or improve a polyvinyl acetate emulsion system for military dust control in the Theater of Operations.

The research was conducted under the supervision of Mr. Jack B. Hammond, project chemist.

The contract was monitored by Mr. Royce C. Eaves, Chief, Stabilization Section, Expedient Surfaces Branch, under the general supervision of Mr. J.P. Sale, Chief, Soils Division, WES. Contracting Officer was COL E.D. Peixotto, CE.

CONTENTS

SUMMARY

This report describes research work conducted to develop an improved polyvinyl acetate (PVA) polymer emulsion. Various manufacturers were contacted for information, recommendations, and samples of basic PVA systems. Some systems were modified with various additives. Tests were conducted on both modified and unmodified samples. These tests included determination of physical properties with particular emphasis placed on toughness. Environmental tests included exposure to ultraviolet light and water spray, soil bacteria, and fungi and heat aging. Modifications studied included viscosity, plasticizers, and fungicides.

The above data were analyzed and six of the most promising formulations were submitted to the U. S. Army Engineer Waterways Experiment Station (WES) for evaluation. Laboratory screening tests and weathering tests were performed on these materials at the WES. The WES completed evaluation of the formulations and requested that procurement specifications for formulation 034001B be prepared.

Procurement specifications were prepared using analysis of the 034001B test data. The specifications contain both physical and chemical properties of this material.

I. INTRODUCTION

The purpose of this program was to develop or improve a polyvinyl acetate polymer emulsion for use as a soil surface treatment for dust control.

Efforts were directed toward environmental changes, soil types, and applications of dust palliative materials. This investigation broadens the evaluation procedures and evaluation methods of materials according to inherent properties. Films of candidate materials were prepared and subjected to tensile tests before and after environmental changes. The importance of physical characteristics was explored along with the effects of common modifiers such as plasticizers, viscosity increases, coalescing agents, and the like. Sufficient data was gathered to formulate conclusions on the effect of any investigated test or additive.

Based on the test results of this study, procurement specifications were developed as shown in Appendix A.

II. MATERIALS AND TEST PROCEDURES

A. SAMPLE PREPARATION

The following manufacturers responded to a request for information, recommendations, and modifications for polyvinyl latex products suitable for dust control.

Airco Chemicals and Plastics
B.F. Goodrich
Union Carbide
Hercules
Monsanto
National Starch and Chemical Corporation
Borden Chemical Company
Rhom and Haas

The emulsions were first tested without modifications of physical properties and then, if necessary, with modifications. The sample preparation data describes all formulas, modifications, and physical properties of the base polymer emulsions, plus the properties of the modified formulations that proved to be of merit.

Viscosity was measured at 20 rpm on a Brookfield viscosimeter. A portion of a formulated sample was spread on a clean plate glass with the aid of a drawdown bar with adjustable gap (usually adjusted to 0.030 in.). Peculiarities during application were noted. The temperature was regulated to 73-77°F and the humidity to 50-70 percent. Once the films were dry, they were peeled and cut into coupons. If sufficient adhesion was obtained such that a uniform dried film could not be removed from the glass, then the glass was pretreated with an inert Teflon spray to act as a release agent before the wet material was applied.

From the dried films, test coupons were sized according to ASTM D882-64T (Tensile Properties of Thin Plastic Sheeting) to the following dimensions:

length - 3 inches
width - 1 inch
thickness - 0.010 to 0.40 inch

The exact dimensions of the coupons were measured with micrometers before testing. Test coupons were then subjected to various environmental conditions.

B. PHYSICAL PROPERTIES OF FILMS

1. Explanation and Significance of Physical Properties

The physical properties of a dust palliative film were described by the following terms:

W	Load
L	Length between jaws (gage)
A	Cross-sectional area
S	Tensile stress (strength)
ϵ	Strain = $\frac{L_u - L_o}{L_o}$ ductility
ϵ'	True strain = $(\ln(L_u/L_o))$
E	Modulus of elasticity
T	Toughness
%El	Percent elongation = 100ϵ

Subscripts:

o	Indicates original dimension
u	Indicates dimension at rupture
′ (prime)	Indicates true properties

These terms are related as follows:

Property	Nominal Original Dimension	True Dimensions at Rupture
Tensile Strength	$S_u = W_u/A_o$	$S'_u = W_u/A_u$
Modulus of Elasticity	$E_u = S_u/\epsilon_u$	$E'_u = S'_u/\ln(1+\epsilon_u)$
Toughness	$T = \int_o^{\epsilon u} s d\epsilon$	$T' = \int_o^{\epsilon' u} s' d\epsilon'$

Graphically, these properties are interpreted as follows:

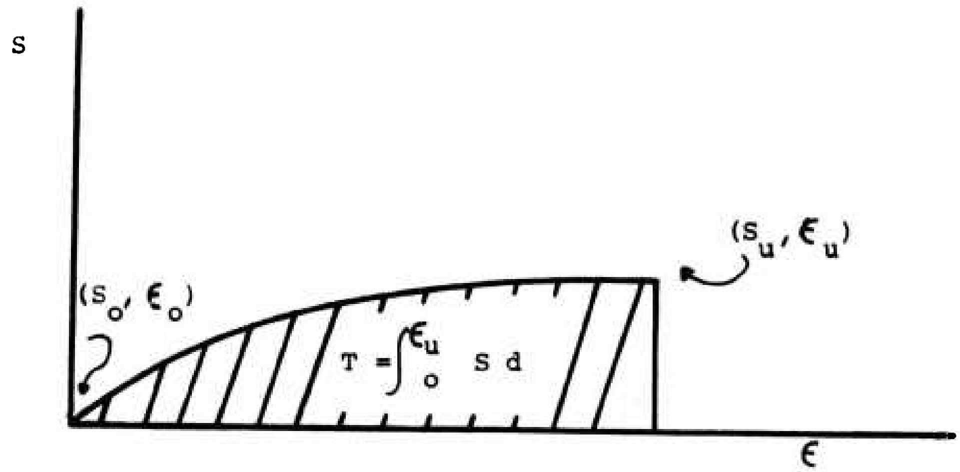

Figure 1. Nominal Stress/Strain Curve

A definition of these physical properties is given in ASTM D-638 (Tensile Properties of Plastics). The significance of the true properties of highly ductile materials such as a good palliative deserves mention. Without laborsome mathematics, the physical dimensions of a film being stretched are constantly changing. Thus, if only the original dimensions of a specimen are considered, then error is made if the final calculations are performed using the original dimensions. In some cases this may be acceptable; but, for the purpose of diagnosing the effects of a particular test or additive, the absolute or "true" property of the film is required.

Referring to the properties above, toughness presents an interesting parameter since it combines both the effects of tensile strength and ductility. By definition, toughness is the area under the stress/strain curve. Also notice that toughness is a transient property (indicated by the lack of subscripts). Essentially, a film which rates high in toughness must be both strong and ductile. Toughness is a good criterion for the performance of a material when subjected to environmental changes. It should be understood that physical properties are not the <u>only</u> requirement for these materials.

The performance of a dust palliative could be considered in four categories.

- Application to soil
- Performance during usage (mechanical-physical)
- Resistance to environment (chemical, bacteriological)
- Cost

The best dust palliative must perform well in all four categories. Physical properties are an important consideration.

2. Method of Measuring Physical Properties

The prepared coupons were placed in a suitable tensile tester and loaded at one-half inch per minute. With the use of an X-Y recorder, the load (W) was plotted versus the gage separation (L). This plot was recomputed (by computer) to reflect a plot of S versus ϵ and again to reflect S' versus ϵ'. From these plots, the desired physical properties were extracted.

C. ENVIRONMENTAL CHANGES IMPOSED ON FILMS

The physical properties of the coupons were first tested under normal conditions (75°F). Those showing reasonable physical strengths were subjected to environmental changes including:

- ultraviolet light and water spray
- soil bacteria and fungi
- heat aging .

The coupons were then retested to determine the effect of exposure. Data for the following tests is included Section III.

1. Weatherometer

A special unit was constructed to expose the films to a constant, calibrated ultraviolet light source and a constant water spray simultaneously. The films were placed on a revolving wheel which rotated to expose both sides of the films to ultraviolet radiation and water spray. A 100-hour exposure was typical.

The intensity of the ultraviolet light was measured according to ASTM D749-43T, (Calibrating a Light Source Used for Accelerating the Deterioration of Rubber). The method consists of decomposing oxalic acid in the presence of uranyl sulfate and in the presence of light. The rate of decomposure is proportional to the intensity of light and this intensity may be reported in weight of oxalic acid decomposed per square decimeter per minute. The above-mentioned weatherometer produced an ASTM intensity of:

2.88 milligrams oxalic acid decomposed
per square decimeter per minute.

