R 612

Technical Report

PLASTIC FILM COATINGS FOR PROTECTION FROM MARINE FOULING AND CORROSION

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PLASTIC FILM COATINGS FOR PROTECTION FROM MARINE FOULING AND CORROSION

Technical Report R-612

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by

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ABSTRACT

Saran and polytetrafluoroethylene (TFE) films with a pressure-sensitive adhesive were applied over the surfaces of painted and unpainted carbon steel panels and unpainted stainless steel and K-Monel panels. These panels were submerged in the sea to determine if the plastic film coverings can be effectively used to (1) protect painted as well as unpainted metal specimens from fouling and corrosion; (2) remove marine growth that becomes attached to the plastic film simply by stripping off the covering; and (3) prolong the fouling-free and corrosion-free intervals so as to decrease the total effort required for reconditioning fouled or corroded surfaces. The saran- and TFE-covered panels were exposed in the sea for 5 and 8.5 months, respectively. When retrieved, the panels were completely covered with marine growth, including numerous large barnacles. Generally, the plastic films protected the test panels from fouling and corrosion. The marine growth could be removed rapidly by stripping off the protective plastic covering. Crevice corrosion will occur under the protective plastic film on susceptible metal panels, such as stainless steel (type 302), when a small amount of seawater enters through ruptures.

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INTRODUCTION

Oceanographic instruments, ships' hulls, buoys, and other structures submerged in the sea eventually become either heavily fouled with biological growth or severely corroded. A short time after submergence such objects become covered with "primary film." This film is composed of microorganisms such as bacteria, yeast, and diatoms.[1] Following the formation of primary film, larger biological organisms such as hydroids, algae, barnacles, tubeworms, mussels, and bryozoans become attached to the surfaces of the materials. Some of the detrimental effects to equipment caused by the fouling of materials are summarized in Table 1.

Table 1. Effects of Fouling on Submerged Objects*

Ship hulls	Fouling increases resistance to motion, thereby reducing a ship's speed and increasing fuel consumption. Increases frequency of dry-docking periods.
Underwater sound equipment	Fouling reduces sensitivity and sound transmission and decreases effectiveness of sound gear by increasing cavitation noise. Measurement of beam pattern and receiving response of fouled underwater transducers show reduction of axial sensitivity ranging from 0 to 10 db in frequency intervals of 1 to 20 kHz.
Salt water pipe system in vessels, industrial power plants, and desalting plants	Fouling on pipe inner surfaces reduces pipe diameter and water flow. Detached organisms (mussel shells) block water flow at valves, at screens, and at constricted places in pipes.
Metallic surfaces	Pitting occurs under shells of dead barnacles, created by oxygen concentration cells. Conditions favorable to corrosion are produced by metabolic products—particularly acids and sulfides. Sulfate-reducing bacteria promote anaerobic corrosion.
Protective coatings	Fouling damages coatings in several ways: when a barnacle shell adhering to the coating is torn loose for any reason, the underlying paint comes off with it; paint film is weakened at the site of attachment due to metabolic products; the sharp edges of barnacle shells cut into the coating as the animals grow, eventually exposing the underlying surface. Paints are also destroyed by seawater bacteria that attack the resin.
Plastic and glass surfaces	Windows of underwater structures and camera lenses become blocked and require frequent cleaning.

* From Reference 2.

For protection from fouling and corrosion, various coatings and antifouling paints are used as seawater barriers. For maximum effective adhesion to the surfaces of metals, the right coating must first be selected, next the protective coating must be carefully prepared, and finally, the coating system must be carefully applied during ideal environmental conditions. Depending upon the severity of use, rate of water flow, water temperature, biological activity, and other factors involved, the existent protective coating—antifouling system for ships (bottom) and for buoys lasts from 1 to 3 years.[3] The sections that become fouled and corroded must then undergo a costly and time-consuming process of reconditioning, which includes scraping or sandblasting and a new application of protective coatings.

Of the many fouling organisms which become attached to the surfaces of submerged objects, barnacles, whether dead or alive, are the most difficult to remove. Because of the tenacity with which the barnacles are able to cement themselves to various types of surfaces, a study to determine the composition of the barnacle cement has been initiated.[4]

Various methods other than the application of antifouling paint systems have been used either to kill existing marine growth or to prevent or discourage further marine growth on submerged objects in the sea. These include the use of (1) hot water,[5] (2) chlorine,[6] (3) alternating electrical current,[7] and (4) plastic and cupro-nickel barrier wrappings.[8]

The present study involves the use of thin plastic films with a pressure-sensitive adhesive backing placed over smooth, clean surfaces (whether painted or unpainted) of carbon steel, stainless steel, and K-Monel. The purpose of this study is to determine if the strippable plastic films can be effectively used to

1. Protect painted as well as unpainted metal surfaces from fouling and corrosion.

2. Prolong the fouling-free and corrosion-free intervals so as to decrease the total effort required for reconditioning fouled or corroded surfaces.

