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)BIC COATINGS FOR ARMY ROTORY-WING AIRCRAFT

May 1975

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This report presents the results of an evaluation of materials having a potential to function as an icephobic coating for use on U. S. Army helicopters. The materials represented the most likely candidates for icephobic coatings proposed by industry as a result of a Government inquiry for this information in the fall of 1974. The evaluation was conducted in a laboratory environment and under controlled conditions. All of the coatings were rejected following simulated rain erosion tests. Therefore, it is concluded that materials which meet the Army's needs for an icephobic coating for use on Army helicopters do not exist. It is recommended that periodic

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reexaminations be made to determine if new chemicals could function as ice repellents for Army helicopters.

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BACKGROUND

It has been the ambition of aircraft designers to find solutions to operational requirements for aircraft which add no weight and which represent a cost savings, if adopted. The protection of aircraft required to operate in icing conditions is one such operational requirement. The Federal Aviation Administration (FAA) examined ice repellent materials, or "icephobic" as they are popularly known, that they believed offered a potential inexpensive alternative to systems that were being used for ice protection of aircraft: e.g., electrothermal, pneumatic, and electroimpulse. These materials were called icephobic because they were intended to repel, or have an aversion for, the ice once it formed. Generally, these materials, applied as coatings, were supposed to reduce the adhesion force of ice to the coated surface. Then the forces that normally exist in the mechanical system (vibration, airloads, centrifugal force) were to remove the accumulated ice, since adhesion of the ice to a coated surface is supposed to be much lower than it is to an uncoated surface. The FAA concluded that of the materials that were examined, none showed either passive anti-icing qualities or tendencies to precipitate the release of accumulated ice.[1,2]

In June 1973, the Eustis Directorate awarded a contract (DAAJ02-73-C-0107) to the Lockheed-California Company to investigate advanced anti-icing/deicing systems for Army aircraft. Under this program, an electrothermal system was designed and built for a representative Army aircraft, the UH-1H. That system involved a fairly extensive modification to the UH-1H to provide ice protection. It was costly ($28,000 per aircraft and up, depending on the study) and involved a weight penalty which, although not severe, was relatively high (165 pounds, estimated). Consequently, new interest arose to determine if new chemicals were available on the market which might serve as icephobic coatings for Army helicopters. The conditions that a proposed coating had to comply with are listed below:

- Two hours of continuous, moderate icing (defined as flight in supercooled clouds containing an average liquid water content of 0.8 gram per cubic meter with a mean effective droplet diameter of 20 microns at any ambient temperature from -4°F to +32°F).

- Application of the coating before each flight or after 2 hours of exposure to icing conditions, whichever involves fewer applications.

- Airspeed of 100 knots.

These limitations were presented in the form of an announcement in the *Commerce Business Daily* on November 7, 1974, Issue No. PSA-6192, requesting information from industry on potential icephobic coatings for Army aircraft.

---

[1] Donald M. Millar, *Investigation of Ice Accretion Characteristics of Hydrophobic Materials*, FAA Report No. FAA-DS-70-11, National Aviation Facilities Experimental Center, Atlantic City, New Jersey, May 1970.

[2] George C. Hay, *Experiments With Icephobic Surfaces*, paper presented to the FAA Symposium on Aircraft Ice Protection, April 30, 1969, General Aviation Safety Division, Aircraft Development Service, Federal Aviation Administration, Washington, D. C.

Responses to that announcement, and a data assessment of published icephobic coating reports, revealed that five coatings existed which had the stated potential:

1. Formamide (60% volume of Formamide to 40% water) – Chemical Research Service.

2. HMOD4/X-27, Hydrophobic Coating Solution – Lockheed-Georgia Company.

3. G635, Silicone Dielectric Compound – General Electric.

4. E-2460-40-1 – Dow Corning.

5. REPCON, Rain Repellent and Surface Conditioner – C. C. Austin Company.

The only sure way of proving whether a proposed coating will function as an icephobic coating is to demonstrate its utility on an operational Army helicopter. However, because flight testing by the Army Aviation Engineering Flight Activity (AEFA), in a previous search for icephobic materials, had proved the potential materials to be unsatisfactory,[3] a decision was made to use laboratory tests as the approach in the current evaluation, before subjecting the materials to flight testing. The coatings evaluated by AEFA – Icephobic Cationic Glaze (ICG), Vortex Company, and XIM Spray, XIM Products – were to be used as controls for the five proposed coatings listed above. The U. S. Army Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire, was selected to conduct the laboratory evaluations. CRREL has an in-house capability to evaluate ice adhesion characteristics and to measure the shear force required to separate ice from flat plates. Shear force is a reasonable measure to evaluate the coatings identified under this program, since ice formed on helicopter rotor blades probably would be shed in shear due to the centrifugal force imparted to the ice by the rotating blade.

[3] Raymond Smith, Marvin Hanks, Carl Mittag, and James Reid, *Artificial Icing Tests, AH-1G Helicopter*, Final Report for USAAEFA Project No. 73-04-2, U. S. Army Aviation Engineering Flight Activity, Edwards Air Force Base, California, November 1974.

TEST DESCRIPTION

All measurements listed in this report as test data are of the adhesive strength of ice against shear at the surface interface of the ice and the test surface. In other words, a section of ice was pulled in shear from a flat surface to which it was adhering and the force needed to dislodge it was recorded. There was no load applied perpendicular to the contact surface of the ice during either freezing or testing. A bubble-free interface was obtained by freezing a very thin (1-2mm) layer of water on the flat surface, which was then strengthened by adding additional water and freezing this to obtain a total thickness of 0.5 inch. This water (and ice) was confined in a ring of aluminum 0.75 inch high and with 1.75 inches inside diameter resting on a 2- by 2- by 0.25-inch test plate of stainless steel. The wall thickness of the ring was 0.125 inch, but the bottom edge resting on the plate was tapered inward (chamfered) so that only an annulus about 1 mm wide was in contact. The polished annulus offered a negligible shear resistance and yet was tight enough to prevent the thin layer of primary water from leaking. The ice in the ring was frozen in the afternoon but not shear tested until the following morning or later, allowing sufficient time for complete temperature equilibrium in the ice sample.

The circular section of ice (area 2.4 sq in.) was chosen as a test form rather than a square because it gives more uniform results than a square, internal strain is more quickly relieved (no corners), and it is easily cradled in the special circular yoke of the testing machine.

The ring of aluminum containing the ice that was frozen to the 2-inch square of stainless steel was positioned flatly and in line with the two correspondingly shaped yokes to be pulled apart by the test machine (see Figure 1). Both holes, square and circular, were slightly oversized; the square frame has a setscrew for gently fixing the edge of the square plate against the driving edge of the yoke, while the circular yoke arises to engage the ring of ice. The line of separation of the shearing yokes was designed to pass directly through the axis of the ice/coating interface so that there would be no detectable moment caused by being off-centered.