2. Soil Bacteria and Fungi Testing

In order to test the resistance to microbiological attack, some of the films were exposed to common soil bacteria and fungi. Two types of media were used: plate count agar for the bacteria and Czapek solution agar for the fungi.

The testing procedure was set up as follows: the sterilized agar solutions were compounded into 100 x 15 mm petri dishes. After solidification, the media was inoculated and a 1-1/2 x 3" coupon of film was placed in each dish. The tops of films were also inoculated. The controls were not inoculated; otherwise, they were prepared in identical fashion. All cultures were incubated for 14 days at 100°F $\pm$ 2°. The films were noted for discoloration and growth of the bacteria or fungi on the film proper. Test results are noted in Table I. After noting the physical appearances, each film was washed in de-ionized water, rinsed in isopropyl alcohol, and then dried at room temperature. As another measure of the effect of a bacterial environment, the film samples were subjected to a tensile test. Data for these tests are contained in Section III.

The bacteria and fungi were isolated from a soil sample taken near the Western Research building and cultured in a nutrient broth and Czapek-Dox broth, respectively, for 48 hours before inoculating the petri dishes.

TABLE I. RESULTS OF BACTERIA AND FUNGI TESTING

Film Code No.	Growth on Film # Bacteria	Growth on Film # Fungi	Appearance of Film ## Bacteria	Appearance of Film ## Fungi
34001B (control)	-	-	1	1
A	-	-	1	Brown, Yellow
B	-	-	1	Brown
40002A (control)	-	-	1	1
A	+	+	1	Rust Red
B	+	+	1	Rust Red
141001BF				
A	-	+	1	Green, Black
B	-	+	1	Green
141001BFZ	+	+	Yellow	Redish, Black areas
146001FZ				
A	-	+	1	Brown
B	-	+	1	Brown, Black, Green
162002J	-	+	1	Yellow, Orange, Black at edge
162002JZ	+	+	Yellow	Black areas, Black at edge
162003I (control)	-	-	1	1
A	+	+	Yellow	Black, Yellow, Rose
162003IZ				
A	+	+	Yellow	Green, Rose
B	1	+	Black	Black, Purple, Rose
166001D				
A	+	+	Black	Yellow
B	+	+	Black	Green, Yellow
191001BF (control)	-	-	1	1
A	-	+	Dk.Brown	Ovary, Yellow
B	-	+	Dk.Brown	Ovary, Yellow

\# + growth on film
\- no growth on film

\## 1 white and swelled

3. Heat Aging

A few of the film samples were aged under heat by placing them 20 inches from a 200-watt sun lamp. This produced a typical film temperature of 135°F.

4. Various Temperature Testing

By placing the tensile tester and film coupons in a controlled temperature chamber, stress/strain relationships at higher and lower temperatures could be determined. Some films were tested at three temperatures 32°F (code %), 75°F, and 120°F (code !). This provided evaluation of a material's worthiness in varying climates. These temperatures were held only during the actual tensile testing and may or may not be in addition to another aging test.

D. MODIFICATIONS

1. Viscosity

Viscosity is important in the application of the wet emulsion and has a minor effect on film properties. Suitable dilution is recommended according to the type of soil encountered. The criterion for dilution limits is dependent upon the desired application rates and cost considerations. Cellulose derivatives work well as viscosity increasers. Some emulsions thicken as pH increases. Fumed silica such as Cab-o-sil (Cabot Company) is a good thickener because it induces high viscosity at low shear rates (sagging) and lower viscosity at high shear rates (pumping); i.e., it induces a pseudoplastic effect. Also solvents (aromatics or aliphatics) often cause viscosity increase in polymer emulsions by inducing a certain degree of insolubility.

2. Plasticizers

There are an unlimited number of plasticizers. Dibutyl phthalate, diethyl phthalate and tricresyl phosphate were used in this study. Distinction is made between plasticizer and flexibilizer, whereby the latter is a process by which a more flexible material is blended into another material by means of copolymerization rather than by external lubrication. Most of the materials tested were flexibilized.

3. Fungicides

Phenyl mercuric acetate was used to stop bacterial growth and is recommended if the materials are to be applied in bacteria growth promoting environments.

III. TEST RESULTS AND ANALYSIS

This section lists the data collected during the study. First (part A), there is an explanation of the coding used to identify the aforementioned tests and the emulsions on which the tests were performed. Second (part B), there is the listing of the actual data output and format. From these listings all test results can be examined.

A. INTERPRETATION OF COMPUTER DATA

Each sample number has two parts. The first part, totally numeric, identifies the formulation. This number is unique to the formulation. The second part identifies the starting material of the formulation and the test which was performed. The two following listings identify these codes. The first listing gives the codes unique to a given polymer emulsion. The second listing gives the codes unique to the test performed.

1. Codes for and Brief Description of Polymer Emulsions

A — Aircoflex 500 - Airco Company. A vinyl acetate ethylene copolymer of nonionic particle charge and very high flexibility having high alkaline resistance and excellent low temperature coalescing. Tacky at higher (100°F) temperatures.

B — Flexbond 860 - Airco Company. A vinyl alkyl maleate copolymer of very high flexibility claiming excellent low temperature coalescing. Slight tackiness at higher temperatures. Minimum film forming temperature 8°C.

C — Aquaze 50 - Hercules Powder Company. A vinyl acetate ethylene copolymer emulsion designed for adhesive applications. Excellent adhesive. Minimum film-forming temperature 12°C.

D X Link 2802 - National Starch and Chemical Corporation. A self-reactive vinyl acetate copolymer of anionic particle charge. Crosslinks at 130°C. Brittle -- intended for blending with more flexible resins. Minimum film-forming temperature 13°C.

E Resyn 25-1105 - National Starch and Chemical Corporation. A polyvinyl acetate homopolymer designed for paper coating. Brittle unless modified.

F Resyn 1025 - National Starch and Chemical Corporation. A typical polyvinyl acetate homopolymer of nonionic particle charge. Brittle unless modified.

G Rhoplex 330 - Rohm and Haas Company.

H Hycar 2679X6 - B.F. Goodrich. A self-thickening (by raising pH) acrylic anionic emulsion with a heat-activated cure system. Forms very strong and resistant film under proper curing conditions.

I Resyn 1251 - National Starch and Chemical Corporation. A high viscosity vinyl acetate copolymer emulsion of nonionic particle charge. Moderately flexible at room temperature or higher.

J Resyn 2813 - National Starch and Chemical Corporation. A self-reactive vinyl acrylic terpolymer emulsion of anionic particle charge. Heating to 130°C instigates crosslinking. Minimum film-forming temperature 0°C. Very stretchy film.

K Geon 460X1 - B.F. Goodrich. A vinyl chloride copolymer emulsion of anionic particle charge. Heating to 300°F improves cure. Extremely tough film. Minimum film-forming temperature 26°C.

L Polyco 804-PL - Borden Chemical Company. A polyvinyl acetate copolymer emulsion. Moderate flexibility.

O X-Link 2833 - National Starch and Chemical Company. A self-crosslinking copolymer emulsion of slight anionic particle charge. Very flexible. Glass transition temperature - 29°C.

R Hycar 1570X36 - B.F. Goodrich. A carboxy modified butadione-acrylonitrile emulsion for general purpose applications. Heat aids cure. Tough film of good flexibility.

S Ucar 180 - Union Carbide. A vinyl acrylic copolymer emulsion of anionic particle charge. For exterior coatings.

T Ucar 360 - Union Carbide. The standard polyvinyl acetate homopolymer of nonionic particle charge. Requires plasticizers for flexibility.

2. Codes for Performance Tests

W Controlled humidity chamber. Coupons were stored before testing at 75°F and 30-35% relative humidity.

X Subjected to bacteria cultures isolated from the soil and of the common soil variety found in the north central Texas area. Exposure: 14 days at 100°F.

Y Subjected to fungus cultures isolated from the soil and of the common soil variety. Exposure: 14 days at 100°F.

Z Weatherometer. Exposure time 100 hours (unless otherwise specified) to ultraviolet light and water fall. Coupons were allowed to dry before testing.

! 120°F testing stress/strain relationships of coupons held at a constant 120°F during straining.

% 32°F testing stress/strain relationships of coupons held at a constant 32°F during straining.