3. Remove barnacles, tubeworms, encrusting bryozoans, and other sessile organisms that become attached to the plastic film, simply by stripping off the plastic film.

Table 2. Characteristics of Plastic Films

Plastic Film	Basic Material	Pressure-Sensitive Adhesive Backing	Thickness With Adhesive Backing (in.)	Width of Material (in.)	Cost Per Square Foot* (dollars)
Skived TFE Film, No. "T"†	polytetrafluoroethylene resin	silicone polymer	0.006	12	2.75
Glass-fiber coated with TFE, No. "A2005"†	polytetrafluoroethylene resin	silicone polymer	0.005	12	2.50
Saran‡	vinylidene chloride resin	blend of crude and synthetic rubber with a modified wood resin tackifier	0.003	6	0.25

* Price for small quantities.

† Comes in rolls with paper backing strip.

‡ Comes in rolls without paper backing strip.

MATERIALS AND METHODS

Two types of polytetrafluoroethylene (TFE) films and a saran film, each with pressure-sensitive adhesive backing, were used in this study. The information on thickness, width, adhesives, and costs is presented in Table 2. These plastic films were selected primarily because of their resistance to solvents and other chemicals, low water absorption, and moisture permeability. In addition, they have a high electrical resistance and are nonflammable, nontoxic, tough, and abrasion-resistant. The biggest difference between TFE and saran is their cost. As shown in Table 2, TFE costs about 10 times more than saran.

Test Panels

A total of fifteen 6 x 12-inch test panels was used in this study (Table 3). Carbon steel, stainless steel, and K-Monel were selected because they are known to corrode in seawater, the object being to determine if the plastic films would protect these metals from corrosion and fouling. Marine paint was applied to the carbon steel panels to determine if the pressure-sensitive adhesive backing on the plastic films would stay attached to the smooth painted surface for long periods of exposure in the sea and if the strippable plastic films would give adequate fouling protection.

Application of Plastic Films

Before the plastic films were applied to the unpainted metal surfaces, the panels were cleaned with alcohol to remove any grease and dust particles. The eight carbon steel panels were sandblasted to a "white metal" surface, and then four of them were spray-painted with the following paint system: first coat—Formula 117, a pretreatment primer (MIL-P-15328B); second coat—Formula 119, a vinyl primer (MIL-P-15929); third coat—Formula 122-82, a white cover paint. The cost of preparing the carbon steel panels, including labor and material, was estimated to be $0.83/sq ft.

It was slightly difficult to apply the plastic film smoothly over the test surfaces without forming air bubbles underneath the plastic film, especially when applied by one person alone. The glass-fiber coated with TFE was much easier to apply than the skived TFE film or the saran film because it was much firmer and stiffer to handle. The edges of the skived TFE and the saran film tended to curl during the application process, thereby making it difficult for one person to apply it smoothly over the test surface. However, all the films could be applied fairly rapidly: it was estimated that the application process of each panel took 5 minutes or less to complete. The pressure-sensitive adhesive backing of TFE and saran film adhered to the clean painted and unpainted test surfaces very well. Figures 1 and 2 show this adhesive quality.

Table 3. Panels Used in Exposure Tests

Metal	Painted Panels			Unpainted Panels		
	TFE Films	Saran Film	Control (no film)	TFE Films	Saran Film	Control (no film)
Carbon steel	2	1	1	2	1	1
Stainless steel	—	—	—	2	1	1
K-Monel	—	—	—	2	—	1

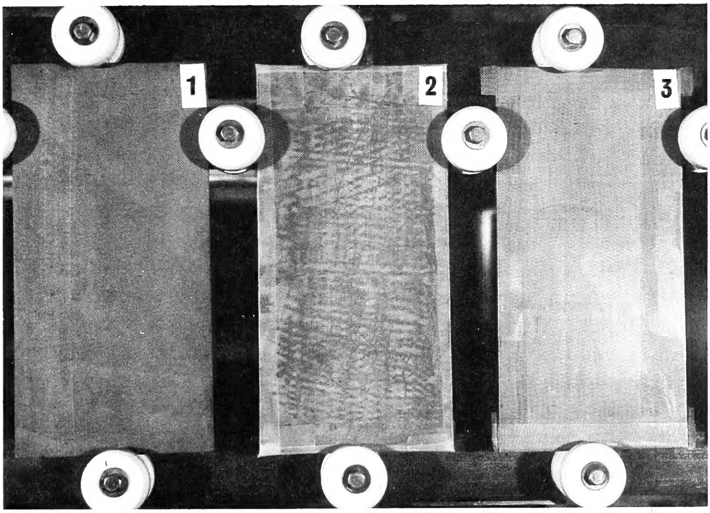

Figure 1. Unpainted carbon steel panels with TFE film. Panel 1 is a control panel.

