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The Navy Clothing and Textile Research Facility (NCTRF) investigated three protective overcoatings, identified as Abcite, 0-22, and Epoxy, as possible improvements to the present transparent protective overcoating on the infrared reflective gold-coated facepiece of the Aluminized Firefighters' Crash-Rescue Protective Hood. Because the current overcoating has very poor durability, the gold becomes wiped off or badly marred after a short time in field use. Thus, the firefighter's radiant heat protection and visibility are compromised. (U)

All samples tested with the three overcoatings easily passed new radiant heat test requirements and showed a substantial improvement in abrasion resistance over the standard coatings. The Abcite and 0-22 coatings were at least 10 times better and the Epoxy at least five times better. When applied to the standard facepiece materials, the coatings showed good adhesion to the gold. The coatings on these materials showed reasonable resistance to a number of environmental exposures (200°F Air; room temperature exposure and 150°F exposure to water and to aqueous solutions of protein foam and light water; and 175°F water vapor) but were not as good in this regard as the standard facepiece coatings. (U)

The Abcite was rated best considering all factors (radiant heat, abrasion, and environmental exposure resistance) with the 0-22 also being a likely candidate. Sufficient tests of the Epoxy coating were not conducted to completely evaluate this material. (U)

Because of the improved durability shown with these three overcoatings, further work is recommended to establish field performance results, to continue investigations for other possible candidates, to establish sources of supply, to eliminate some cosmetic defects in these experimental samples, and to improve adhesion further. (U)

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FACEPIECE-VISOR ASSEMBLY FOR ALUMINIZED FIREFIGHTERS' CRASH-RESCUE PROTECTIVE HOOD (INVESTIGATION OF ABRASION-RESISTANT OVERCOATINGS)

INTRODUCTION

The Navy Clothing and Textile Research Facility (NCTRF), at the request of the Aircraft Ground Fire Suppression and Rescue Systems Program Office (AGFSRS), Wright Patterson Air Force Base, investigated the performance characteristics of some abrasion-resistant coatings for application over the infrared reflective gold coatings used on the facepiece-visor assembly of the Aluminized Firefighters' Crash-Rescue Protective Hood.

Both the firefighting community and NCTRF have previously acknowledged that the present facepiece coating has poor durability (1). In associated work in which a series of potential visor substrate materials were coated with gold and overcoated with abrasion-resistant coatings having different optical characteristics, NCTRF achieved some success in improving the durability of the facepiece-visor coatings and recommended that development efforts be continued to resolve the poor durability problem (2). AGFSRS enhanced the potential for making a significant improvement to the durability of the facepiece coatings by changing the radiant heat test requirement for the facepiece-visor coatings. AGFSRS studies on the radiant heat exposures experienced by firefighters indicated that the 1.5 gcal/cm^2/sec radiant heat flux level and 300-second exposure period currently employed to evaluate the suitability of the facepiece coatings were too severe standards. AGFSRS established two other exposure conditions that were severe enough to insure good radiant heat protection for the firefighter. These conditions were: 1.9 gcal/cm^2/sec radiant heat flux for a 30-second exposure; and 0.4 gcal/cm^2/sec for a 300-second exposure. These new radiant heat requirements allowed the application of thicker overcoatings to the facepiece gold coatings.

Because the current investigation of abrasion-resistant coatings was limited to the period of November 1975 to June 1976, only three overcoating material types were evaluated. They were Abcite, 0-22, and Epoxy. The Abcite, previously evaluated in a very limited way, had shown good abrasion characteristics (2). Some limited tests of the other two materials had also indicated they were superior to the present facepiece coatings in abrasion resistance. To fully evaluate the potential of these three materials sufficient samples were obtained of each to evaluate their radiant heat resistance, abrasion and adhesion characteristics, and resistance to several environmental conditions, such as hot air, water, water vapor, aqueous solutions of protein foam, and Aqueous Film Forming Foam (AFFF). Both Abcite and 0-22 were applied to the present facepiece material (gold-coated 7-mil polyester film) and specially prepared gold-coated 1/8-inch-thick polycarbonate substrates. The Epoxy was applied only to the facepiece material.

Considering all factors (radiant heat, abrasion, and environmental exposure resistance), the Abcite overcoatings on the standard facepiece materials performed best, but the O-22 overcoating was almost as good. It was superior to the Abcite in terms of environmental exposure resistance but did not have as good radiant heat or abrasion resistance. In limited and incomplete tests the Epoxy overcoating gave promise also but was rated worse than the other two. All three overcoatings demonstrated superior abrasion resistance over the standard coatings (at least five times better for Epoxy and 10 times better for Abcite and O-22) and passed the radiant heat test requirements.

This report includes the results of radiant heat and environmental exposure of the three overcoating materials as well as abrasion and adhesion test performance data and discusses the relative virtues of each overcoating as determined from these data. Further work is also recommended.

MATERIAL DESCRIPTION

General

Three potential abrasion-resistant overcoat materials were evaluated under this program and their performance compared to the standard facepiece coatings. These materials were identified as Abcite, O-22, and Epoxy.

The Abcite (Dupont) is a crosslinked flourocarbon type copolymer, which has been used in the past to improve the abrasion resistance of acrylic and polycarbonate sheet for various glazing and plastic lens applications. The abrasion resistance of the material has been associated with its good lubricity. The chemical characteristic of the O-22 coating is unknown, but in relation to Abcite was reported to have slightly less abrasion resistance but better resistance to wet environments and better adhesion to metallized surfaces. The Epoxy coating was claimed by the manufacturer to have good infrared transparency and has been used in the past as a protective overcoating for infrared detectors.

Abcite and O-22 Samples

Two general sample groups overcoated with Abcite and O-22 were obtained. For one group the standard facepiece material (gold-coated 7-mil polyester film) was dip-coated with these materials and for the other sample group the coatings were applied to specially prepared gold-coated 1/8-inch-thick polycarbonate substrates having certain required optical characteristics. All samples were 4-5/8 inches long and 2-5/8 inches wide.

Initially the coatings on the standard facepiece material were to have a nominal thickness of 5 microns (μ) and the polycarbonate samples were to be coated with overcoating thicknesses of 3, 5, and 7 μ. Because of the heat and adhesion results obtained on the initial polycarbonate samples received, however, this requirement was later changed to 3 to 4 μ for all O-22 overcoated samples, 3 and 7 μ for the remaining Abcite overcoated polycarbonate samples, and 3 to 4 μ for the Abcite overcoated facepiece materials.

All Abcite and O-22 polycarbonate samples were required to have the following optical characteristics to insure adequate visibility and good infrared radiant energy protection.

Luminous Transmittance to Illuminant "C"	- 20 to 25%
Infrared Transmittance from 0.8 to 6.0 μ	- less than 10% at any point

No luminous and infrared transmittance requirement could be assigned for the overcoated standard facepiece materials since the facepiece materials had been previously gold coated by another supplier. Nevertheless, these optical parameters were measured on some of these samples for information purposes.

The cosmetic condition of a large number of the samples was poor. Many of the overcoated facepiece samples had coating cracks, and polycarbonate samples had pinholes and small impurities under the overcoat. In most cases these factors did not appear to affect performance results. We did not determine how the coating cracks developed on the facepiece materials. The cause of these cracks must be resolved to insure that they are not inherent in the coating process employed with these overcoatings and the thin polyester film materials they were applied to. The problem does not appear to be related to the brittleness of these overcoat materials because the samples can be bent to a sharp radius with no breakdown (cracking) of the coating.