B. <u>COMPUTER DATA</u>

1. <u>Format</u>

<u>123456A</u>	<u>Formulation and Comments</u>			
Viscosity (poise)	pH	% Solids	Sp.Gr.	Cost ($/lb)
ABCD	Comments	w	d	L_o
	A_o S_{max}	ϵ_u	T	E
	A'_u S'_{max}	ϵ'_u	T'	E'

The number 123456 is formulation identification number for the following test series and ABCD are identification codes. A numeric identification code indicates from which prepared film the coupons were cut.

w = width, inches

d = thickness, inches

L_o= initial gage separation, inches

A = cross-sectional area, square inches

S = tensile strength, pounds/square inch

ϵ = strain, inches per inch

T = toughness $\int S\,d\epsilon$

E = modulus of elasticity, pounds per square inch, per inch

$100\epsilon_u$ = % elongation before rupture

A zero value indicates an undetermined property

2. Abbreviations

Acry	Acrylic
Buty. Cellos.	Butyl Cellosolve. A brand of solvent
DBP	Di Butyl Phthalate
DEP	Di Ethyl Phthalate
HLA	Heat-lamp aged
J12HS	Brand of cellulose thickener - Dow Chemical Co.
No Br	No Break
Non ion	Non Ionic - refers to emulsifiers
N.M.	No modification
Pap. Mat.	Paper matting
PVA	Polyvinyl acetate
UV	Ultraviolet light, 40 UV, 40 hours of UV aging
VAE	Vinyl acetate ethylene
VA-ALK	Vinyl acetate alkyl

3. <u>Example of Computer Readout</u>

An example of a typical computer readout follows:

```
34001B   FLEXBOND 860;VA-ALK MALEATE; N.M.;GOOD FILM
           10.00   5.3  56.0   1.090 0.120

   B9W   CUT 1            1.50 0.0150   0.75
           0.02250     400.0      6.933   1570.37     57.69
           0.00284    3173.3      2.071   1761.42   1532.22

   B9W   CUT 3            1.50 0.0115   0.75
           0.01725     411.6     10.800   2363.67     38.11
           0.00146    4856.8      2.468   2679.49   1967.83
```

The sample number 34001 was assigned to a formulation consisting of Flexbond 860 with no modifications. The B is the code for this specific emulsion. The wet physical properties of this formulation are:

Viscosity	10.00	poise
pH	5.3	
Percent solids	56	
Specific gravity	1.09	
Cost ($/lb)	.12	

The first entry under the formulation data indicates that from film number 9 (prepared from formulation 34001B) a coupon was cut (cut number 1) and stored in the humidity chamber (indicated by the W) until test time. At test time, the coupon was inserted into the tester. The dimensions of the coupon at this time were:

width	1.5 inches
thickness	.015 inches
length (between tester jaws)	.75 inches

Upon testing, this coupon yielded the following physical strengths:

	Nominal	At Rupture or True
Cross-sectional area (square inch)	.02250	.00284
Tensile strength (psi)	400	3173.3
Strain (inches per inch)	6.933	2.071

	Nominal	At Rupture or True
Toughness	1570.37	1761.42
Elastic modulus (pounds per square inch per inch)	57.69	1532.22

The second entry lists the physical strengths for the third cut coupon from film number 9.

4. Actual Data

40002A AIRCOFLEX 500; VAE; N.M.; SOMECRACK ON DRY; STRONG FILM

3.50 5.3 55.5 1.080 0.120

A2W CUT 2		1.50	0.0110	0.75	
	0.01650	375.8	11.333	1787.07	33.16
	0.00134	4634.3	2.512	2055.50	1844.66
A2W CUT 3		1.50	0.0110	0.75	
	0.01650	339.4	11.467	1631.92	29.60
	0.00132	4231.1	2.523	1865.47	1676.98
A3Z CUT 2		1.50	0.0135	0.75	
	0.02025	232.1	10.533	1159.51	22.03
	0.00176	2676.9	2.445	1305.74	1094.73
AZ CUT#1		1.50	0.0150	0.75	
	0.02250	2533.3	4.933	8785.19	513.51
	0.00379	15031.1	1.781	10037.97	8441.66
AZ CUT#2		1.50	0.0150	0.75	
	0.02250	2466.7	4.133	7687.41	596.77
	0.00438	12662.2	1.636	9415.92	7740.90
A! CUT#1 NØ BREAK		1.50	0.0150	0.50	
	0.02250	22.2	18.000	297.33	1.23
	0.00118	422.2	2.944	397.97	143.40
AX #2		1.50	0.0170	0.75	
	0.02550	211.8	8.267	854.38	25.62
	0.00275	1962.4	2.226	993.46	881.39
AX #3 CØNTRØL		1.50	0.0170	0.75	
	0.02550	180.4	9.467	1050.98	19.06
	0.00244	1888.1	2.348	1202.47	804.07
AX #1		1.50	0.0170	0.75	
	0.02550	172.5	7.733	834.51	22.31
	0.00292	1506.9	2.167	971.72	695.35
AY CUT#1		1.50	0.0140	0.75	
	0.02100	171.4	7.333	799.37	23.38
	0.00252	1428.6	2.120	999.32	673.77
AY CUT #2		1.50	0.0140	0.75	
	0.02100	219.0	7.733	884.44	28.33
	0.00240	1913.0	2.167	1054.89	882.73
AY CUT#3 CØNTRØL		1.50	0.0140	0.75	
	0.02100	219.0	9.867	1235.56	22.20
	0.00193	2380.3	2.386	1396.46	997.74

```
57001A    AIRCØFLEX 500; VIN-ETH; 6% ETH GLY
            0.       0.       0.     0.      0.

    AZ    CUT 1                1.50 0.0120    0.75
             0.01800      291.7       9.467    1319.07       30.81
             0.00172     3052.8       2.348    1605.87     1300.05

    AZ    CUT 2                1.50 0.0120    0.75
             0.01800      261.1       9.733    1197.96       26.83
             0.00168     2802.6       2.373    1416.25     1180.86

    A2    NØ BR.2 CUT          1.50 0.0150    0.75
             0.02250       22.2      12.667     211.85        1.75
             0.00165      303.7       2.615     268.00      116.14

64002A    AIRCØFLEX 500; 2% CARBITØL
            0.       0.       0.     0.      0.

    AZ    CUT 1                1.50 0.0130    0.75
             0.01950       41.0      12.000     408.89        3.42
             0.00150      533.3       2.565     571.42      207.93

89001A    75 AIRCO 500; 55 WATER; 100 TALC; 7 ETH GLY;.2 J12HS;PVC=50
          28.20      0.       0.     0.      0.

91001A    N.M. SATURATED NEWSPAPER; .010-.020 AFTER DRY
            0.       0.       0.     0.      0.

     A    PAP MAT 2            1.50 0.0190    1.00
             0.02850      631.6       0.100      31.58     6315.79
             0.02591      694.7       0.095      33.11     7289.22

     A    PAP MAT 3            1.50 0.0190    1.00
             0.02850      442.1       0.200      43.68     2210.53
             0.02375      530.5       0.182      45.65     2909.84

91003A    AIRCØ 500 IN PAPER KNIT;UNEVEN FILM;SLØW DRY
            0.       0.       0.     0.      0.

     A    KNIT PAP 1           1.50 0.0150    1.00
             0.02250     1106.7       0.600     419.33     1844.44
             0.01406     1770.7       0.470     446.65     3767.35

196001AF  AIRCØ 500:N.S.1025; 3:1;GØØD FILM
            5.70     0.       0.     0.      0.

    AF      CUT#1              1.50 0.0160    0.75
             0.02400      450.0      15.067    5475.56       29.87
             0.00149     7230.0       2.777    6478.96     2603.77

    AF      CUT#2              1.50 0.0160    0.75
             0.02400      487.5      12.267    4631.39       39.74
             0.00181     6467.5       2.585    5410.40     2501.69
```

```
      AF!  CUT#1                1.50 0.0160   0.50
            0.02400        29.2     13.200    295.42      2.21
            0.00169       414.2      2.653    399.89    156.10

      AF%   CUT#2               1.50 0.0165   0.75
            0.02475      2545.5      1.733   3742.76   1468.53
            0.00905      6957.6      1.006   4190.57   6919.37

202002A    150 AIRCO 500, 8 ETH. GLY., 2 TERG. NPX,50 TALC;SMOOTH FILM
            0.      0.      0.     0.      0.

      A    CUT#1                1.50 0.0160   0.75
            0.02400       100.0     12.000    981.67      8.33
            0.00185      1300.0      2.565   1304.34    506.83

211001AI   AIRCO 500:N.S.1251, 1:1
            0.      0.      0.     0.      0.

      AI    CUT#1               1.50 0.0140   0.75
            0.02100       385.7      9.067   2268.25     42.54
            0.00209      3882.9      2.309   2601.89   1681.45

      AI    CUT#2               1.50 0.0140   0.75
            0.02100       347.6      7.867   1595.24     44.19
            0.00237      3082.2      2.182   1872.86   1412.37

      AI! #1 NO BR.             1.50 0.0145   0.50
            0.02175        23.0     18.000    274.02      1.28
            0.00114       436.8      2.944    346.70    148.34

      AI%   CUT#1               1.50 0.0145   0.75
            0.02175      1172.4      0.133     78.16   8793.10
            0.01919      1328.7      0.125     83.15  10616.03

      AI%   CUT#2               1.50 0.0145   0.75
            0.02175      2413.8      0.133    160.92  18103.45
            0.01919      2735.6      0.125    171.20  21856.53

  34001B   FLEXBOND 860;VA-ALK MALEATE; N.M.;GOOD FILM
            10.00   5.3   56.0   1.090  0.120

  B9W CUT3                  1.50 0.0115   0.75
        0.01725       411.6      10.800    2363.67      38.11
        0.00146      4856.8       2.468    2679.49    1967.83
```