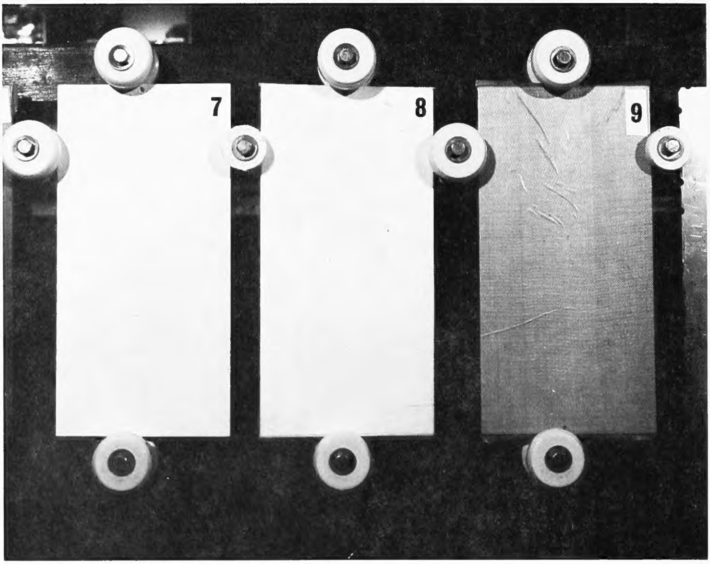

Figure 2. Painted carbon steel panels with TFE film. Panel 7 is a control panel.

Exposure Site

A site was desired where the test specimens would be exposed to biological growth and subjected to the strong tidal currents, high waves, and rough sea conditions encountered during storms. Such a test site was provided near the end of the 400-foot-long Point Mugu pier, which is located at the head of the Mugu Submarine Canyon (Figure 3).

The test panels were placed in a metal rack. The individual panels were held separately and securely in place by four ceramic insulators (see Figures 1 and 2). The ceramic insulators also served to prevent galvanic corrosion, which is caused by the presence of an electrical circuit between two dissimilar metals. The racks with the test specimens were lowered from the pier and submerged approximately 15 feet below high tide level. At high tide the water depth is about 20 feet at the exposure site.