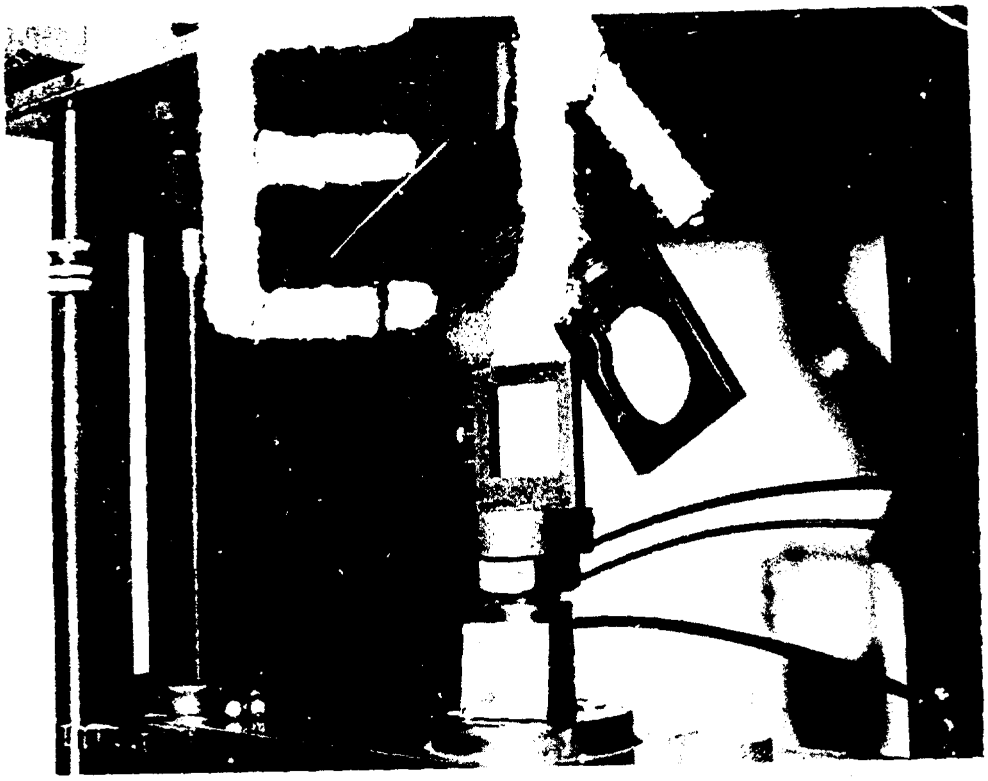

Figure 1. Yoke assembly for ice shear tests.

TEST PROCEDURES AND RESULTS

ABLATION TESTS

Procedure

The following procedure was followed in the ablation tests:

a. The coating being examined was applied to a stainless-steel flat plate according to the manufacturers' instructions and allowed to dry for at least 12 hours at room temperature prior to applying ice. Twelve hours of drying time was required to ensure uniform drying conditions for all the coatings. According to the manufacturers' instructions, no coating required more than 12 hours to dry.

b. Distilled water contained by the aluminum cylinder was frozen onto the coated plate in two layers and stabilized at -4°F (-20°C).

c. The ice was removed, in shear, from the coated plate, and the shear force required was recorded. All testing was done at -4°F* at a shearing rate of 0.2 cm/min (see Figures 2 and 3).

d. Water was again frozen on the same sample surface as described in step b.

e. Steps c and d were repeated four times to obtain a total of five ice releases from the same coated plate.

f. Steps a through e were repeated on another flat plate coated with the same coating examined above.

g. Step f was repeated four times to obtain a total of five replicates for the coating being examined.

h. Tests described above by steps a through g were conducted for each coating using a new, not previously coated, flat plate made of the same material.

i. Using an uncoated flat plate, ice was applied in the same manner as in step b and removed as in step c, measuring shear force required to remove the ice.

j. Step i was repeated four times to obtain a total of five replicates of the test.

---

*A test temperature of -4°F was selected (1) since it is the lower limit for moderate ice conditions to occur and is well below the 8.6°F (-13°C) value below which little ice was shed from test helicopter rotor blades,[3] and (2) since it is the worst case (greatest ice adhesion) for the temperature range of interest for anti-icing/deicing Army helicopters (32°F to -4°F). Generally, the lower the temperature, the higher the ice adhesion to helicopter rotor blades.

Figure 2. A prepared test specimen being installed in the shear test machine.