R9W CUT 1		1.50	0.0150	0.75	
	0.02250	400.0	6.933	1570.37	57.69
	0.00284	3173.3	2.071	1761.42	1532.22
R5Z CUT 2		1.50	0.0100	0.75	
	0.01500	220.0	10.800	1072.89	20.37
	0.00127	2596.0	2.468	1211.27	1051.82
R9W CUT 2		1.50	0.0120	0.75	
	0.01800	438.9	10.400	1902.59	42.20
	0.00158	5003.3	2.434	2335.26	2055.93
R2 #1		1.50	0.0060	0.75	
	0.00900	633.3	7.600	1837.78	83.33
	0.00105	5446.7	2.152	2159.62	2531.26
R2 #2		1.50	0.0060	0.75	
	0.00900	600.0	6.933	1634.81	86.54
	0.00113	4760.0	2.071	1863.10	2298.33
RZ CUT#1		1.50	0.0140	0.75	
	0.02100	2571.4	1.333	1463.49	1928.57
	0.00900	6000.0	0.847	1592.52	7081.34
R% CUT#2		1.50	0.0140	0.75	
	0.02100	2333.3	1.867	2476.19	1250.00
	0.00733	6688.9	1.053	2800.57	6351.32
R! CUT#1		1.50	0.0130	0.50	
	0.01950	15.4	16.600	169.74	0.93
	0.00111	270.8	2.868	253.57	94.41
RX #2		1.50	0.0165	0.75	
	0.02475	307.1	10.000	1789.09	30.71
	0.00225	3377.8	2.398	2065.21	1408.64
RY CUT#1		1.50	0.0145	0.75	
	0.02175	427.6	7.733	1650.27	55.29
	0.00249	3734.3	2.167	1911.06	1723.12
RY CUT#2		1.50	0.0145	0.75	
	0.02175	377.0	8.000	1439.69	47.13
	0.00242	3393.1	2.197	1662.16	1544.27
RY CUT#3 CONTROL		1.50	0.0145	0.75	
	0.02175	441.4	9.600	2152.95	45.98
	0.00205	4678.6	2.361	2413.55	1981.75

```
106002B    FLEXBØND W/SCRIM#1659
             0.       0.       0.      0.      0.

       B    SCRIM #1              1.50 0.0100    1.00
              0.01500     4333.3      1.200     803.33    3611.11
              0.00682     9533.3      0.788     864.14   12091.12

       B    SCRIM #2              1.50 0.0100    1.00
              0.01500     3866.7      1.600     970.00    2416.67
              0.00577    10053.3      0.956    1037.71   10521.42

141001BF     FLEXBØND 860:NS 1025,2:1; BUBBLES
             0.       0.       0.      0.      0.

       BFZ   CUT#1                1.50 0.0125    0.75
              0.01875     2773.3      0.133     184.89   20800.00
              0.01654     3143.1      0.125     196.70   25112.11

       BFZ    CUT#2               1.50 0.0125    0.75
              0.01875     2506.7      0.133     167.11   18800.00
              0.01654     2840.9      0.125     177.79   22697.49

       BF    CUT#1                1.50 0.0120    0.75
              0.01800      983.3      6.667    4415.56     147.50
              0.00235     7538.9      2.037    5416.37    3701.19

       BF   #2 BUBBLES            1.50 0.0135    0.75
              0.02025      479.0      7.200    2218.27      66.53
              0.00247     3927.9      2.104    2567.66    1866.75

       BF!   CUT #1               1.50 0.0135    0.75
              0.02025       19.8     12.000     223.87       1.65
              0.00156      256.8      2.565     460.60     100.12

       BF!Z CUT#1                 1.50 0.0130    0.50
              0.01950       15.4     18.000     272.31       0.85
              0.00103      292.3      2.944     729.08      99.27

       BFX  #1                    1.50 0.0140    0.75
              0.02100     1214.3      7.200    6592.38     168.65
              0.00256     9957.1      2.104    7929.70    4732.18

       BFX  #2                    1.50 0.0140    0.75
              0.02100     1071.4      6.400    4800.00     167.41
              0.00284     7928.6      2.001    5919.69    3961.35
```

```
        BFZX CUT#1             1.50 0.0145   0.75
              0.02175      772.4      4.400   2662.99     175.55
              0.00403     4171.0      1.686   3094.29    2473.34

        BFZY CUT#1             1.50 0.0140   0.75
              0.02100      857.1      3.600   2657.14     238.10
              0.00457     3942.9      1.526   3143.68    2583.69

        BFY  CUT#1             1.50 0.0150   0.75
              0.02250      866.7      5.733   3365.93     151.16
              0.00334     5835.6      1.907   4106.93    3059.96

173001BF   FLEXBØND 860:NATL STAR 1025; 3:1;
            0.        0.       0.     0.      0.

        BF   CUT#2             1.50 0.0130   0.75
              0.01950      600.0      6.533   2687.18      91.84
              0.00259     4520.0      2.019   3558.07    2238.36

        BF2 CUT#1 NØ BREAK     1.50 0.0450   0.75
              0.06750      385.2     12.000   3143.70      32.10
              0.00519     5007.4      2.565   3787.40    1952.24

        BF2 CUT#2 NØ BREAK     1.50 0.0450   0.75
              0.06750      340.7     12.000   2797.53      28.40
              0.00519     4429.6      2.565   3537.29    1726.99

        BF! #1 NØ BR.          1.50 0.0135   0.50
              0.02025       19.8     18.000    315.06       1.10
              0.00107      375.3      2.944    513.46     127.46

        BFZ  CUT#1             1.50 0.0140   0.75
              0.02100     3452.4      0.133    230.16   25892.86
              0.01853     3912.7      0.125    244.86   31260.79

        BFZ   CUT#2            1.50 0.0140   0.75
              0.02100     2881.0      0.133    192.06   21607.14
              0.01853     3265.1      0.125    204.33   26086.59

190001B    FLEXBØND 860 WITH SCRIM #16-444
            0.        0.       0.     0.      0.

        B    CUT #1            1.50 0.0160   0.75
              0.02400     3333.3      1.867   1438.89    1785.71
              0.00837     9555.6      1.053   1575.31    9073.31

        B    CUT #2            1.50 0.0160   0.75
              0.02400     3291.7      1.733   1277.78    1899.04
              0.00878     8997.2      1.006   1389.94    8947.81
```

```
47002C    AQUAZE 50:VAE: N.M.: GØØD FILM: STRØNG GLASS ADH.
           13.50    5.7   56.0  0.     0.

      CZ   CUT 1                 1.50 0.0100    0.75
              0.01500        46.7      11.400     413.22       4.09
              0.00121       578.7       2.518     563.08     229.84

      C2W   CUT 2 NØ BREAK    1.50 0.0120    0.75
              0.01800       375.0      12.667    2610.00      29.61
              0.00132      5125.0       2.615    2914.04    1959.88

86001C    AQUAZE 50:9.09% EPØN 828 & VERSAMID X265-WR70:
            0.       0.       0.      0.      0.

      CW   CUT2                  1.50 0.0135    0.75
              0.02025       266.7       5.200     960.33      51.28
              0.00327      1653.3       1.825    1176.98     906.16


70007D    NAT'L STAR 2802: 2% DØW J12HS: TØØ THICK
            0.       0.       0.      0.      0.

70009D    N.S. 2802: .25% DØW J12HS: TØØ THICK
           38.00     0.       0.      0.      0.

85001D    N.S. 25-2802: VIN. ACET. COPOL.; N.M.; 0% FLONG
            1.00     4.7     45.0   1.080  0.175

90003D    NATL STAR 25-2802:10 PHR DEP: .25% ØXALIC ACID
           23.00     0.       0.      0.      0.

      DW   CUT 1                 1.50 0.0130    0.75
              0.01950       189.7       3.733     290.26      50.82
              0.00412       898.1       1.555     322.04     577.71

166001DØ  NATL. STAR. 2802:2833, 50:50:
            0.       0.       0.      0.      0.

      DØ% CUT#1                  1.50 0.0115    0.75
              0.01725       782.6       0.533     311.11    1467.39
              0.01125      1200.0       0.427     356.83    2807.39

      DØ% CUT#2                  1.50 0.0115    0.75
              0.01725       782.6       0.667     421.26    1173.91
              0.01035      1304.3       0.511     501.69    2553.41
```

```
        DØ!   CUT#1              1.50 0.0085    0.50
                0.01275       117.6       8.000      541.18       14.71
                0.00142      1058.8       2.197      891.81      481.89

        DØ!   CUT#2              1.50 0.0085    0.50
                0.01275        94.1       7.000      372.55       13.45
                0.00159       752.9       2.079      587.73      362.09

        DO    CUT #1             1.50 0.0160    0.75
                0.02400       500.0       3.333     1566.67      150.00
                0.00554      2166.7       1.466     2820.26     1477.60

        DØ    CUT #2             1.50 0.0160    0.75
                0.02400       375.0       3.067     1069.44      122.28
                0.00590      1525.0       1.403     1467.53     1087.09

        DØX   CUT#1              1.50 0.0110    0.75
                0.01650       963.6       1.067      805.25      903.41
                0.00798      1991.5       0.726      898.17     2743.37

        DØX   CUT#2              1.50 0.0110    0.75
                0.01650       903.0       2.000     1677.98      451.52
                0.00550      2709.1       1.099     1913.13     2465.92

        DØY   CUT#1              1.50 0.0165    0.75
                0.02475       848.5       4.267     3280.81      198.86
                0.00470      4468.7       1.661     3928.22     2689.72

        DØY   CUT#2              1.50 0.0165    0.75
                0.02475       787.9       3.067     2044.44      256.92
                0.00609      3204.0       1.403     2352.62     2283.99


  85002F     N.S. 25-1105 ; PVA; N.M.
               0.50     6.0    47.0    1.100 0.130
NØ TEST DATA

 90001F      9.9%DPP;.12%J12HS;EMUL BRØKE
               0.56     0.      0.      0.      0.
NØ TEST DATA

 64001F        NAT'L STAR.1025; 3.84% DEP
               26.20    0.      0.      0.      0.

        FW    CUT 1              1.50 0.0100    0.75
                0.01500      1506.7       5.200     4180.00      289.74
                0.00242      9341.3       1.825     4743.69     5119.80

        FW    CUT 2              1.50 0.0100    0.75
                0.01500      1246.7       4.933     3827.11      252.70
                0.00253      7396.9       1.781     4288.24     4154.19
```

```
  F2W CUT 1              1.50 0.0125   0.75
         0.01875     837.3      7.200   2792.89      116.30
         0.00229    6866.1      2.104   3129.25     3263.16

  F3  CUT #1             1.50 0.0065   0.75
         0.00975    1282.1      5.067   3007.18      253.04
         0.00161    7777.8      1.803   3394.74     4314.25

  F3  CUT 2              1.50 0.0065   0.75
         0.00975    1528.2      6.400   5028.38      238.78
         0.00132   11308.7      2.001   5522.49     5650.18

64003F    NAT'L STAR 1025; 6% DFP
        23.60    0.     0.    0.     0.

  FW  CUT 2              1.50 0.0120   0.75
         0.01800     694.4      8.800   2798.89       78.91
         0.00184    6805.6      2.282   3140.84     2981.78

  F2W CUT 1              1.50 0.0120   0.75
         0.01800    1083.3     12.800   5990.37       84.64
         0.00130   14950.0      2.625   6681.75     5695.96

  FZ  #1;5HR@150F        1.50 0.0145   0.75
         0.02175     620.7      9.867   2980.84       62.91
         0.00200    6744.8      2.386   3329.18     2827.19

70008F    NAT'L STAR 1025; 2% J12HS; T00 THICK
         0.      0.     0.    0.     0.

70011F    N.S. 1025; 6% CARBIT0L
         4.20    0.     0.    0.     0.

  F2W CUT 2              1.50 0.0120   0.75
         0.01800     255.6      8.667   1124.81       29.49
         0.00186    2470.4      2.269   1319.31     1088.90

  FWZ 40UV;#1            1.50 0.0120   0.75
         0.01800    4861.1      0.267    583.33    18229.17
         0.01421    6157.4      0.236    617.18    26047.80

  FWZ 40UV;#2            1.50 0.0120   0.75
         0.01800    3972.2      0.200    443.52    19861.11
         0.01500    4766.7      0.182    456.80    26144.29

85003F    N.S. 25-1025;PVA N0N I0N;N.M. T00 BRIT
        14.00    4.7   55.0  1.190 0.172
```