To eliminate the impurities and pinholes observed on the polycarbonate samples better quality control is required for both the vacuum metalizing process and the material handling methods prior to overcoating. The degree to which the processing technique has to be changed to improve the cleanliness of the samples requires further investigation.

Epoxy Samples

The Epoxy coatings were applied only to the standard facepiece materials. Because the application of the Epoxy coating to the film material had not been tried previously, it resulted in a good deal of experimentation by a coating vendor to establish a coating method. Various forms of knife, spray, flow, and dip-coating techniques were attempted, and the dipping techniques were finally employed. Most of the preliminary samples had quite a bit of dirt trapped in the coating, especially when the spray method was attempted. The sample coatings subsequently evaluated under this program were mostly applied by a flow coating method and a few samples by the dip process method. While all of these samples also had impurities trapped in the coatings, the dipped samples appeared cleanest. These impurities did not seem to affect the performance of the coatings to any significant degree. All of these samples had an overcoating thickness of between 0.6 to 1.0 mil. No optical data were obtained for these samples.

None of the final Epoxy samples to be coated for this program were obtained in time to be evaluated and the results incorporated in this report. If this program were to be continued, the evaluation of these samples will be part of any additional work.

PROCEDURES

General

The coatings were evaluated for their adhesion to the substrates, abrasion resistance, radiant heat resistance, and resistance to various environmental exposures, such as air temperature of 200°F, water vapor at 175°F, water at room temperature and 150°F, and 6% aqueous solutions of protein foam and AFFF at room temperature and 150°F. The environmental exposure temperatures were established from testing some of the initial samples at various temperatures in these environments to determine where some observable or measurable breakdown occurred (e.g., delamination of coatings or loss of adhesion). A temperature was then selected at which reasonable exposure times were possible before failures were observed. Tests at the selected temperature would then permit some possible discrimination between the coating types in each environment and the influence of the AFFF and protein foam solutions on the coatings with respect to the water exposures. In no event was a temperature of more than 212°F employed to prevent possible adverse effects to the plastic substrates from influencing coating performance. The standard facepiece materials were also exposed to these various test conditions for comparison with the experimental coatings. For most of the tests at least 3 and usually 5 samples of any coating type were evaluated. In many cases the adhesion and abrasion tests were conducted on the same samples with the samples being subjected to a sequence of adhesion test, abrasion test, and another adhesion test.

Adhesion Tests

For all tests adhesion was determined by employing a 1-inch-wide acetate-fiber pressure-sensitive tape (3M type 898) rated as having a minimum adhesion of 40 ounces per inch when tested in accordance with method 205 of Federal Test Method Standard No. 101B - Preservation, Packaging, and Packing Materials. In each case the tape was applied by laying the tape on the coated surface and pressing it to the surface by rolling a 1-1/2-inch-wide 10-lb. steel roller over the tape surface 5 times in each direction. One end of the tape was doubled over before being laid on the surface to create a non-adhering section. The doubled-over end of the tape was then bent back 180 degrees and was stripped from the coating by being pulled parallel to the coated surface. After the tape was stripped from the coated surface, the surface was observed to determine if any of the overcoating was removed from the gold layer and the gold layer from the substrate. Any failure to each was noted. In most cases the test was performed manually with the tape being stripped as quickly as possible. Some machine tests were also conducted with an Instron Tester. In these tests the tape was pulled at a rate of 20 inches per minute.

Abrasion Resistance

These tests were conducted on a Stoll Abrasion Tester, which is described in Methods 5300.1 and 5302 of Federal Test Method Standard No. 191 - Textile Test Methods. The Stoll device has a stationary head to which the abradant material is attached, and it can be weighted to create a particular force level to the specimen being abraded. The specimen is mounted on a reciprocating support which oscillates under the stationary head at a frequency of 120 HZ. For our tests a special holder was designed for the 4-5/8 inch x 2-5/8 inch samples. When the coated standard facepiece materials were evaluated, they were attached by double-backed tape to a 1/8-inch-thick polycarbonate plate to simulate the same support surface as the coated polycarbonate samples. The abradant in most tests was 1-1/4-inch-wide strips of No. 6 Cotton Duck conforming to Type I of Military Specification CCC-C-419 - Cloth, Duck, Cotton, Unbleached Plied Yarns. The head load of 10 pounds created an abradant surface pressure to the coatings of approximately 1.75 psi. In some tests the samples were abraded until excessive marring or penetration of the coatings was observed; in other tests the samples were subjected to a fixed number of abrasion cycles and their visible condition noted.

Radiant Heat Resistance Tests

These tests were conducted with the quartz lamp radiant heat test apparatus described in reference 2. The test samples were subjected to incident radiant heat pulses of 0.4 gcal/cm^2/sec and 1.9 gcal/cm^2/sec. For the 0.4 gcal/cm^2/sec tests exposure times were 300 seconds. For the 1.9 gcal/cm^2/sec tests, exposures of 30 seconds were used as well as extended exposure times that caused some visible destruction to the coated surface. In all tests the maximum heat flux level transmitted through the specimen was measured by a transducer located 1/4 inch behind the rear surface of the test specimen. The coated standard facepiece materials were attached to 1/8-inch polycarbonate plates as was done in the abrasion tests to provide the same type of heat sink as the coated polycarbonate samples. A 60-second lamp preheat time was used in all tests.

Environmental Exposure Tests

For many of the environmental exposures except the room temperature tests, one sample of each type being exposed would be examined each hour to ascertain whether any visible change or any loss of adhesion (adhesion test) of the coatings took place. If no change was found, the sample was returned for futher exposure. If some change occurred, a second sample would be tested. If this sample were affected, the remaining samples of this type would be evaluated before any further exposure was attempted. If the second sample showed no change, it would be returned for further exposure with the remaining samples. The procedure would be repeated each hour until a maximum exposure time of 4 hours was achieved. The samples at room temperature were tested only at the end of their exposure period, which was usually 24 hours. All samples were adhesion-tested prior to exposure to insure the coatings had proper adherence. All samples which passed the exposure test with no major adhesion failures to the overcoating were abraded for 1000 cycles, their condition noted, and then adhesion-tested again.

Air at 200°F

The samples were hung in an oven preheated to 200°F for a maximum of 4 hours. Good air circulation existed around the samples.

Water Vapor at 175°F

The samples were hung in the enclosed vapor space of a water bath preheated to 175°F for a maximum of 4 hours.

Water, Aqueous AFFF and Protein Foam Solutions

Room Temperature Tests. Samples were hung in beakers containing the solutions for 24 hours prior to testing. The aqueous solutions of AFFF and protein foam were 6% by weight.

150°F Temperature Tests. Samples were hung in beakers containing the heated solutions for a maximum of 4 hours. The beakers were located in an oven to maintain the solution temperature. The aqueous solutions of AFFF and protein foam were 6% by weight.

INITIAL MATERIAL TEST RESULTS

Abcite and O-22 Overcoating Materials

To establish the effectiveness of the Abcite and O-22 coatings before all the samples were received, a partial shipment of the gold-coated polycarbonate sample types was obtained so that some changes could be made if necessary to the final samples. This group contained Abcite samples coated to nominal thicknesses of 3, 5, and 7 μ and O-22 samples coated to nominal thicknesses of 3 and 5 μ . Samples of the O-22 coating in 7 μ thicknesses were to be obtained also but these thicker coatings crazed during processing and were eliminated from further consideration. Thirty samples of each type and thickness were received. This sample group was checked by the vendor for optical characteristics and we evaluated them for adhesion, abrasion resistance, radiant heat resistance, and resistance to a number of environmental exposures.