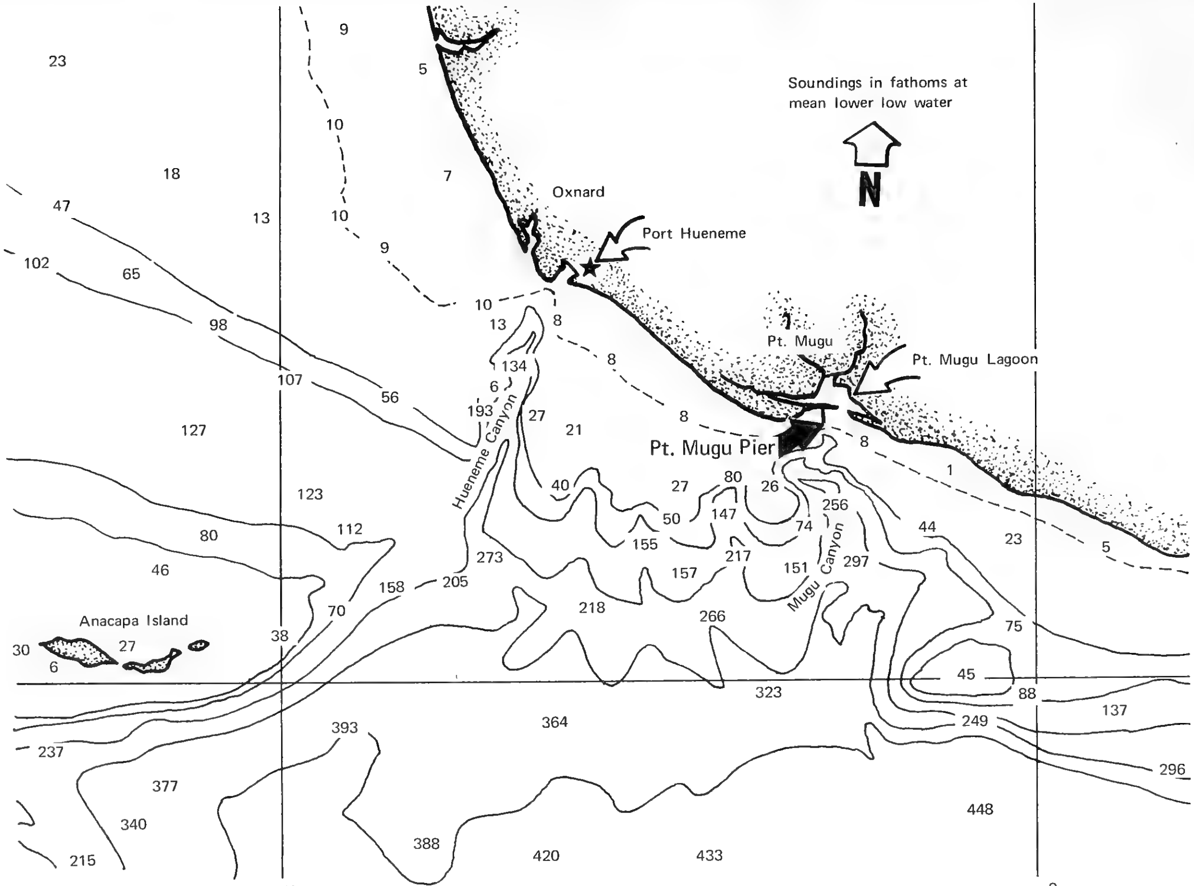

Figure 3. Point Mugu pier in relation to local offshore topography.

RESULTS AND DISCUSSION

Fouling Accumulation

The saran-covered panels were retrieved from the sea after 5 months of continuous exposure and the TFE-covered panels after 8.5 months. The saran and TFE films were in very good condition when recovered. Probably these films could be left in the sea for many additional months to serve as protective coatings. The saran-covered test panels and the TFE-covered test panels (Figures 4 and 5) were completely encrusted with marine growth. The fouling accumulation was composed mostly of hydroids, bryozoans, barnacles, tubeworms, and mussels.

There was an average of 75 barnacles securely attached to the surface of each of the eight TFE-covered panels. The barnacles and tubeworms were covered and hidden among dense growths of hydroids and bryozoans. The average wet weight of fouling accumulation, including barnacles and mussel shells, was about 700 grams per panel (1 square foot).

Figure 4. Biological growth over K-Monel steel panels.

Figure 5. Biological growth over painted carbon steel panels.

Saran-covered panels were also laden with marine growth composed mostly of hydroids and barnacles as well as some colonial tunicates, bryozoans, and algae. Mussels and tubeworms, which were found on TFE, were absent from saran, probably because the latter was placed in the sea at a different time of the year. There were 14 to 44 barnacles, measuring up to 1 inch in diameter at the base, attached to the surface of the saran-covered panels; the average wet weight of fouling accumulation was about 400 grams per panel.

Table 4 lists the kinds of fouling organisms found on the test panels. There was much less fouling on the control panels of unpainted carbon steel and K-Monel than on the painted and plastic-covered carbon steel panels. This may be due to the thin layers of corrosion products formed over the control panels. Such corrosion products may have discouraged the settling of fouling organisms.

Table 4. Fouling Organisms on Test Panels Exposed at Point Mugu Pier*

Animals	Plants
Phylum Coelenterata—Class Hydrozoa	Phylum Rhodophyta
Campanularia flexuosa	*Porphyra* sp.
Obelia sp.	*Dasya sinicola*
	Chondria nidifica
Phylum Arthropoda	
Balanus crenatus	Phylum Chlorophyta
Balanus glandula	*Ulva* sp.
Balanus tintinnabulum	
Caprella sp.	
Chiton	
Phylum Mollusca	
Membranipora sp.	
Crisia sp.	
Bugula sp.	
Phylum Chordata	
Ascidians	
Colonial tunicates	
Phylum Annelida (segmented worms)	
Nereis sp.	
Serpulids (tube dwellers)	
Calcareous tube dwellers	
Parchment tube dwellers	

* Major sessile organisms and plants on test panels.

The biological growth, such as bryozoans, hydroids, and algae, could be scraped off the panels without too much difficulty; however, some small structures of the animals and plants would remain firmly attached to the panels. Mussel shells and the calcareous tubes of tubeworms were slightly more difficult to remove from the surfaces of the panels. The animal growths most difficult to remove were barnacle shells. The barnacle shells of live or dead animals could be removed only by breaking the shells off the panels with a large spatula. In almost every case, the upper section of these barnacles would part from the baseplate, which remained securely attached to the panels. The majority of the barnacles attached to the TFE films could be pried off by applying a steady pressure with one's fingers. Normally, the barnacle's whole shell, including the baseplate, could be dislodged.

Plastic Films

TFE. In general, TFE films performed very well in protecting the panels from fouling and corrosion (Figures 6 through 9). The TFE film covered with marine growths, including barnacles and mussels, could be stripped off the 6 x 12-inch panels without difficulty. The entire stripping process took 3 to 5 minutes per panel. Underneath this plastic film, there was a surface as clean as if the panel had never been exposed in the sea. On the other hand, the control panels were heavily corroded and some of them were covered with heavy biological growth which required considerable time and effort to remove. The glass-fiber TFE film was slightly stronger and tougher than the skived TFE film.