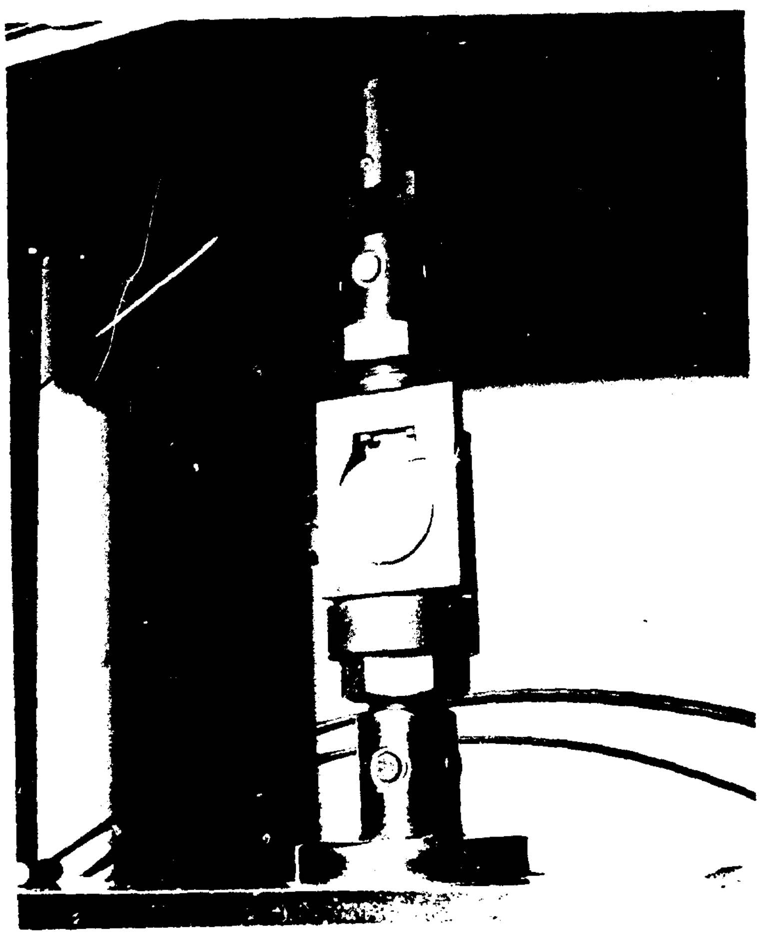

Figure 3. Test specimen ready for shear testing.

Results

Table 1 lists the test results. Figure 4 shows representative plates following shear tests. Figure 5 shows all the test plates used for this phase of the testing program.

An assessment of Table 2, which was obtained using the data from Table 1, shows that the coatings identified as E-2460 and G635 offer potential as icephobic materials. The average shear force for these coatings remained nearly constant through successive release cycles (ablations) and was much smaller than that of the control coatings (ICG and XIM Spray). The validity of the last release cycle (V) or ablation test is questionable, since in three cases there was a drastic deviation from the trends; i.e., ICG, HMOD4, and REPCON. However, the overall results of the shear tests show that E-2460 and G635 have the best potential as icephobic coatings.

G635 HMOD4

Figure 4. Representative test plates with different coatings, following shear testing.

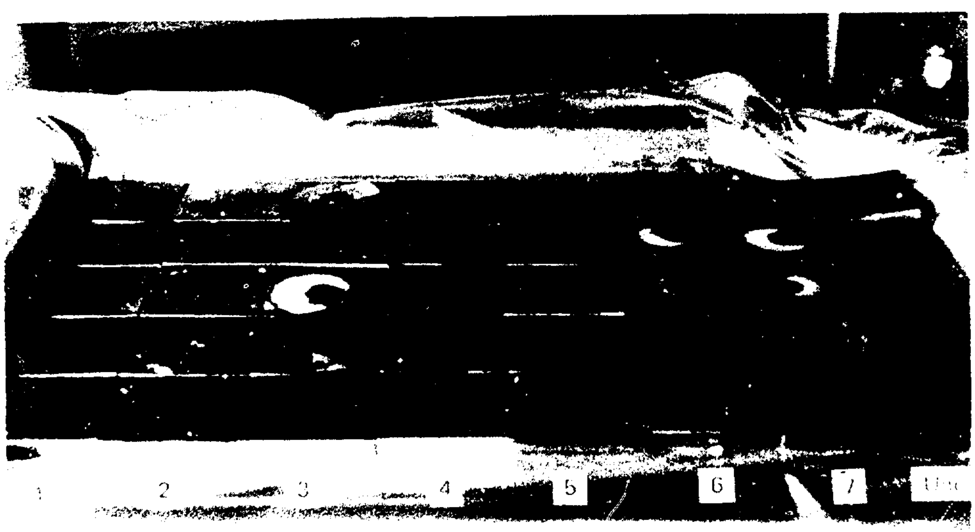

Figure 5. Test plates used for shear testing.