Optical Characteristics. The coating thickness and luminous transmittance (LT) values were measured on each sample. In addition at least seven characteristic infrared spectral transmission curves covering the wavelength range from 0.8 to 2.5 μ were obtained in each thickness range for each coating type to cover the span of LT values measured on the samples. Table I summarizes this optical data.

Table I. Optical Characteristics of Initial Abcite and 0-22 Overcoatings on Gold-Coated Polycarbonate Samples

Sample Type	Nominal Coating Thickness (μ)	Coating Thickness Range (μ)	LT Range (%)	Infrared Transmission			
				Max. (%)	Wave Length (μ)	Min. (%)	Wave Length (μ)
Abcite	3	3.0 to 3.6	20 to 24	10	.8	0	2.5
Abcite	5	4.6 to 5.8	20 to 23	8	.8	0	2.5
Abcite	7	6.7 to 7.9	20 to 27	9	.8	0	2.5
0-22	3	3.0 to 3.8	19 to 25	10	.8	0	2.5
0-22	5	4.8 to 5.9	16.5 to 24.5	9	.8	0	2.5

All the samples met the infrared criteria. Some of the LT values for the 0-22 samples were below the 20% requirements (5 of 30 of the 3 μ thickness and 15 of 30 of the 5 μ thickness). They were acceptable for the purposes of this study, however, since this characteristic would only affect radiant heat results and it would be of interest to see how much these lower LT values would improve radiant heat performance (lower LT values were associated with applying too heavy a gold layer).

Adhesion. These initial samples showed poor adhesion characteristics. Of 12 Abcite samples tested in the as-received condition, 50%, or 6, failed. Of seven 0-22 samples tested, 40%, or three, failed. For each type the Abcite or 0-22 overcoat came off.

Apparently because of the poor adhesion of the coatings to the gold layer, the overcoating on most of these sample types delaminated during environmental exposures. Both coating types began to delaminate in a 175°F water bath within 30 minutes, in a 150°F water bath within 1 hour for the 0-22 overcoating and 2 hours for the Abcite. Abcite-coated samples exposed to room temperature aqueous protein foam solutions for 24 hours showed coating delaminations about the edges and were completely delaminated after 4 hours in a 200°F aqueous protein foam solution. Delamination of the overcoating and the formation of small water bubbles under the overcoatings were observed on both overcoating types exposed to 210°F water vapor for 30 minutes.

The effect of surface abrasion on adhesion was also studied. Of 23 Abcite samples subjected to an adhesion test after being abraded for 2000 cycles, all 23 failed. For most samples more than 50% of the overcoating came off. These adhesion failures of the overcoating were also noted on the 0-22 samples. Of 19 tested, 18 failed with at least 40% of the overcoating being removed. Since the failure rate was essentially 100% after abrasion and approximately 40 to 50% before, the abrasion of the surface apparently caused some breakdown in the coating's adhesion or increased the adhesive force between the tape and the coated surface because of the marring of the surface.

Abrasion. For these initial sample tests the abradent strips were 4 inches wide as opposed to the 1-1/4 inch wide strips used in additional testing. This created an abradant pressure to the sample surface of approximately 0.75 psi with a 10-lb. head load.

Tables II and III give the abrasion data for both overcoating types and the standard coating materials in the as-received condition and after exposure to several types of environments. The data show that both the Abcite and O-22 overcoatings have at least four times the abrasion resistance of the standard coatings (2000 cycles versus 500 without the same degree of wear) and that radiant heat, 200°F air and room temperature aqueous protein foam solution exposures do not perceptibly affect the abrasion resistance of these coatings. There were also indications that the O-22 coating may have been somewhat better than the Abcite in abrasion resistance (no penetrations to the O-22 coatings were observed).

Radiant Heat. The various sample types were tested to establish their ability to pass the radiant heat test requirements. All samples met the requirements without any failure to the coatings (Table IV). Maximum heat transmission values were slightly higher for the thicker coatings.

Radiant heat tests were also conducted at the higher heat flux condition (1.9 gcal/cm^2/sec) to establish the exposure time when the coatings failed. These tests were run on some samples in the as-received condition and on some that had been abraded (Table V).

As can be seen from Table V for the as-received condition, both coating types can withstand the 1.9 gcal/cm^2/sec exposure well beyond the 30-second requirement. The thinner coatings withstood longer exposures and the O-22 coatings failed at shorter exposures than the Abcite for equivalent coating thicknesses and showed a dramatic reduction in exposure time (184 to 78 sec) for a coating thickness increase from 3 to 5 μ.

After 2000 abrasion cycles, some Abcite samples exhibited a reduced exposure time, particularly for the thickest coating. The transmitted heat flux values were similar to those measured for the samples in the as-received condition. A noticeable effect on the standard facepiece samples abraded for 500 cycles was their early failure (a new facepiece can last 300 seconds under this heat flux exposure without failure of the coatings). More important, however, was the large increase in heat transmission. The .156 gcal/cm^2/sec transmission value for the 40-second exposure could cause pain to humans within 10 seconds. (3)

The effect of LT values on maximum heat transmission values was also noted from some of the results. For the 30-second 1.9 gcal/cm^2/sec exposures, an LT rise of from 19 to 24% increased the maximum heat flux transmission value by 25%. For a similar LT range at 0.4 gcal/cm^2/sec 300-second exposures, the maximum heat flux transmission values were essentially unchanged.

(continued on page 14)

Table II. Abrasion Results of Initial Abcite and O-22 Overcoatings on Gold-Coated Polycarbonate Samples and Standard Facepiece Materials in As-Received Condition

Sample Type	Nominal Coating Thickness (μ)	No. of Samples	No. of Cycles	Condition of Samples
Abcite	3	4	2000	Slight surface marring to one small penetration of coating to substrate
Abcite	5	4	2000	Slight surface marring to several penetrations of coatings to substrate
Abcite	7	4	2000	Very slight to slight surface marring
O-22	3	4	2000	Very slight to slight surface marring
O-22	5	4	2000	Very slight to slight surface marring
Standard		7	500	Many penetrations of coatings to substrate

Table III. Abrasion Results of Initial Abcite and 0-22 Overcoatings on Gold-Coated Polycarbonate Samples and Standard Facepiece Materials after Environmental Exposure

Envir. Exposure	Sample Type	Nominal Coating Thickness (μ)	No. of Samples	No. of Cycles	Condition of Samples
Radiant Heat 1.9 gcal/cm^2/sec for 30 seconds	Abcite	3	2	2000	Very slight surface marring
	Abcite	5	2	2000	Slight surface marring
	Abcite	7	2	2000	Very slight surface marring
	0-22	3	2	2000	Slight surface marring
	0-22	5	2	2000	Very slight surface marring
	Standard		2	500	Many penetrations of coating to substrate
0.4 gcal/cm^2/sec for 300 seconds	Abcite	3	1	500	One penetration of coating to substrate
	Abcite	5	2	2000	Slight surface marring
	Abcite	7	2	2000	Slight surface marring
	0-22	3	2	2000	Slight surface marring
	0-22	5	2	2000	Very slight surface marring
	Standard		2	200	Several penetrations of coatings to substrate

Table III. (continued)