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107001F    NATL STAR 1025 ; 3.74% DEP; 1.26% DBP; FOAMY
             0.        0.        0.       0.       0.

        F     CUT 1                  1.50 0.0155    0.75
                 0.02325      1380.6        6.667    4935.05      207.10
                 0.00303     10584.9        2.037    5520.99     5196.64

        F     CUT 2                  1.50 0.0155    0.75
                 0.02325      1354.8        7.067    5359.14      191.72
                 0.00288     10929.0        2.088    6014.30     5234.86

        F!    CUT #1                 1.50 0.0155    0.50
                 0.02325       262.4       12.400    2376.34       21.16
                 0.00174      3515.7        2.595    2842.22     1354.66

        F!    CUT #2                 1.50 0.0155    0.50
                 0.02325       249.5       11.400    1995.70       21.88
                 0.00188      3093.3        2.518    2352.56     1228.64

        F%      CUT#1                1.50 0.0130    0.75
                 0.01950      2000.0        0.133     133.33    15000.00
                 0.01721      2266.7        0.125     141.85    18109.70

        F%      CUT#2                1.50 0.0130    0.75
                 0.01950      2076.9        0.133     138.46    15576.92
                 0.01721      2353.8        0.125     147.31    18806.22

146001F    NS 1025; 8% DBP
             0.        0.        0.       0.       0.

        FZ%  CUT#3                   1.50 0.0120    0.75
                 0.01800      2277.8        0.667     403.70     3416.67
                 0.01080      3796.3        0.511     434.43     7431.69

        FZ%  CUT#4                   1.50 0.0120    0.75
                 0.01800      2333.3        0.267     314.81     8750.00
                 0.01421      2955.6        0.236     333.77    12502.94

        FZ%   CUT#1                  1.50 0.0120    0.75
                 0.01800      2388.9        0.133     159.26    17916.67
                 0.01588      2707.4        0.125     169.43    21631.03

        FZ%   CUT#2                  1.50 0.0120    0.75
                 0.01800      2333.3        0.133     155.56    17500.00
                 0.01588      2644.4        0.125     165.49    21127.98

        F%   #1                      1.50 0.0125    0.75
                 0.01875      2080.0        0.133     138.67    15600.00
                 0.01654      2357.3        0.125     147.53    18834.09
```

FZ #2		1.50	0.0125	0.75	
	0.01875	2800.0	0.133	186.67	21000.00
	0.01654	3173.3	0.125	198.59	25353.58
FI #1		1.50	0.0120	0.75	
	0.01800	166.7	12.267	1510.00	13.59
	0.00136	2211.1	2.585	1757.61	855.28
FZI CUT#1 NO BREAK		1.50	0.0120	0.50	
	0.01800	50.0	18.000	737.78	2.78
	0.00095	950.0	2.944	1009.33	322.64
F CUT#1		1.50	0.0135	0.75	
	0.02025	414.8	9.200	1703.70	45.09
	0.00199	4231.1	2.322	2016.81	1821.88
F CUT #2		1.50	0.0135	0.75	
	0.02025	503.7	9.733	2095.14	51.75
	0.00189	5406.4	2.373	2533.96	2277.97
FX #1		1.50	0.0130	0.75	
	0.01950	466.7	6.533	1730.60	71.43
	0.00259	3515.6	2.019	2041.76	1740.94
FX #2		1.50	0.0130	0.75	
	0.01950	446.2	7.733	1787.01	57.69
	0.00223	3896.4	2.167	2198.31	1797.94
FZY CUT#1		1.50	0.0135	0.75	
	0.02025	444.4	7.067	2186.01	62.89
	0.00251	3585.2	2.088	2842.08	1717.26
FZY CUT#2		1.50	0.0135	0.75	
	0.02025	246.9	5.333	944.86	46.30
	0.00320	1563.8	1.846	1251.47	847.20
83001F 4% DEP; 4% CARBITOL					
	0.	0.	0.	0.	0.
FW CUT 2		1.50	0.0110	0.75	
	0.01650	254.5	10.133	1267.88	25.12
	0.00148	2833.9	2.410	1535.46	1175.94
FWZ 40UV;#1		1.50	0.0100	0.75	
	0.01500	2700.0	4.133	6398.67	653.23
	0.00292	13860.0	1.636	7387.04	8473.15
FWZ 40UV;#2		1.50	0.0100	0.75	
	0.01500	2600.0	3.200	5388.89	812.50
	0.00357	10920.0	1.435	6160.93	7609.31
FWZ #1; 40HR UV		1.50	0.0105	0.75	
	0.01575	952.4	5.333	2827.51	178.57
	0.00249	6031.7	1.846	3452.58	3267.77

```
84002F     3.75% DIETHYLPHTHALATE; 2.5% CARBITØL
               0.        0.        0.       0.       0.