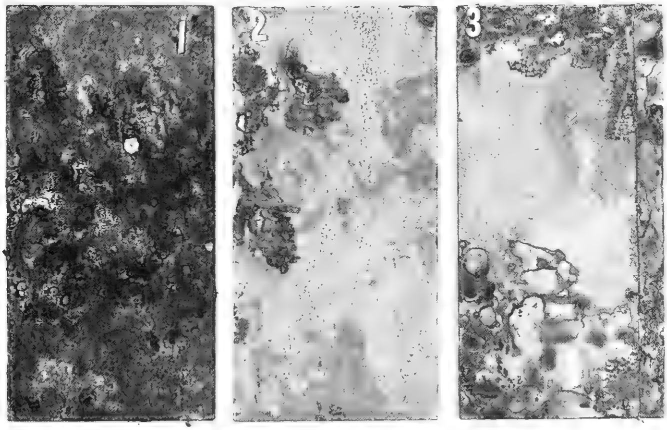

Figure 6. Unpainted carbon steel panels after biological growth and plastic covering had been removed. Panel 1 is a control panel. Panels 2 and 3, protected by TFE films, show a large noncorroded area of white metal.

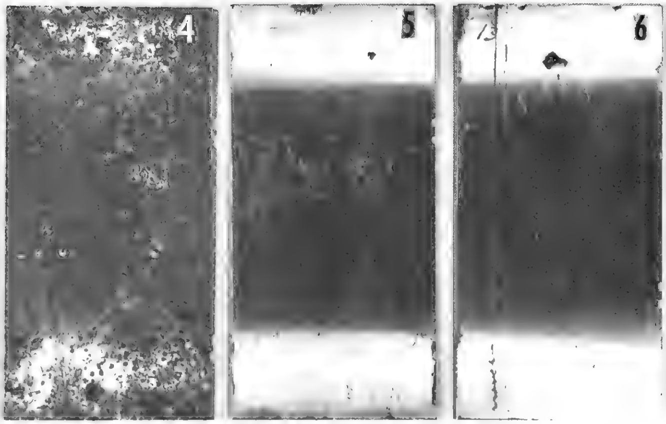

Figure 7. K-Monel panels after biological growth and plastic coverings had been removed. The entire surface of control panel 4 is covered with pits due to corrosion. Panels 5 and 6 were protected by TFE film. The surfaces of these panels are free of corrosion. Lines of discoloration are shown on panel 5.

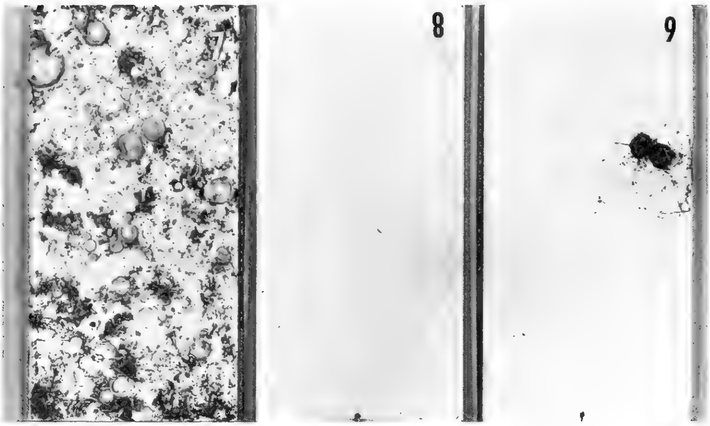

Figure 8. Painted carbon steel panels after biological growth and plastic covering had been removed. Control panel 7 has a large number of barnacle baseplates still attached to the surface. Panels 8 and 9 were protected with TFE film. Barnacles grew over one small area of panel 9 where a small section of plastic covering was torn.

Saran. Saran also performed well in protecting the surfaces of the panels from fouling and corrosion. However, heavy crevice corrosion along the edges of the stainless steel panels was experienced when seawater came in contact with the metal through small rupture holes made in the plastic film. The pressure-sensitive adhesive material on the saran film seemed to adhere more tenaciously to various clean test surfaces than the adhesive material on the TFE film. The saran film was especially well attached to the surface of sandblasted carbon steel. For this reason, considerable difficulty was encountered during the stripping process because the saran film would tear off into small pieces. However, the plastic film did peel off in fairly large sections from painted carbon steel panels and from stainless steel panels without too much difficulty. A slightly thicker saran film should be used for the fouling and corrosion protection of submerged materials.