Envir. Exposure	Sample Type	Nominal Coating Thickness (μ)	No. of Samples	No. of Cycles	Condition of Samples
200° F Air (4 hours)	Abcite	3	1	2000	One small penetration of coatings to substrate
	Abcite	5	2	2000	Slight surface marring
	Abcite	7	2	2000	Very slight surface marring
	0-22	3	2	2000	Very slight surface marring
	0-22	5	2	2000	Very slight surface marring
	Standard		4	500	Many penetrations of coatings to substrate
Room Temp. Aqueous Protein Foam Solution (24 hours)	Abcite	3	2	2000	Slight surface marring
	Abcite	5	2	2000	Very slight surface marring
	Abcite	7	2	2000	Very slight surface marring to one penetration of coatings to substrate
	Standard		2	200	Several penetrations of coatings to substrate

Table IV. Radiant Heat Results of Initial Abcite and 0-22 Overcoatings on Gold-Coated Polycarbonate Samples and Standard Facepiece Materials in As-Received Condition Tested to Requirements

Incident Radiant Heat Flux ($gcal/cm^2/sec$)	Sample Type	Nominal Coating Thickness (μ)	No. of Samples	Exposure Time (sec)	Avg. Max. Heat Flux Transmitted ($gcal/cm^2/sec$)	Coating Condition
1.9	Abcite	3	3	30	.032	OK
	Abcite	5	3	30	.032	OK
	Abcite	7	3	30	.034	OK
	0-22	3	3	30	.033	OK
	0-22	5	3	30	.036	OK
	Standard		1	30	.038	OK
0.4	Abcite	3	3	300	.020	OK
	Abcite	5	3	300	.025	OK
	Abcite	7	3	300	.027	OK
	0-22	3	3	300	.023	OK
	0-22	5	3	300	.030	OK
	Standard		2	300	.009	OK

Table V. Exposure Times to Cause Coating Failures to Abcite and 0-22 Overcoatings on Gold-Coated Polycarbonate Samples in As-Received and Abraded Condition for Abcite and Standard Facepiece Materials

Sample Condition	Sample Type	Nominal Coating Thickness (μ)	No. of Samples	Exposure Time to Failure (sec)	Avg. Max. Heat Flux Transmitted ($gcal/cm^2/sec$)	Coating Condition
As-Received	Abcite	3	1	215	.068	Surface Blemish
	Abcite	5	1	190	.070	Surface Blemish
	Abcite	7	1	173	.070	Surface Blemish
	0-22	3	1	184	.079	Crease mark outlining heat affected area
	0-22	5	2	78 to 73	.057 to .060	Crazed
Abrasion 2000 cycles	Abcite	3	3	216 to 198	.064 to .074	Surface Blemish
	Abcite	5	3	205 to 161	.065 to .071	Surface Blemish
	Abcite	7	2	145 to 121	.064 to .060	Surface Blemish
500 cycles	Standard		2	147*to40**	.119 to .156	Hole in polyester substrate

* Nonabraded standard facepiece coatings can withstand this exposure for more than 300 seconds.
** No failure at 40 seconds. Test stopped because of high heat flux transmission value.

Summary. Because of the results in these initial samples NCTRF decided to:

a. Improve adhesion by masking the border of the polycarbonate substrate prior to metallization so that, when samples were dip-coated after metallization, a direct substrate-to-overcoating bond would exist around the border. Past work by the vendor had shown better adhesion was achieved when these coatings were bonded to plastic substrates in comparison to metallized surfaces. We hoped that the improved border coating adhesion would aid in supporting the film applied over the gold section. The substrate and gold surfaces were also primed with another material in an attempt to improve adhesion of the gold surface to the substrate and the overcoating at the gold section.

b. The O-22 samples with 5-μ-thick coatings were eliminated because their radiant heat resistance was worse than the other overcoating types.

c. The Abcite samples with 5-μ-thick coatings were eliminated because we felt that further characterization of this coating type could be achieved with only two thicknesses (3 and 7 μ).

d. All coating thicknesses required in the standard facepiece materials were changed from 5 to 3 to 4 μ to have comparative data with the polycarbonate samples.

Epoxy-Overcoated Facepiece Materials

These samples were received in small quantities on four separate occasions and were set into four separate groups because of differences in sample preparation. The first group, which had not been cured properly (200°F - 2 hrs), showed poor abrasion resistance. Most of these samples received an additional cure (275°F - 4 hrs) before further tests were conducted. The second group were similar to the first with the exception that they underwent one cure at 280°F for 2 hrs and the substrates were not vapor-degreased prior to coating. Vapor degreasing was thought to have been the cause of some failures to the gold-substrate bond witnessed in some of the Group 1 tests. These first two groups were coated by a flow-coating technique and had a large number of impurities trapped in the coatings. The third group were cured similar to the second but were dip-coated. These samples were cleaner than the first two groups. The last group were prepared similar to Group 3 and represented the final-sample condition. Although these final samples still contained impurities, they were much cleaner than any samples received previously.

Group 1

Adhesion. Of 10 samples tested in the as-received condition all passed the adhesion test. Five of these samples were tested by the machine method and developed adhesive forces between the tape and coatings of from 2.6 to 3.6 lbs.

Water vapor exposures at 200°F were conducted on 11 samples (three for 1 hr, five for 2 hrs, and three for 4 hrs). For 1 hr, two of three passed; 2 hrs, three of five passed; and 4 hrs, one of three passed. For those samples that failed, in no case did the overcoat come off. Failure always occurred at the gold-substrate bond.

The effect of surface abrasion on adhesion results was not consistent. Of 11 samples tested the gold was removed from the substrate of five samples (abrasion cycling range from 200 to 2000 cycles). No cases existed in which the overcoat was removed from the gold layer.

Abrasion. For samples which were tested as-received, severe marring occurred within 100 to 200 cycles. Experimentation with different cure temperatures and times did not produce consistent results. While one sample could withstand 1000 cycles before the coating substrate was penetrated, others would be badly marred within 300 cycles. One sample went 2000 cycles with very slight marring of the coatings.

Radiant Heat. The sample coatings met the heat test requirements (Table VI). Minimum exposure times of 82 seconds were measured before any coating failure was noted. A coating thickness change from 1.0 down to 0.6 mil did not measureably increase exposure time before coating failures occurred.

Group 2

Adhesion. Of 20 samples subjected to an initial adhesion test, failure to the gold-substrate bond occurred eight times. No overcoat-to-gold-bond failures were witnessed.

For samples exposed to a 200°F water bath and water vapor environment, loss of adhesion to the gold-substrate bond occurred within 2 hours for the water bath for two of three samples and all three samples went 3 hours in the water vapor with no failures. The remaining water bath sample went 4 hours without failure. Again no adhesion failure to the overcoat-gold bond occurred.

Of seven samples subjected to 1000 cycles of surface abrasion, only two showed a breakdown to the gold-substrate bond. There were no failures to the overcoat-gold bond.

Abrasion. Four samples were abraded in the as-received condition for 1000 cycles. They showed many small penetrations to the substrate. One sample exposed to a 200°F water bath for 4 hours and three samples exposed to a 200°F water vapor environment for 3 hours demonstrated similar abrasion resistance.

Table VI. Radiant Heat Results for Group 1 and Group 2 Epoxy-Overcoated Facepiece Materials

Incident Radiant Heat Flux ($gcal/cm^2/sec$)	Group Type	Nominal Coating Thickness (mils)	No. of Samples	Exposure Time (sec)	Avg. Max. Heat Flux Transmitted ($gcal/cm^2/sec$)	Coating Conditions
1.9	1	1.0	3	30	.040	OK
			4	85 to 89	.067	Surface blemish
	2	0.6	3	30	.035	OK
				82 to 95	.067	Surface blemish
0.4	1	1.0	3	300	.034	OK

Group 3

Adhesion. Five samples were tested in the as-received condition and all passed. Of three samples subjected to a 175°F water vapor environment for 4 hours, one passed. Failure at the gold-substrate bond occurred to the other two. No overcoat-gold-bond failure occurred. Of four samples checked for adhesion after undergoing 1000 cycles of abrasion, all passed.