       F2W    CUT 1                       1.50  0.0125     0.75
                 0.01875          453.3        10.533     2230.04       43.04
                 0.00163         5228.4         2.445     2634.17     2138.21

       F2W    CUT 2                       1.50  0.0125     0.75
                 0.01875          442.7        11.333     2418.49       39.06
                 0.00152         5459.6         2.512     2770.79     2173.13

86002F     3.74% DEP;1.26% CARBITØL; FØAMY
               0.        0.        0.       0.       0.

       FW     CUT 4                       1.50  0.0120     0.75
                 0.01800          683.3         8.667     2693.70       78.85
                 0.00186         6605.6         2.269     3073.27     2911.62

       FWZ  40UV;#1                       1.50  0.0125     0.75
                 0.01875         1440.0         3.600     4012.80      400.00
                 0.00408         6624.0         1.526     4506.69     4340.60

91002F     3.8% DEP;.7% CARBITØL;NEEDS DAY FØR FØAM RELEASE
               50.00     0.        0.       0.       0.

       FW     CUT 1                       1.50  0.0125     0.75
                 0.01875         1402.7         8.267     4290.84      169.68
                 0.00202        12998.0         2.226     4782.46     5838.08

       FWZ  40UV;#1                       1.50  0.0125     0.75
                 0.01875         1930.7         3.867     5419.02      499.31
                 0.00385         9395.9         1.582     6028.69     5937.73

       FWZ  40UV;#2                       1.50  0.0125     0.75
                 0.01875         2080.0         4.400     5717.33      472.73
                 0.00347        11232.0         1.686     6410.93     6660.35

       F      #2                          1.50  0.0125     0.75
                 0.01875         1002.7         9.333     3165.16      107.43
                 0.00181        10360.9         2.335     3532.28     4436.50

       F!     CUT#1                       1.50  0.0130     0.50
                 0.01950          210.3        13.400     2034.36       15.69
                 0.00135         3027.7         2.667     2361.58     1135.15

       F!     CUT #2                      1.50  0.0130     0.50
                 0.01950          215.4         9.200     1200.51       23.41
                 0.00191         2196.9         2.322     1457.26      945.98
```

```
F%     CUT#1               1.50 0.0130    0.75
        0.01950      1794.9       0.267     242.74     6730.77
        0.01539      2273.5       0.236     257.35     9617.65

F%     CUT#2               1.50 0.0130    0.75
        0.01950      1846.2       0.533     283.76     3461.54
        0.01272      2830.8       0.427     301.87     6622.55

84001F    10% DBP; G00D FILM
        4.20    0.      0.    0.      0.

    FW  #2                 1.50 0.0130    0.75
        0.01950       400.0       8.933    1919.66       44.78
        0.00196      3973.3       2.296    2183.73     1730.62

    FW  #1;5HR@150F        1.50 0.0130    0.50
        0.01950       584.6      14.200    4720.00       41.17
        0.00128      8886.2       2.721    5383.20     3265.41

    FWZ2 #2; 40HR UV       1.50 0.0150    0.75
        0.02250       226.7      11.467    1402.96       19.77
        0.00180      2825.8       2.523    1607.76     1119.98

    F!  CUT#1              1.50 0.0130    0.50
        0.01950       179.5       6.000     658.97       29.91
        0.00279      1256.4       1.946     796.88      645.67

    F!  CUT #2             1.50 0.0130    0.50
        0.01950       169.2       6.200     624.62       27.30
        0.00271      1218.5       1.974     742.73      617.23

    F%     CUT#1           1.50 0.0130    0.75
        0.01950      2230.8       0.133     148.72    16730.77
        0.01721      2528.2       0.125     158.22    20199.28

    F%     CUT#2           1.50 0.0130    0.75
        0.01950      1589.7       0.133     105.98    11923.08
        0.01721      1801.7       0.125     112.75    14394.89

        36001H    HYCAR 2679X6; UNABLE T0 PREPARE FILM
                  2.00     5.0    48.5   1.060 0.

162003I    NATL. STARCH 1251;N.M.;PVA-C0P0LY.;MIN FILM 0C.
        38.00     4.8    55.0   1.058  0.

    IZ% CUT#1              1.50 0.0110    0.75
        0.01650       666.7       0.133      44.44     5000.00
        0.01456       755.6       0.125      47.28     6036.57

    IZ% CUT#2              1.50 0.0110    0.75
        0.01650       545.5       0.133      36.36     4090.91
        0.01456       618.2       0.125      38.69     4939.01
```

I% CUT#1		1.50	0.0150	0.75	
	0.02250	1155.6	0.133	77.04	8666.67
	0.01985	1309.6	0.125	81.96	10463.38
I% CUT#2		1.50	0.0150	0.75	
	0.02250	533.3	0.133	35.56	4000.00
	0.01985	604.4	0.125	37.83	4829.25
I! CUT#1		1.50	0.0120	0.75	
	0.01800	116.7	12.000	942.59	9.72
	0.00138	1516.7	2.565	1159.86	591.30
IZ! CUT#1 NO BREAK		1.50	0.0110	0.50	
	0.01650	18.2	18.000	255.76	1.01
	0.00087	345.5	2.944	404.94	117.32
I CUT #1		1.50	0.0110	0.75	
	0.01650	1060.6	5.733	3828.28	184.99
	0.00245	7141.4	1.907	4481.73	3744.70
I CUT #2		1.50	0.0110	0.75	
	0.01650	1060.6	5.467	3952.32	194.01
	0.00255	6858.6	1.867	4803.38	3674.25
IX CUT#2		1.50	0.0140	0.75	
	0.02100	1190.5	6.267	5793.65	189.97
	0.00289	8650.8	1.983	6683.30	4361.82
I CUT#1 HLA 136HR		1.50	0.0120	0.75	
	0.01800	1472.2	8.800	9593.70	167.30
	0.00184	14427.8	2.282	10808.28	6321.37
I CUT#2 HLA 136HR		1.50	0.0120	0.75	
	0.01800	1250.0	4.800	4114.81	260.42
	0.00310	7250.0	1.758	4974.73	4124.34
IZY CUT#1		1.50	0.0130	0.75	
	0.01950	1153.8	5.733	5251.28	201.25
	0.00290	7769.2	1.907	6546.43	4073.91
IZY CUT#2		1.50	0.0130	0.75	
	0.01950	666.7	3.200	1794.87	208.33
	0.00464	2800.0	1.435	2068.71	1951.10

```
      IY     CUT#1              1.50 0.0140    0.75
               0.02100       761.9       3.733    2244.44      204.08
               0.00444      3606.3       1.555    2725.85     2319.75

      IY     CUT#2              1.50 0.0140    0.75
               0.02100      1452.4       6.933    6447.62      209.48
               0.00265     11522.2       2.071    8184.98     5563.41

1970011J   N.S.1251:N.S.2813; 1:1;
             2.40    0.      0.      0.      0.

      IJ     CUT#1              1.50 0.0110    0.75
               0.01650       600.0       8.933    2900.20       67.16
               0.00166      5960.0       2.296    3363.38     2595.94

      IJ     CUT#2              1.50 0.0110    0.75
               0.01650       545.5       7.333    2400.81       74.38
               0.00198      4545.5       2.120    2848.45     2143.82

      IJ!    CUT #1             1.50 0.0120    0.50
               0.01800        83.3      18.000    1148.89        4.63
               0.00095      1583.3       2.944    1432.72      537.74

      IJ%     CUT#1             1.50 0.0125    0.75
               0.01875      3040.0       0.133     202.67    22800.00
               0.01654      3445.3       0.125     215.61    27526.74

      IJ%     CUT#2             1.50 0.0125    0.75
               0.01875      2613.3       0.133     174.22    19600.00
               0.01654      2961.8       0.125     185.35    23663.34

2050011J   N.S.1251:N.S.2813, 2:1;
             34.50    0.      0.      0.      0.