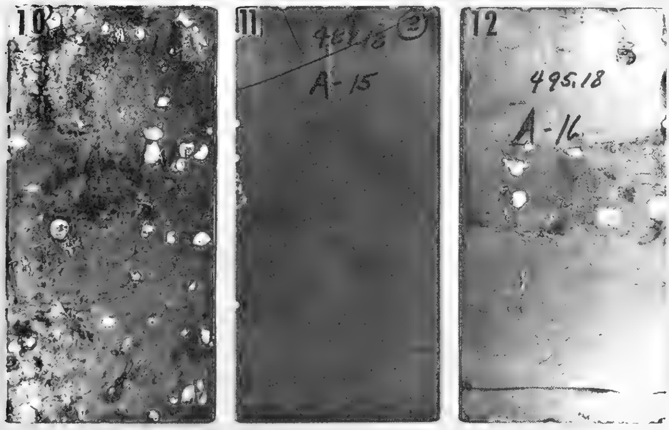

Figure 9. Stainless steel panels after biological growth and plastic covering had been removed. Control panel 10 has numerous barnacle baseplates attached to the surface. Panels 11 and 12 were protected with TFE film. Evidence of fouling growth is visible where TFE film was torn due to unknown causes. Crevice corrosion along the edges of panels 11 and 12 is visible.

Table 5 summarizes the effectiveness of TFE and saran film in protecting carbon steel, stainless steel, and K-Monel panels from marine fouling and corrosion. Table 6 compares the weight lost by TFE-protected and control panels as a result of corrosion after 8.5 months of exposure. The weight loss due to corrosion of saran-protected carbon steel panel (unpainted) was about identical to that of TFE-protected test panels.

Because the application of the thin plastic films over test surfaces is difficult, a specially designed dispenser is needed to apply the plastic film over large surface areas smoothly, quickly, and efficiently. The film should be applied without producing air pockets underneath the plastic films.

COST ESTIMATES

It is estimated that the cost of labor for applying the plastic film over a clean, flat 1-square-foot area would be about $0.25/hr. This assumes that the plastic film can be placed over the 1-square-foot area in about 3 minutes and that, including overhead, the labor cost is about $4.80/hr.

The total cost of application, including labor and materials, would be as follows:

1. $0.50/sq ft for saran film
   $0.25 (labor) + $0.25 (materials)

2. $3.00/sq ft for TFE skived film
   $0.25 (labor) + $2.75 (materials)

3. $2.75/sq ft for TFE, glass-fiber film
   $0.25 (labor) + $2.50 (materials)

By comparison the cost of labor (sandblasting and application of paint) and materials for applying an effective paint system over carbon steel is estimated to be about $0.83/sq ft.[9]

FUTURE WORK

This present study on strippable plastic films as protective coatings over various test panels exposed at Point Mugu pier has been completed. Aluminum (6061-T6) and several plastic panels have been covered with the plastic films for evaluation and secured to STU I-5 for a 6-month exposure test at a depth of 6,000 feet off the coast of Port Hueneme. In the future, certain selected oceanographic instrument packages will also be covered with these plastic films prior to submergence in the sea, primarily for fouling protection.

Table 5. Performance of Plastic Film Coverings on Test Panels

Test Panel	TFE Films (glass-fiber and skived)	Saran Film	No Film	Remarks
Unpainted carbon steel	The TFE films were found adhering to the surface over a major portion of the sandblasted panels. In some areas where seawater had penetrated the plastic at the overlaps and through small puncture holes, the plastic film did not adhere to the metal due to red rust formation. The surface of the metal underneath the plastic film was protected from corrosion and fouling, stripping revealed the original sandblasted bright white metal (Figure 6). The plastic films could be easily and rapidly peeled off the metal panel in large sections.	Saran film was found adhering to the surface of the sandblasted metal. Because the pressure-sensitive adhesive material was securely attached to the surface, it was very difficult to remove the plastic film. During the removal process the saran film would tear off into small pieces. However, the metal surface underneath the plastic film was corrosion free	The control panel was severely corroded with a uniform distribution of red rust over the entire panel. Underneath this layer of red rust there was a layer of gelatinous black iron sulfide corrosion products. Sulfate-reducing bacteria were found associated with such corrosion products.	The surface of a newly sandblasted carbon steel panel should be covered immediately with a plastic film. The pressure-sensitive adhesive backing on a plastic film will not adhere too well over a corroded surface.
Painted carbon steel	The TFE films were found adhering nicely to the surfaces of the painted panels. The films could easily be removed in large sections from each panel in about 3 minutes. During the removal process, where the baseplate of the barnacle adhered to the plastic, the plastic would rip around the edges of the base. The painted surface underneath the plastic film was very clean as if it had never been exposed in the sea (Figure 8). A small section of the paint underneath the protective film was exposed to biological growth when the plastic film was destroyed by the abrasive action of the ceramic insulator which held the panel in place.	The saran film was strongly adhering to the surface of the panel. The film with biological growths could be removed easily from the surface of the panel in fairly large sections. It is advisable to remove all of the barnacle shells attached to the plastic film before peeling because the plastic will start to tear at the site of barnacle attachment during the removal process. The edges of the plastic adhered very well to the metal and painted surfaces	The control panel had the heaviest fouling growth among all the test panels. The barnacles growing on the painted surface were extremely difficult to remove. Nearly all of the barnacles were broken during the removal process and their baseplates remained attached to the painted surface. Considerable time was spent trying to remove the baseplates of these barnacles.	The surfaces of the protected panels were so clean that the panel could be recoated and resubmerged in the sea immediately. On the other hand, the control panels probably would have to undergo extensive reconditioning before exposure.