Abrasion. Three samples abraded to 1000 cycles in the as-received condition showed slight surface marring to the coating, and one sample which had previously been exposed 4 hours in a 175°F water vapor environment showed equivalent abrasion resistance.

Group 4

Adhesion. Three samples subjected to initial adhesion passed. Two samples exposed to 175°F water vapor for 4 hours and then abraded for 1000 cycles also passed.

Abrasion. One sample in the as-received condition and two having previously been exposed for 4 hours to a 175°F water vapor environment were subjected to 1000 abrasion cycles. All showed slight surface marring of the coatings.

Summary

These initial Epoxy samples showed excellent overcoat adhesion to the gold layer under some rather severe environmental exposures. In all adhesion experiments, failures that did happen occurred at the gold-substrate bond.

The final dip-coated samples (Group 3 and 4) showed abrasion resistance at least five times better than that of the standard facepiece materials (1000 cycles with slight marring).

The coatings easily passed the radiant heat test requirements, withstanding an exposure to 1.9 gcal/cm^2/sec for at least 82 seconds before the coating failed.

Because of a delay in receiving the final Epoxy coated samples, a complete evaluation of these coatings to all test environments was not done.

FINAL MATERIAL TEST RESULTS

Abcite and 0-22 Overcoated Standard Facepiece Materials

Optical Characteristics. Table VII summarizes the optical data obtained on these sample materials. All samples showed acceptable low infrared transmission for the LT ranges shown.

Table VII. Optical Characteristics of Abcite and 0-22 Overcoated Standard Facepiece Materials

Sample Type	Nominal Coating Thickness (μ)	Coating Thickness Range (μ)	LT Range (%)	Infrared Transmission			
				Max. (%)	Wave Length (μ)	Min. (%)	Wave Length (μ)
Abcite	4	3.5 to 4.0	22 to 28	10	0.8	0.5	2.5
0-22	4	3.4 to 4.0	22 to 27	8	0.8	0.3	2.5

<u>Adhesion</u>. Table VIII summarizes adhesion results for samples tested in the as-received and abraded conditions as well as for a number of environmental exposures. For reference purposes the standard facepiece materials received similar environmental exposures. The adhesion characteristics of the standard materials were not affected by any of the environments.

The Abcite and 0-22 samples showed excellent coating adhesion in the as-received condition for either overcoat type (56 of 57 Abcite and 57 of 58 0-22 samples passed). Both coating types showed similar performance after being abraded for 2000 cycles. Sixty percent passed the adhesion test and all failures occurred at the gold-substrate bond.

Table VIII. Adhesion Results of Abcite and 0-22 Overcoated Standard Facepiece Materials for Different Environmental Exposure Conditions

Envir. Exposure	Sample	No. of Samples	Number Passed	Sample Appearance	Condition of Failed Specimens
As-received	Abcite	57	56	OK	Small amount of gold removed from substrate near one edge
	0-22	58	57	OK	Small amount of gold removed from substrate near one edge
After 2000 abrasion cycles	Abcite	5	3	Very slight surface marring	10% gold removed from substrate
	0-22	5	3	Slight surface marring	15 to 30% gold removed from substrate

Table VIII. (continued)

Envir. Exposure	Sample	No. of Samples	Number Passed	Sample Appearance	Condition of Failed Specimens
Radiant Heat					
1.9 gcal/cm^2/sec for 30 seconds	Abcite	5	5	OK	
	0-22	5	5	OK	
0.4 gcal/cm^2/sec for 300 seconds	Abcite	5	5	OK	
	0-22	5	5	OK	
200°F Air for 4 hours	Abcite	5	5	OK	
	0-22	5	4	OK	One gold speck removed from substrate
150°F H_2O	Abcite	5	3	OK	Less than 1% overcoat and gold removed. Failures at coating crack
	0-22	5	5	OK	
150°F Aq. Protein Foam Solution for 4 hours	Abcite	5	1	OK	Less than 10% overcoat and 2% gold removed. Failures began after 2-hours of exposure
	0-22	5	5	OK	
150°F Aq. AFFF Solution for 4 hours	Abcite	5	3	Water bubbles formed under overcoating within 3 hours exposure	Less than 2% overcoat and gold removed
	0-22	5	3	OK	One pinhole size gold speck removed from substrate

Table VIII. (continued)

Envir. Exposure	Sample	No. of Samples	Number Passed	Sample Appearance	Condition of Failed Specimens
Rm. Temp. H_2O for 24 hours	Abcite	5	5	OK	
	0-22	5	5	OK	
Rm. Temp. Aq. Protein Foam Solution for 24 hours	Abcite	5	5	OK	
	0-22	5	4	OK	20% gold removed from substrate
Rm. Temp. Aq. AFFF Solution for 25 hours	Abcite	5	4	OK	One pinhole size gold speck removed from substrate
	0-22	5	5	OK	
175°F Water Vapor	Abcite	5	4	Water bubbles formed under overcoating of one sample after 3 hrs of exposure	5% overcoat removed from gold layer. Failure occurred after 3 hours of exposure
	0-22	5	3	OK	Some gold specks were removed from substrate

For the various environmental conditions it appeared that radiant heat and 200°F air exposures had little effect on adhesion characteristics for either overcoating. Of 30 specimens tested only one 0-22 sample failed and, even in this case, only one gold speck was removed from the substrate. For the 150°F water, protein foam, and AFFF exposures, the Abcite coating was most affected. This was particularly true for the protein foam exposure, because four of five samples failed the adhesion test. For these failures some of the overcoat material was removed from the gold layer and some gold from the substrate. Forty percent of the Abcite samples also failed after exposure to the water and AFFF. Adhesion failures to the 0-22 samples occurred only for the AFFF exposure for 40% of the samples and was slight (one pinhole-size gold speck removed from the substrate).

In the room-temperature water, protein foam, and AFFF exposures, few failures were noted to either coating type. None occurred during the water exposure, one 0-22 sample failed the protein foam exposure, and one Abcite sample failed the AFFF exposure. The 0-22 sample failure was more significant than the Abcite sample failure (20% of gold removed from 0-22 sample compared to one pinhole-size gold speck removed from the Abcite sample). No adhesion failures occurred at the overcoat-gold bond.

For the 175°F water vapor exposure one of five Abcite samples and two of five 0-22 samples failed adhesion. The Abcite failure occurred at the overcoat-gold bond and the 0-22 failure at the gold-substrate bond. Coating failures in each case were not substantial.

Most samples subjected to the various environments and then abraded for 2000 cycles showed adhesion failures after abrasion. For all-dry environments and room temperature wet tests the failure always occurred at the gold-substrate bond for both coatings. For the elevated-temperature wet tests the Abcite samples also failed at the overcoat-gold bond.

Abrasion. Table IX lists the abrasion data for both overcoat-type samples in the as-received condition and for various environmental exposures. Also shown are the abrasion data for the standard facepiece materials in the as-received condition.

As received both coating types showed very little marring after 1000 cycles. Of the two types the Abcite was less marred. Both types were superior to the standard coating by at least a factor of five. Other abrasion data in Table VIII indicate that five samples of each overcoat type abraded for 2000 cycles were at least 10 times more durable than the standard facepiece coatings.