TABLE 1. ICE SHEAR STRENGTH TESTS

Release Cycle	Replicate Number	Shear Force for Icephobic Coatings (lb) ICG Code 1	FORMAMIDE Code 2	HMOD4 Code 3	E-2460 Code 4	G635 Code 5	REPCON Code 6	XIM Spray Code 7	Uncoated
I	1	SWM	36.1	SWM	2.6	SWM	SWM	SWM	91
	2	40.5	4.6	SWM	3.1	SWM	SWM	3.6	75
	3	SWM	14.1	SWM	SWM	SWM	SWM	SWM	101
	4	44.0	36.1	SWM	SWM	SWM	SWM	21.8	75
	5	45.4	93.5	SWM	SWM	1.4	2.6	SWM	163
II	1	61.7	207.0	SWM	1.1	0.4	15.9	44.1	89
	2	24.2	27.1	6.8	SWM	SWM	SWM	9.0	109
	3	1.1	8.8	SWM	SWM	SWM	SWM	58.8	143
	4	22.9	53.5	11.9	SWM	SWM	SWM	SWM	113
	5	83.7	79.3	4.9	4.4	8.1 peak* 0.2 slide	8.1	62.6	91
III	1	63.4	173.0	77.8	2.2	SWM	18.7	92.2	90
	2	SWM	46.7	SWM	SWM	1.1	SWM	SWM	49
	3	37.7	28.4	SWM	SWM	SWM	SWM	SWM	79
	4	43.0	91.6	SWM	SWM	SWM	SWM	SWM	84
	5	54.4	172.0	37.4	SWM	2.6	35.5	75.8	192
IV	1	43.6	220.0	62.8	SWM	SWM	83.0	78.2	147
	2	69.8	30.8	SWM	SWM	SWM	SWM	SWM	45
	3	broke, no data	39.9	2.2	SWM	SWM	SWM	SWM	9
	4	57.3	89.9	SWM	SWM	SWM	SWM	2.2	173
	5	69.2	56.2	91.4	SWM	3.1 peak* 0.2 slide	98.0	77.5	104
V	1	SWM	167.0	14.5	SWM	2.6	SWM	147.0	79.0
	2	7.7	SWM	11.0	SWM	SWM	34.1	78.2	117.0
	3	SWM	17.6	SWM	SWM	SWM	SWM	SWM	86.0
	4	28.6	37.9	SWM	SWM	SWM	7.7	89.4	84.0
	5	70.5	117.0	77.7	SWM	SWM	7.9	78.2	104.0

Remarks: SWM—sample separated from mounting in shear testing machine before force was applied.

*Separation did not occur after peak load was reached.

TABLE 2. AVERAGE SHEAR FORCE FOR POTENTIAL ICEPHOBIC COATINGS FOR ARMY AIRCRAFT

Release Cycles (Five Replicates per Cycle)	Average Shear Force for Coatings (lb)							Average Shear Force, Uncoated (lb)
	Control Coatings		Potential Icephobic Coatings					
	ICG Code 1	XIM Spray Code 7	FORMAMIDE Code 2	HMOD4 Code 3	E-2460 Code 4	G635 Code 5	REPCON Code 6	
I	26.0	5.1	36.9	0.0	1.1	0.3	0.5	101.0
II	38.7	34.9	75.1	4.7	1.1	0.1	4.8	109.0
III	39.7	33.6	102.3	23.0	0.4	0.7	10.8	98.8
IV	60.0	31.6	86.2	31.3	0.0	0.1	36.2	95.6
V	21.4	78.6	67.9	6.6	0.0	0.5	9.9	94.0

DRY AIR TESTS

Procedure

The following procedure was used to evaluate the effectiveness of the icephobic coatings after exposure to high-velocity dry air:

a. Each coating examined (Cationic Silicone E-2460-40-1 and Silicone G635) was applied to five stainless steel flat plates according to the manufacturers' instructions and allowed to dry for at least 12 hours prior to further testing.

b. Dry air was blown onto the coated test plates at a velocity of 1000 mph at an impingement angle of 45° for 30 minutes so that the coated faces of the test plates were immersed in the airflow (the test plan called for ⩾ 550 mph (807 ft/sec); however, 1000 mph capability was available so the test was run at that velocity).

c. Water was frozen in the form of glaze onto the coated test plates and stabilized at -4°F to a thickness and shape required by the shear test machine used in these tests (see Figures 1 and 3).

d. The ice was removed, in shear, from the coated test plates, and the shear force required at -4°F was recorded.