Table 5. Continued

Test Panel	TFE Films (glass-fiber and skived)	Saran Film	No Film	Remarks
K-Monel	The TFE films were found adhering to the surface of the entire panel. When the plastic film was removed, the metal surface was very bright and free of corrosion and fouling growth. There were streaks of dark discoloration over the metal where seawater had leaked through the plastic film at the overlap (Figure 7). The TFE films covered with marine growth, including barnacles, could be peeled off the test panel without much effort.	Saran film was not placed over K-Monel panels.	The entire surface of the control panel was covered with pits (Figure 7). There were also pits surrounding the base of the barnacle growths (Figure 10).	TFE films gave complete protection from corrosion and fouling for 8.5 months of exposure.
Stainless steel	The TFE films were found adhering to the surface of the panels. When the plastic films were removed from the panels, the underlying surfaces of the stainless steel panels were very clean and bright (Figure 9). There was only minute weight loss There was some crevice corrosion present on the surface of the metal where seawater had penetrated the plastic film through punctures (Figure 11). Elongated tunnel pits present in control panels were not present on TFE-covered panels.	The saran film was found adhering well to the surface of the stainless steel except along the edges of the panel. The edges of the panel were affected by crevice corrosion due to penetration of seawater through ruptures in the plastic film. The saran film covering could be removed fairly rapidly from the panel without the plastic being torn into very small pieces The underlying surface of the panel was very bright and clean (Figures 12, 13, and 14)	The control panel was severely marked with several tunnel pits (Figure 15) and crevice corrosion underneath the barnacle shells (Figure 16).	The crevice corrosion found on stainless steel (type 302) under barnacles and under the plastic films resulted from oxygen concentration cells. As shown in Figure 9, the original writings under plastic covering are visible.

Table 6. Weight of Test Panels Before and After 8.5 Months of Marine Exposure

Panel No.	Test Panel	Type of Protection	Weight Before Exposure (gm)	Weight After Exposure (gm)	Weight Loss Due To Corrosion (%)
1	unpainted carbon steel	none (control)	1,310.0*	1,195.0**	8.80
2		skived TFE	1,333.2*	1,325.8**	0.55
3		glass-fiber TFE	1,310.2*	1,301.2**	0.68
4	K-Monel	none (control)	1,116.5	1,093.2	2.08
5		skived TFE	1,119.0	1,118.0	0.09
6		glass-fiber TFE	1,117.2	1,116.7	0.04
7	painted carbon steel	none (control)	1,378.4	1,377.9	0.03
8		skived TFE	1,395.0	1,394.5	0.03
9		glass-fiber TFE	1,387.8	1,387.7	0.01
10	stainless steel	none (control)	497.61	493.18	0.89
11		skived TFE	489.18	488.7	0.09
12		glass-fiber TFE	495.18	493.57	0.32

* Weight after sandblasting.
** Weight after chemical cleaning.

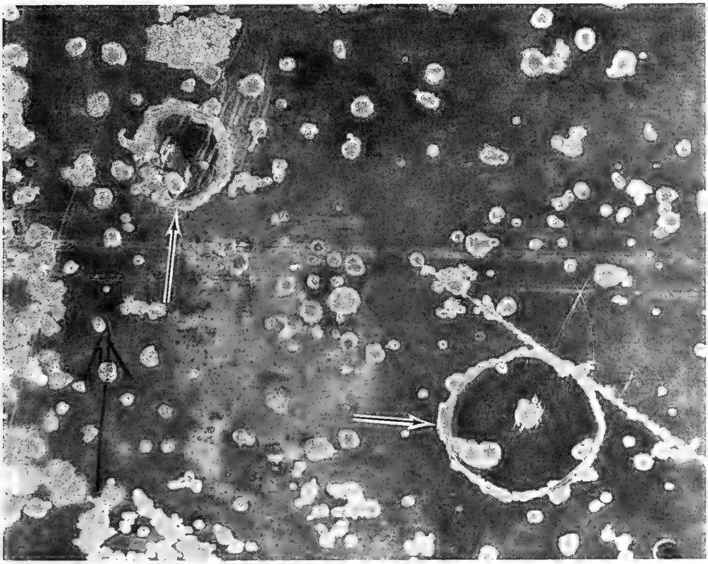

Figure 10. Close-up of K-Monel panel 4, showing pits and circular corrosion pattern around barnacle growth.