All environmental exposures showed little influence on the abrasion characteristics of the coatings. There may have been some slight degradation in durability as evidenced by some small penetration of both coating types to the substrate after some of these exposures. Even with this increased wear, however, we believe these samples would still pass radiant heat requirements and would not hamper vision to any noticeable extent. Again, as was noted previously, the Abcite in most cases appeared to be slightly more resistant to abrasion than the 0-22 coating.

Table IX. Abrasion Results for Abcite and 0-22 Overcoated Standard Facepiece Materials and Standard Facepiece Coatings for Different Environmental Exposure Conditions

Envir. Exposure	Sample Type	No. of Samples	No. of Cycles	Condition of Samples
As-received	Abcite	5	1000	None to extremely slight surface marring
	0-22	5	1000	Very slight surface marring
	Stand.	5	200	Many significant penetrations of coatings to substrate
Radiant Heat				
1.9 gcal/cm^2/sec for 30 seconds	Abcite	5	1000	Slight Surface Marring
	0-22	5	1000	Several small penetrations of coatings to substrate
0.4 gcal/cm^2/sec for 300 seconds	Abcite	5	1000	Slight surface marring
	0-22	5	1000	Several small penetrations of coatings to substrate
200°F Air for 4 hours	Abcite	4	1000	Slight surface marring
	0-22	5	1000	Slight surface marring
150°F H_2O for 4 hours	Abcite	4	1000	Slight surface marring
	0-22	5	1000	Several small penetrations of coatings to substrate
150°F Aq. Protein Foam Solution for 4 hours	Abcite	1	1000	Several small penetrations of coatings to substrate
	0-22	5	1000	Slight surface marring to several small penetrations of coatings to substrate
150°F Aq. AFFF Solution for 4 hours	Abcite	3	1000	Slight surface marring
	0-22	5	1000	Several small penetrations of coatings to substrate

Table IX. (continued)

Envir. Exposure	Sample Type	No. of Samples	No. of Cycles	Condition of Samples
Room Temp. H_2O for 24 hours	Abcite	5	1000	Several small penetrations of coatings to substrate
	0-22	5	1000	Several small penetrations of coatings to substrate
Room Temp. Aq. Protein Foam Solution for 24 hours	Abcite	5	1000	Slight surface marring to several small penetrations of coatings to substrate
	0-22	5	1000	Several to many small penetrations of coatings to substrate
Room Temp. Aq. AFFF Solution for 24 hours	Abcite	5	1000	Very slight surface marring
	0-22	5	1000	Slight surface marring to several small penetrations of coatings to substrate
175°F Water Vapor	Abcite	4	1000	Very slight surface marring
	0-22	3	1000	Slight surface marring to two small penetrations of coatings to substrate

Radiant Heat. All samples withstood the radiant heat requirements with no damage to the coating (Table X). Extended exposure tests at the 1.9 gcal/cm^2/sec heat-flux level showed minimum coating failure times of 214 seconds for the Abcite and 147 seconds for the 0-22. The Abcite overcoating apparently has a lower heat absorptance than the 0-22 coating in equivalent thicknesses.

Environmental Exposures. Based upon some of the results given in Table VIII, it appears that the Abcite overcoat is more affected by wet environments than the 0-22 coating as judged from its appearance and adhesion performance. In both the 150°F AFFF and 175°F water vapor exposures, there was visible evidence of the formation of water bubbles under the Abcite overcoat. No change in the appearance of the 0-22 samples was noted. Adhesion failures for the Abcite samples exposed to these same environments were at the overcoat-gold bond. No 0-22 failures to this bond were indicated in any of the exposure tests.

Table X. Radiant Heat Results for Abcite and O-22 Overcoated Standard Facepiece Materials

Incident Radiant Heat Flux ($gcal/cm^2/sec$)	Sample Type	Nominal Coating Thickness (μ)	No. of Samples	Exposure Time (sec)	AVG. Max. Heat Flux Transmitted ($gcal/cm^2/sec$)	Coating Condition
1.9	Abcite	4	10	30	.037	OK
	Abcite	4	2	214 to 270	.074 to .077	Crease Mark Down Center of Specimen
	O-22	4	10	30	.037	OK
	O-22	4	2	147 to 154	.076 to .071	Surface Blemish
0.4	Abcite	4	8	300	.025	OK
	O-22	4	8	300	.025	OK

In comparing the adhesion results for samples exposed to water and protein foam and AFFF (Table VIII), we noted that protein foam had a significant effect on the Abcite coatings at the 150°F condition. The protein foam and AFFF solutions did not appear to have any significant effect on the 0-22 samples compared with the water bath results.

Abcite and 0-22 Overcoatings on Gold-Coated Polycarbonate Substrates

Optical Characteristics. All samples met infrared criteria but many had low LT values (Table XI). Since the major thrust of this work at this point was to establish the abrasion and adhesion characteristics of these coatings, these low LT values had only secondary importance. Thus, these samples were considered acceptable.

Table XI. Optical Characteristics of Abcite and 0-22 Overcoatings on Gold-Coated Polycarbonate Substrates

Sample Type	Nominal Coating Thickness (μ)	Coating Thickness Range (μ)	LT Range (%)	Infrared Transmission Max. (%)	Infrared Transmission Wave Length (μ)	Infrared Transmission Min. (%)	Infrared Transmission Wave Length (μ)
Abcite	4	3.4 to 4.2	17 to 21	8	0.8	0	2.5
Abcite	7	6.8 to 8.4	16 to 21	7	0.8	0	2.5
0-22	4	3.4 to 4.5	15 to 26	10	0.8	0	2.5

Adhesion. Table XII summarizes the adhesion data for these samples as-received, abraded, and for various environmental exposures. In the as-received condition all 50 Abcite samples passed. For those 0-22 samples that did not pass, six of 51, failures occurred at both the overcoat-gold and gold-substrate bonds. For those samples tested for adhesion after abrasion cycling, four of 10 Abcite and all five 0-22 samples failed. For the Abcite samples, failures occurred at the overcoat-gold bond; and, for the 0-22 samples, at both the overcoat-gold and gold-substrate bonds.

For the one dry environmental exposure (200°F air for 4 hours) eight of 10 Abcite samples passed and no 0-22 coatings passed. Abcite samples failed at the overcoat-gold bond; 0-22 samples failed at both the overcoat-gold and gold-substrate bonds. For all wet environmental exposures at elevated temperatures, no samples of either overcoating types lasted the entire 4-hour exposure period. Ninety percent of the samples failed after a 2-hour exposure. Abcite samples typically failed at the overcoat-gold bond and 0-22 samples at the gold-substrate bond. For room temperature wet exposures a sufficient number of 0-22 samples only were available for evaluation. Under these conditions 80% of these samples failed, and in all cases, the failure was to the gold-substrate bond.