      IJ     CUT#1              1.50 0.0130    0.75
               0.01950       641.0       8.000    3261.54       80.13
               0.00217      5769.2       2.197    4306.06     2625.69

      IJ     CUT#2              1.50 0.0130    0.75
               0.01950       769.2       7.067    3136.75      108.85
               0.00242      6205.1       2.088    4139.74     2972.17

      IJ     CUT#1              1.50 0.0135    0.75
               0.02025       785.2       7.200    3878.19      109.05
               0.00247      6438.5       2.104    4332.51     3059.94

      IJ     CUT#2              1.50 0.0135    0.75
               0.02025       745.7       9.600    5001.15       77.67
               0.00191      7904.2       2.361    5761.75     3348.02
```

```
IJ! #1 NØ BR.            1.50 0.0140  0.50
         0.02100    100.0      18.000   1393.81      5.56
         0.00111   1900.0       2.944   1654.81    645.28

IJ%    CUT#1             1.50 0.0130  0.75
         0.01950   2153.8       0.133    143.59   16153.85
         0.01721   2441.0       0.125    152.76   19502.75

IJ%    CUT#2             1.50 0.0130  0.75
         0.01950   2615.4       0.133    174.36   19615.38
         0.01721   2964.1       0.125    185.50   23681.91

204001JF   N.S.2813;N.S.1025;2:1;  3.5% DBP; 2% BUTY. CELLØS.
         1.20    0.     0.     0.      0.

JF!  CUT #2              1.50 0.0130  0.50
         0.01950    153.8      14.800   1274.87     10.40
         0.00123   2430.8       2.760   1610.30    880.71

JF%    CUT#1             1.50 0.0130  0.75
         0.01950   2076.9       1.600   2917.95   1298.08
         0.00750   5400.0       0.956   4247.73   5651.42

JF%    CUT#2             1.50 0.0130  0.75
         0.01950   2102.6       2.400   4167.52    876.07
         0.00574   7148.7       1.224   6809.83   5841.53

JF   CUT #1              1.50 0.0115  0.75
         0.01725    382.6       6.800   2193.62     56.27
         0.00221   2934.3       2.054   2870.28   1452.86

162002J    NATL. STARCH 2813;N.M.;SELF REACT.VIN ACRY TERPØLY;
         3.00    4.6    45.0   1.058  0.

JZ% CUT#1                1.50 0.0120  0.75
         0.01800   1944.4       0.667    988.89   2916.67
         0.01080   3240.7       0.511   1083.28   6344.12

JZ% CUT#2                1.50 0.0120  0.75
         0.01800   2166.7       0.933   1625.93   2321.43
         0.00931   4188.9       0.659   1854.72   6354.06

J  % CUT#1               1.50 0.0135  0.75
         0.02025   2617.3       5.067  11562.14    516.57
         0.00334  15878.2       1.803  13799.00   8807.47

J%   CUT#2               1.50 0.0135  0.75
         0.02025   1925.9       4.000   6846.09    481.48
         0.00405   9629.6       1.609   8220.50   5983.23
```

```
J!   CUT #1                1.50 0.0125    0.75
         0.01875        74.7      12.000     445.51        6.22
         0.00144       970.7       2.565     563.72      378.44

J    CUT#1 NØ BREAK        1.50 0.0140    0.75
         0.02100       171.4      12.000    1634.92       14.29
         0.00162      2228.6       2.565    1957.04      868.86

J    CUT#2 NØ BREAK        1.50 0.0140    0.75
         0.02100       209.5      12.000    1722.22       17.46
         0.00162      2723.8       2.565    2083.12     1061.94

JZ    CUT#2                1.50 0.0100    0.75
         0.01500       466.7       6.267    1624.00       74.47
         0.00206      3391.1       1.983    1995.60     1709.83

JX   #1                    1.50 0.0125    0.75
         0.01875       277.3       5.333     894.58       52.00
         0.00296      1756.4       1.846    1087.33      951.58

JZX CUT#1                  1.50 0.0130    0.75
         0.01950       384.6       4.400    1162.39       87.41
         0.00361      2076.9       1.686    1588.65     1231.57

JZY   CUT#1                1.50 0.0140    0.75
         0.02100       357.1       6.133    1576.19       58.23
         0.00294      2547.6       1.965    1867.75     1296.64

JY    CUT#1                1.50 0.0150    0.75
         0.02250       400.0       9.333    2059.26       42.86
         0.00218      4133.3       2.335    2574.16     1769.88

70001K     GEØN 460X1;N.M.;STRETCHY FILM
             2.00    2.2   51.2   1.120 0.370

133001K    SAME AS 70001K,NEWER SAMPLE
             2.00    2.2   51.2   1.120 0.370

  K    #1;1HR@160F          1.50 0.0200    0.75
         0.03000      1883.3       7.333   10760.00      256.82
         0.00360     15694.4       2.120   12429.83     7402.12

  K%   #1 4HR@160F          1.50 0.0160    0.75
         0.02400      5291.7       2.267    5855.56     2334.56
         0.00735     17286.1       1.184    6863.66    14602.59

  K%   #2 4HR@160F          1.50 0.0160    0.75
         0.02400      4916.7       5.867   23647.22      838.07
         0.00350     33761.1       1.927   28772.73    17522.96
```

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        K1   #1                     1.50 0.0160    0.75
               0.02400       483.3       11.333    2313.89        42.65
               0.00195      5961.1        2.512    2857.16      2372.77

        K    CUT#1 HC&HLA           1.50 0.0140    0.75
               0.02100      1785.7        4.267    5357.14       418.53
               0.00399      9404.8        1.661    6293.91      5660.75

        K    CUT#2 HC&HLA           1.50 0.0140    0.75
               0.02100      1857.1        6.533    8488.89       284.26
               0.00279     13990.5        2.019   10105.59      6928.25

  70006L     BØRDEN PØLYCØ 804; PVA CØPØLYMER
              0.      0.      0.     0.      0.

        L1   CUT 1                  1.50 0.0160    0.75
               0.02400       112.5       12.267    1003.06         9.17
               0.00181      1492.5        2.585    1147.55       577.31

1620010      NATL. STARCH 2333;N.M.;SFLF REACT.VIN-ACRY TERPØLY
              3.00    4.6   45.0   1.058 0.
NØ TEST DATA

139C01R      HYCAR 1570X36; NØ SATISFACTORY FILM ØBTAINED
              0.14    3.3   40.2   0.      0.

  97003S     UCAR 180;VIN-ACRY,CAT;CLEAR FILM
              3.00    4.8   55.0   1.080 0.

        S    CUT #2                 1.50 0.0140    0.75
               0.02100       161.9       19.867    1834.92         8.15
               0.00101      3378.4        3.038    2260.01      1112.00

  97001T     UCAR 360;VIN-ACRY;N.M.;CLEAR FILM
              5.00    4.5   55.0   1.080 0.

        T    CUT 1                  1.50 0.0145    0.75
               0.02175       133.3        9.067     705.29        14.71
               0.00216      1342.2        2.309     838.83       581.24

104001V      UCAR 130;PVA;N.M.
              20.00   5.0   58.0   1.104 0.
NØ TEST DATA
```

C. CASE STUDIES

A thorough discussion of all the data recorded in this report would be endless. Naturally, any material which would show the best performance in all the tests would be rated excellent. Also, the type of climate in which the material is to be used would alter the physical properties desired in a material. Many of the materials exhibited very similar performance. In such cases, cost becomes important. Otherwise, the data is presented for reader use in formulation of his own conclusions. A few case studies are included at this time to familiarize the reader with the inferences of some of the data.

1. Plasticized Systems

Three basic polyvinyl acetate homopolymers were tested. These were National Starch's 1025 and 1105 and Union Carbide's Ucar 130. All of these materials require plasticizing to obtain flexible films. These three materials react similarly to the addition of modifiers. Most of the tests were run on 1025 (code letter F). Formulation 85003F was this basic material, but testing was impossible because of the brittleness of the unmodified material. Formulations 64001F, 64003F, 70011F, 107001F, 146001F, 83001F, 84002F, 86002F, 91002F, and 84001F were plasticized versions of the basic material. Formulation 107001F (3.74% diethyl phthalate and 1.26% dibutyl phthalate added) seemed to be the best of the blends tested, producing a toughness in the 5000-6000 range. This blend also fared well in the 120°F tests but suffered embrittlement at 32°F, as did most of the plasticized materials. It appears that the plasticizers did not reduce water resistance, i.e., the water spray (Z code) did not significantly reduce strengths.