Figure 11. Close-up of a stainless steel panel, showing crevice corrosion at the edge. The corrosion occurred underneath the TFE film where seawater had leaked inside through small ruptures.

Figure 12. Biological growth over a stainless steel panel covered with saran film after 5 months of exposure at Point Mugu pier.

Figure 13. Stainless steel panel with saran film after biological growth had been removed with a spatula.

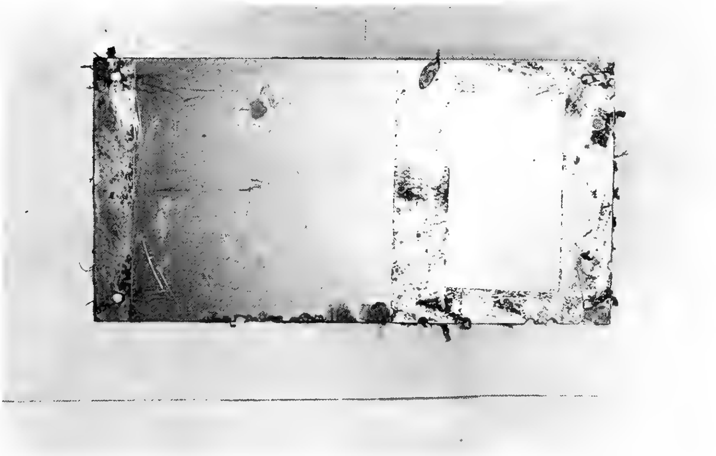

Figure 14. Surface of stainless steel panel after saran covering had been removed. Crevice corrosion along the edge of the panel was produced underneath the plastic when seawater was introduced through tiny rupture holes. A clean, shining metal surface was found underneath a rectangular (patch-like) saran covering (right side).

Figure 15. Close-up of stainless steel control panel showing elongated corrosion (tunnel pits). Tunnel pits were not found on protected panels.

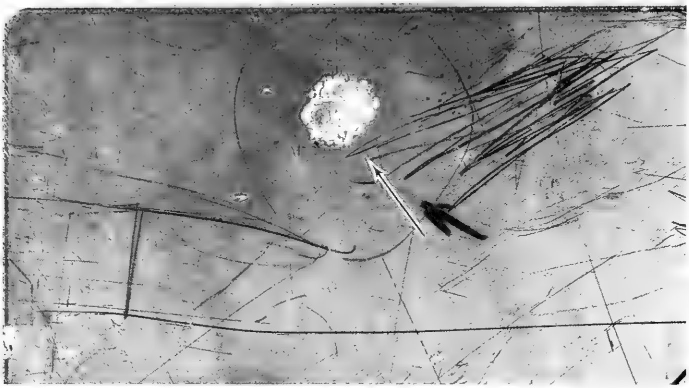

Figure 16. Close-up of stainless steel control panel showing crevice corrosion underneath barnacle growth.

CONCLUSIONS

1. The application of strippable plastic films will prolong the fouling-free and corrosion-free interval. This will decrease the total time required for reconditioning fouled or corroded metal surfaces.

2. The heavy biological growth over the plastic films can be removed more rapidly by stripping away the plastic film than by conventional methods such as scraping and sandblasting.

3. The plastic films will protect metal panels (carbon steel and K-Monel) from corrosion. Crevice corrosion will be produced on susceptible metal panels (stainless steel, type 302) under protective films when a small amount of seawater enters through ruptures.

4. The pressure-sensitive adhesive on saran film seems to adhere to the various test surfaces better than the pressure-sensitive adhesive on TFE film.

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PLASTIC FILM COATINGS FOR PROTECTION FROM MARINE FOULING AND CORROSION, by James S. Muraoka
TR-612 23 p. illus February 1969 Unclassified

1. Protective coverings 2. Plastic films I. YF 38.535.005.01.003

Saran and polytetrafluoroethylene (TFE) films with a pressure-sensitive adhesive were applied over the surfaces of painted and unpainted carbon steel panels and unpainted stainless steel and K-Monel panels. These panels were submerged in the sea to determine if the plastic film coverings can be effectively used to (1) protect painted as well as unpainted metal specimens from fouling and corrosion; (2) remove marine growth that becomes attached to the plastic film simply by stripping off the covering; and (3) prolong the fouling-free and corrosion-free intervals so as to decrease the total effort required for reconditioning fouled or corroded surfaces. The saran- and TFE-covered panels were exposed in the sea for 5 and 8.5 months, respectively. When retrieved, the panels were completely covered with marine growth, including numerous large barnacles. Generally, the plastic films protected the test panels from fouling and corrosion. The marine growth could be removed rapidly by stripping off the protective plastic covering. Crevice corrosion will occur under the protective plastic film on susceptible metal panels, such as stainless steel (type 302), when a small amount of seawater enters through ruptures.

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13. ABSTRACT

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