(continued on page 30)

Table XII. Adhesion Results for Abcite and 0-22 Overcoatings on Gold-Coated Polycarbonate Substrates for Various Environmental Exposures

Envir. Exposure	Sample Type	Nominal Coating Thick. (μ)	No. of Samples	No. of Samples Passed	No. of Samples Failed Exposure Time (HR.)				Sample Appearance	Condition of Failed Specimens
					1	2	3	4		
As-received	Abcite	4	24	24					OK	
	Abcite	7	26	26					OK	
	0-22	4	51	45					OK	Gold specks to 70% overcoat and 30% gold removed from substrate
Abrasion 2000 cycles	Abcite	4	5	2					Slight surface marring	40 to 80% overcoat removed
	Abcite	7	5	4					Very slight surface marring	10% overcoat removed
	0-22	4	5	0					Slight surface marring	60 to 100% overcoat and 1 to 10% gold removed
$200^{\circ}F$ Air for 4 hours	Abcite	4	5	3		1		1	OK	1% to 40% overcoat removed
	Abcite	7	5	5					OK	
	0-22	4	5	0	4			1	OK	25 to 100% overcoat and gold specks to 40% gold removed

Table XII. (continued)

Envir. Exposure	Sample Type	Nominal Coating Thick. (μ)	No. of Samples	No. of Samples Passed	No. of Samples Failed Exposure time (HR.)				Sample Appearance	Condition of Failed Specimens
					1	2	3	4		
150°F H_2O for 4 hours	Abcite	4	3	0		3			Bubble formation under over-coating	100% overcoat removed
	Abcite	7	2	0		2			Bubble formation under over-coating	50 to 100% over-coat removed
	0-22	4	5	0	1	4			OK	50 to 100% gold removed
150°F Aq. Protein Foam Solution for 4 hours	Abcite	4	3	0		2	1		OK	90 to 100% over-coat removed
	Abcite	7	2	0	2				OK	30 to 100% over-coat removed
	0-22	4	5	0	5				OK	100% gold removed
150°F Aq. AFFF Solution for 4 hours	Abcite	4	3	0	1	2			OK	80 to 100% over-coat removed
	Abcite	7	2	0			2		Bubble formation under over-coating	30 to 100% over-coat removed
	0-22	4	5	0	4	1			OK	100% gold removed

Table XII. (continued)

Envir. Exposure	Sample Type	Nominal Coating Thick. (μ)	No. of Samples	No. of Samples Passed	No. of Samples Failed Exposure time (HR.)				Sample Appearance	Condition of Failed Specimens
					1	2	3	4		
Room Temp. H_2O for 24 hours	0-22	4	5	2					OK	60 to 100% gold removed
Room Temp. Aq. Protein Foam Solution for 24 hours	0-22	4	5	1					OK	15 to 100% gold removed
Room Temp. Aq. AFFF Solution for 24 hours	0-22	4	5	0						50 to 90% gold removed
175°F Water Vapor for 4 hours	Abcite	4	5	0		3	2		Bubble formation under over-coating after 2 hours of exposure	30 to 100% over-coat removed
	Abcite	7	3	0		3			"	50 to 100% over-coat removed
	0-22	4	5	0	5				OK	60 to 100% gold removed

Table XIII. Abrasion Results for Abcite and O-22 Overcoatings on Gold-Coated Polycarbonate Substrates for Various Environmental Exposures

Envir. Exposure	Sample Type	Nominal Coating Thickness (μ)	No. of Samples	No. of Cycles	Condition of Samples
As-received	Abcite	4	5	2000	Slight surface marring
	Abcite	7	5	2000	Very slight surface marring
	0-22	4	5	2000	Slight surface marring
200°F Air for 4 hours	Abcite	4	3	1000	Very slight surface marring
	Abcite	7	5	1000	Very slight surface marring to several small penetrations of coatings to substrate
Room Temp. H_2O for 4 hours	0-22	4	2	1000	Very slight to slight marring
Room Temp. Aq. Protein Foam Solution for 4 hours	0-22	4	1	1000	Slight marring

Abrasion. The abrasion results are listed in Table XIII. As received both types of overcoating samples could withstand 2000 cycles with slight surface marring or less. The thicker Abcite sample showed the least marring.

Few samples were available for determining the effect of environmental exposure on abrasion resistance because of the large number of adhesion failures discussed previously. Only some Abcite samples remained after the 200°F air tests and a few 0-22 samples were available for test after the room-temperature wet exposures. The abrasion resistance of only the thicker Abcite samples appeared affected by the 200°F air exposure where some coating penetrations to the substrate occurred, whereas only very slight surface marring had been witnessed on similar samples in the as-received condition. The abrasion characteristics of the 0-22 samples were not affected by room temperature wet environmental exposures.

Radiant Heat. All samples of each overcoating type passed the radiant heat test requirements (Table XII). Samples subjected to extended exposure times did not survive as long as their initially tested equivalents (Tables IV and XIV). This may have been caused by the primer coatings used for this later sample group. The wide spread in reported coating failure times for the 0-22 coating was due in part to a difficulty in spotting the failure when it first occurred.

Environmental Exposures. This sample group showed poor resistance to wet environments. Most showed some coating breakdown within 2 hours in the elevated-temperature wet environments. For the Abcite samples this breakdown was discerned both visually and by adhesion tests. The 0-22 samples showed no evidence of coating breakdowns. Breakdowns to these coatings were substantiated through adhesion tests (Table XII). There was some evidence that the protein foam and AFFF solution exposures accelerated this breakdown for the 0-22 samples since in these tests most failures occurred within 1 hour as opposed to 2 hours in water alone. Quicker failures also occurred more frequently to the Abcite samples in these solutions when compared with water results but not to the degree experienced with the 0-22 coatings.

DISCUSSION OF RESULTS

Radiant Heat Resistance

All overcoating types passed the radiant heat test requirements easily as can be seen from Tables IV, V, VI, X, and XIV. When each overcoating has an equivalent thickness, the Abcite overcoating on either the standard facepiece materials or the gold-coated polycarbonate samples can withstand radiant heat exposures longer than the 0-22 (Tables V, X, and XIV). With either overcoating, the initial gold-coated polycarbonate samples showed better heat resistance than the final samples (Tables V and XIV), which may have been due to the use of primer coatings on the final samples. The Abcite overcoating on the standard facepiece materials showed resistance times equivalent to those of the initial gold-coated polycarbonate samples (Tables V and X), and the 0-22 overcoating on the standard facepiece materials performed better than the final gold-coated polycarbonate samples and worse than the initial ones (Tables V, X, and XIV). The Epoxy overcoatings applied to

Table XIV. Radiant Heat Results of Abcite and 0-22 Overcoatings on Gold-Coated Polycarbonate Substrates

Incident Radiant Heat Flux (gcal/cm^2/sec)	Sample Type	Nominal Coating Thickness (μ)	No. of Samples	Exposure Time (sec)	AVG. Max. Heat Flux Transmitted (gcal/cm^2/sec)	Coating Condition
1.9	Abcite	4	5	30	.033	OK
	Abcite	4	5	141 to 155	.062 to .070	Blistered
	Abcite	7	5	30	.035	OK
	Abcite	7	5	114 to 120	.064 to .072	Blistered
	0-22	4	5	30	.035	OK
	0-22	4	5	95 to 168	.054 to .076	Cracks to Substrate
0.4	Abcite	4	5	300	.024	OK
	Abcite	7	5	300	.029	OK
	0-22	4	5	300	.022	OK

the standard facepiece materials were much thicker than the Abcite and 0-22 overcoatings (0.6 to 1.0 mil versus $4\ \mu$) and thus showed poorer radiant heat resistance when these overcoatings were applied at these thicknesses (Tables VI and X). But even with these much thicker coatings the Epoxy overcoatings showed resistance times equivalent to the initial five μ 0-22 overcoated gold-coated polycarbonate samples (Tables V and VI). This indicates that the Epoxy overcoating has a much lower heat absorption characteristic than the 0-22 overcoating. In all tests of the three coating types, the coatings withstood exposure for at least twice the required time before they failed.

The Abcite-overcoated gold-coated polycarbonate samples tested for radiant heat resistance after being abraded 2000 cycles showed a maximum loss in exposure time of 30% and little effect on the maximum heat flux transmission values. Standard facepiece coatings exposed similarly after being abraded 500 cycles showed high heat flux transmission values and at least a 50% reduction in normal protection times (Table V). These higher heat flux transmission values for the standard coatings were caused by the removal and penetration of a significant amount of the gold coating to the substrate during abrasion.