2. Flexibilized Systems (Copolymers)

All the polymer emulsions tested besides the PVA homopolymers were of the copolymer variety and usually very flexible (codes A, B, I, and J, for example). Elongations at rupture ($100\epsilon_u$) typically ranged from 1000-1200%. These materials also performed very well at 32°F, elongations seldom falling below 150% as compared to 10% for most of the plasticized materials. But, as to be expected, the flexible copolymers also tended to become rubbery at higher temperatures, elongations exceeding 1500% at 120°F with a significant loss of tensile strength (S), usually falling to less than 200 psi. Formulation 40002A, which was an unmodified vinyl acetate ethylene copolymer, is a good illustration of this, exhibiting good tensile strengths (~ 2000 psi) and good flexibility (450%) producing toughness in the range 9000 to 10,000. The only other material that performed equivalently at 32°F was Geon 460 x 1 (code K) which must be initially dried at higher temperatures.

National Starch 1251 (code I) was another material worthy of mention. This material is recommended for applications at higher temperatures (60 to 140°F). Films from this material were aged under a heat lamp (Formula No. 162003I). After 130 hours, no decrease in flexibility (480 to 570%) was noticed. Increase in tensile strength did occur (improved from 1060 psi to about 1350 psi), resulting in higher toughness values.

3. Blends

Most of the flexible copolymers tended to be over flexible. Several attempts were made to compromise between the properties of a rigid homopolymer and those of the more elastic copolymers. Formulation 141001BF and 173001BF were such blends. However, the elongations at lower temperatures failed to improve.

Another blend, formulation 204001JF (a homopolymer, copolymer, and plasticizer) showed significant improvement at 32°F over the basic plasticized homopolymer without loss of strength at 120°F. This blend was the most successful compromise.

4. Incorporation of Mats or Scrims

Formulas 91003A, 91001A, 106002B, and 19001B include the incorporation of some type of matting. In this sort of application, the matting would be laid in place before the application of the polymer emulsion.

In formulas 91001A and 91003A, two different types of inexpensive paper weavings were saturated with emulsion. In both cases, the maximum tensile strengths before rupture were raised but the maximum elongations were decreased significantly, producing a weaker membrane.

In formulas 106002B and 19001B, fiberglass scrims were cast into a layer of emulsion. An eightfold increase in tensile strengths (from 500 psi to 4000 psi) was realized but again at the expense of maximum elongation, which dropped from 1050% to 150%. These types of materials may have special applications, but it is felt that very little, if any, benefit is gained for the additional handling involved in their application.

D. TESTING AT WATERWAYS EXPERIMENT STATION

A variety of samples were sent to Waterways Experiment Station for testing to include application ease, drying speed, water spray, wind erosion, and heat resistance. In all, six materials were tested. One material was of the flexible copolymer variety, number 034001B; one was of the typical plasticized variety, number 107001F; and four were blends of materials, numbers 173001BF, 104001JF, 196001AF and 205001IJ. The two best applying materials were 034001B and 107001F. Since no material was less expensive than 034001B, nor did any other material offer sufficient improvement to warrant higher cost, 034001B was selected as the best material of the materials examined during this study.

E. LARGE SCALE PLOTS

Three random selected formulations were applied at 5 pounds per square yard over 10-foot by 20-foot test plots of dry black chernozemic soil. A small gear pump was used to supply three fan-spray nozzles each of 0.030-inch orifice. The delivery rate was approximately five gallons per minute. Application was made at an ambient temperature of 92°F, soil temperature of 125°F.

Sample	Results
04002A	Very foamy appearance, some puddling. Remained tacky after dry.
196001AF	Smooth film. Reduced foaming. Slight tackiness. Cracking.
162003I	Very smooth film. No foaming. No tackiness.

None of the materials were reduced (no water added) and all pumped easily with a good spray pattern.

IV. CONCLUSIONS AND RECOMMENDATIONS

1. All the PVAs, or copolymers, tested were affected by water spray as noted by cloudiness, but none of the materials degraded to the extent that strength was not recovered after drying.
2. Sophisticated equipment is not necessary for application of the polymer emulsions studied. Fan-spray nozzles and gear pumps are sufficient.
3. The use of scrim as a preplaced structure before the application of polymer emulsions is beneficial to tensile strength, but is harmful to ultimate elongation.
4. The plasticized materials were generally better at higher temperatures and the flexibilized materials (copolymers) performed better at lower temperatures.
5. A variance of 5 to 70 percent in the results from the tensile testing scheme was typical due to the difficulty of preparing perfect test specimens. Repeated tests are recommended to establish an accurate range of values.
6. The inherent physical properties of a film cast from an emulsion can be determined and these tests give insight into the worthiness of a material as a dust palliative by establishing minimum values for a material's tensile strength and ductility.
7. There was no correlation between the appearance of bacteria or fungi growth on a film and the changes in physical properties of that same film for 14-day exposures, or less.
8. Comparison of physical properties, as measured in this study, and the performance of these materials on a large-scale basis in field use would provide feedback to further establish the type of materials that would perform best in various climates.
9. It is recommended that, for use of these dust control materials in extreme hot or cold climates, this report be consulted for selection of the proper material.
10. The testing technique described is an excellent medium to test the effect of special additives such as buffers, bacteriocides, wetting agents, fillers, and the like.

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Appendix A

PROCUREMENT SPECIFICATIONS FOR A DUST PALLIATIVE MATERIAL

Contract DACA-39-70-C-0012

MATERIAL DESCRIPTION

The following specifications are supplied as procurement information to aid the Government in selecting dust palliative polymer emulsions. This material is an internally flexibilized polyvinyl acetate alkyl maleate copolymer of high ductility.

WET PHYSICAL PROPERTIES

These properties describe the basic material, before application, as packaged in the receiving container.

Viscosity - as measured on a Brookfield Model LV viscosimeter with a No. 2 spindle at 20 rpm. Range: 800 - 1,200 centipoise.

Percent Solids - 55 to 57%

pH - 4.5 to 5.5

Specific Gravity - 1.08 to 1.1 (9.0 to 9.2 lbs/gal)

APPLICATION

1. The material must be applicable with fan nozzles and gear pumps.
2. If the material is to be diluted (with water only), the total applied volume shall not exceed two gallons per square yard of treated ground surface. Typical application rates range from 3 to 7 pounds per square yard.
3. The materials must also be compatible with fiberglass scrim, which can be used in conjunction with the emulsion.
4. The material must not contain any substances which could be hazardous to human beings or animals and must be nonflammable.

5. The material must dry tack free to cotton in 3 1/2 hours, or less, when applied to a non-absorbent surface (glass for example, solely for the purpose of establishing dry time) at 25°C, 50% humidity, and at a wet film thickness of .030 inch.
6. The material must dry to form a continuous film which will meet the minimum film performance specifications at any temperature from 8°C to 55°C.

STORAGE

1. The materials should be supplied in containers found best for maximum storage times. Lined steel 55-gallon drums or polyethylene bagged steel drums are suitable storage containers.
2. The incorporation of additional mercury bacteriocides is recommended for extended storage.
3. Ideal storage temperature is 75°F. Deterioration should not be noted for one year at this temperature. Deviation from this temperature shortens storage life. For shorter storage periods, reasonable temperature limits would be 40°F to 110°F.
4. Material which has degraded during storage can be identified by an obvious sour odor and/or a decrease in viscosity. The material cannot meet performance specifications.

PERFORMANCE

The following properties reflect the physical characteristics of the dried film.

Film Preparation and Test Procedures

Films for obtaining the following properties will be prepared by applying a .030-inch film on glass and dried at 75°F, 50% humidity, which results in a film of .012- to .018-inch thickness. This film will then be tested by normal tensile procedures as described in ASTM D882-64T. The film must exhibit the following minimum strengths at the specified temperature.

Minimum Values for Film Properties

Nominal Property	32°F	75°F	120°F
Tensile Strength (psi)	2,000	400	15
Strain (inches/inch)	1.4	8.5	15.0
Approximate Toughness	2,800	3,400	225

The above values reflect a typical performance of the material under consideration.

Resistance of the Prepared Film to Environment

1. The prepared film must not dissolve when exposed to water.
2. The film must not suffer embrittlement or other deviations beyond the minimum physical specifications when exposed to ultraviolet light, bacteria, and fungi for the specified performance period.