Of the three overcoatings the Abcite-overcoated samples demonstrated the best radiant heat resistance.

Adhesion Characteristics

The initial Abcite and 0-22 overcoatings showed extremely poor adhesion to the gold-coated polycarbonate samples, a condition which was improved substantially on the final overcoatings applied to these same types of samples. However the improvement was not sufficient. Of these final sample materials, the 0-22 samples showed the worse adhesion with most breakdowns occurring at the gold-substrate bond. The 0-22 samples showed adhesion failures in all cases after abrasion cycling, 200°F air, and wet exposures at elevated temperatures. None completed the 4 hours of exposure time planned for the various environments. The Abcite overcoatings on these same substrates also showed adhesion failures within the 4-hour exposure period for all wet environments at elevated temperatures. Typical failures for these samples were at the overcoat-gold bond (Table XII).

The Abcite and 0-22 overcoatings on the standard facepiece materials showed better adhesion results than these same coatings on the gold-coated ploycarbonate samples. The 0-22 overcoated samples showed a failure rate of 40% or less after abrasion cycling and exposure to all test environments. Similar results were obtained on the Abcite samples except for the 150°F aqueous protein foam solution exposure. In this environment 80% of the Abcite samples failed. Failures to the Abcite samples normally occurred at the overcoat-gold bond and at the gold-substrate bond for the 0-22 samples when applied to the standard facepiece materials (Table VIII).

Some of the initial Epoxy-overcoated facepiece materials showed poor adhesion to the gold-substrate bond as-received when the overcoating was applied by flow coating techniques. Final dip-coated samples (Group 4) showed no adhesion failures in the as-received condition or after a 4-hour, 175°F water vapor exposure. There were not enough of these final dip-coated samples to make a complete comparison with the other coatings.

Of all overcoatings the 0-22 and Epoxy on the standard facepiece materials demonstrated the best adhesion to the gold layer under all wear and environmental exposure conditions. Samples of these materials that failed normally showed gold-substrate bond breakdowns. The Abcite overcoatings on the standard facepiece materials showed reasonable adhesion performance for all environments except the 150°F aqueous protein foam exposure. The improved adhesion of these overcoatings on the standard facepiece coatings when compared with the overcoated gold-coated polycarbonate samples indicates that the present protective coating used to protect the gold layer for the standard coatings provides an excellent interface material for bonding the overcoating to the gold.

Abrasion

Whether on the gold-coated polycarbonate substrate or on the standard facepiece coatings, the Abcite and 0-22 overcoatings showed abrasion resistance results at least 10 times better than those of the standard coatings, with the Abcite performing somewhat better than the 0-22 overcoating (Tables VIII,IX, and XIII). The Epoxy-overcoated facepiece samples were at least five times better than the standard facepiece coatings.

Environmental exposures did not appear to have any serious influence on the abrasion resistance of the three overcoatings. There was a slight degradation in durability in some cases in which small penetration of the coatings to the substrates was observed. Even under these conditions, however, the resultant effect was still five to 10 times less severe than the normal abrasion experienced by the standard coatings.

Thicker overcoatings appeared to increase resistance to coating penetration to the substrate, but similar marring characteristics resulted regardless of overcoating thickness.

Sample Condition

The best materials cosmetically were the initial Abcite and the 0-22 overcoated gold-coated polycarbonate samples. The worst were the Epoxy samples. The Epoxy samples had many impurities trapped under the overcoatings. The Abcite and 0-22 overcoated standard facepiece samples also were not free of defects. Many samples had coating cracks across their surface. Since the Abcite and the 0-22 overcoated facepiece samples showed good performance results in these tests, the elimination of these coating cracks must be achieved before these materials can be used as substitutes for the standard coatings.

As mentioned previously, adhesion failures of the 0-22 and Epoxy-overcoated standard facepiece samples normally occurred at the gold-substrate bond. Yet, in similar tests on the standard facepiece coatings, failures to this bond did not occur. It appears that some reaction to the overcoat material or the processing methods used in applying the overcoating degraded the gold-substrate bond somewhat. The cause of this degradation needs to be explored more fully.

CONCLUSIONS

1. Regardless of their thickness, all overcoatings evaluated (Abcite, 0-22, and Epoxy) on the various sample types passed the radiant heat requirements (1.9 gcal/cm^2/sec for 30 seconds and 0.4 gcal/cm^2/sec for 300 seconds) without any observable damage to the coatings. The Abcite overcoated samples showed the best radiant heat resistance.

2. The Abcite and 0-22 overcoatings on the standard facepiece materials performed best. These two overcoatings showed similar abrasion and radiant heat resistance qualities whether placed on the standard facepiece materials or the gold-coated polycarbonate substrates, but they exhibited superior adhesion characteristics on the standard facepiece. The better adhesion of these overcoatings to the standard facepiece coatings resulted in superior resistance to wet environmental exposures (water, water vapor, and aqueous protein foam and AFFF solutions) at both room and elevated temperatures.

3. The 0-22 overcoating on the standard facepiece materials had somewhat better adhesion characteristics than the Abcite overcoating on the same materials, particularly for exposures to aqueous protein foam solutions at elevated temperatures.

4. Adhesion failures to Abcite overcoated samples normally occurred at the overcoat-gold bond, whereas the 0-22 overcoated samples had adhesion failures to the gold-substrate bond.

5. The standard facepiece coatings had better adhesion characteristics than any of the Abcite or 0-22 overcoated samples. No degradation to the coating bonds of the standard coatings was observed in any of the test environments.

6. The Abcite overcoatings in most cases showed somewhat better abrasion resistance than the 0-22 overcoating. Both overcoatings were at least 10 times better than the standard facepiece coatings in abrasion resistance. Since laboratory abrasion results provide only relative information, it is unknown whether a 10-fold improvement in abrasion resistance will substantially extend the useful life of the facepiece materials under field conditions. Thus, field trials are needed of facepieces overcoated with the coatings discussed in this study.

7. Final samples of the Epoxy overcoatings were not available in time to be fully evaluated. The limited samples studied passed the radiant heat test requirements, had good overcoat adhesion to the standard facepiece materials, and were at least five times better than the standard facepiece coatings in abrasion resistance.

8. Of the three overcoatings evaluated the Abcite overcoating on the standard facepiece materials was judged best because it demonstrated superior radiant heat and abrasion resistance. But the O-22 overcoating attained better adhesion on these same materials and this quality may prove more beneficial in field applications because it results in better environmental resistance particularly to wet environments. The O-22 overcoated samples had acceptable radiant heat resistance and superior abrasion resistance to currently used coatings.

9. This investigation showed that the abrasion resistance of the present facepiece coatings can be substantially improved and still meet the radiant heat test requirements. Since the evaluated samples were experimental in nature, further work is required before any one of these coatings can be substituted for the standard facepiece coatings.

RECOMMENDATIONS

Additional work is required to:

1. Eliminate the coating cracks in many of the Abcite and O-22 overcoated facepiece materials.

2. Establish sources for these materials. The experimental overcoatings on the standard facepiece materials represented the products of two manufacturers. It must be determined whether one or more sources can provide materials having performance characteristics similar to the samples evaluated herein.

3. Establish if other overcoating materials are available with equal or better properties than those evaluated.

4. Determine from field trials if sample facepieces overcoated with the coatings evaluated in this study improve durability significantly with respect to the standard facepiece materials.

Appendix A. REFERENCES

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