Results

As shown in Table 3, dry air blown at 1,000 mph did not adversely affect the ability of the two coatings to function as icephobic materials.

TABLE 3. DRY AIR TEST RESULTS – ICEPHOBIC COATINGS E-2460 AND G635

	Shear Force (lb)	
Replicate Number	E-2460	G635
1	SWM*	1.8
2	SWM	3.1
3	SWM	1.8
4	1.1	2.2
5	SWM	1.8
Average Shear Force	0.2	2.1

*SWM–sample separated from mounting in shear testing machine.

Remarks: Dry air was blown on coated flat plates for 30 minutes at approximately 1,000 mph. No additional or prior release cycles were attempted for this test.

RAIN EROSION TESTS

Procedure

Following completion of the dry air tests, rain erosion tests were performed on the same two coatings. In this case, the UH-1H main rotor tip speed at hover was to be used as the rain erosion test velocity; i.e., 550 mph. CRREL indicated that the highest velocity water available at that facility was 60 mph (88 ft/sec). The decision was made to examine the coatings at the lower velocity (60 mph) to get at least one data point upon which to base further effort. Therefore, CRREL was authorized to proceed with testing using the following procedures to evaluate the effectiveness of E-2460 and G635:

a. The test plates were covered with coatings of E-2460 and G635 and had previously gone through five release cycles or ablation tests without exposure to high-velocity dry air or high-velocity water. The previous tests had shown that the average shear force of the coatings (see Table 2) was near zero and had not significantly changed with each new release or ablation. Therefore, they were still in virtually "new" condition.

b. A stream of tap water was directed onto each coated face of the test plates at a velocity of 60 mph for a total of 30 minutes (15 minutes exposure to each half of the same surface), at an impingement angle of 45°. Tap water was used for these tests because distilled water was not available in the quantities that would be required. The use of tap water was not considered to be detrimental for this evaluation since the force of the stream of water was judged to have a much greater impact on the coatings than would the chemical action that might result from using tap water instead of distilled water.

c. Water was frozen onto the coated test plates in two layers, as described earlier, and stabilized at -4°F.

d. The ice was removed in shear from the coated test plates, and the shear force required at -4°F was recorded.

Results

Table 4 shows the results of the rain erosion tests on E-2460 and G635. A comparison of the results of this test with those of the uncoated case given in Table 2 shows that the water effectively removed the coatings. Therefore, these coatings did not pass this test.

TABLE 4. RAIN EROSION EFFECT ON ICEPHOBIC COATINGS E-2460 AND G635

	Shear Force (lb)	
Replicate Number	E-2460	G635
1	88.5	57.3
2	116.3	104.0
3	70.9	99.1
4	94.3	76.4
5	bad test (dropped)	110.8
Average Shear Force	92.5	89.5

To ensure a fair assessment of all the coatings that showed a possibility of acceptance as an icephobic coating, the two remaining coatings (HMOD4 and REPCON) that showed improvement over the control coatings were examined (see Table 2). The original test plates that were used to obtain the data listed in Table 1 were not suitable for this assessment since the coated surfaces had been altered by CRREL as a result of other unrelated tests conducted on the coatings. Therefore, new, coated test plates were used for this test. The procedure used for this examination was the same as that for the previous rain erosion tests on E-2460 and G635 except that each of the two coatings to be tested (REPCON and HMOD4) was applied to five stainless steel flat test plates according to the manufacturers' instructions and allowed to dry for at least 12 hours prior to testing.

Table 5 shows the results of the rain erosion tests on REPCON and HMOD4. A comparison of the results of this test and those of the uncoated case given in Table 2 shows that the water effectively removed the coatings; therefore, these coatings did not pass this test.

TABLE 5. RAIN EROSION EFFECT ON ICEPHOBIC COATINGS REPCON AND HMOD4

	Shear Force (lb)	
Replicate Number	REPCON	HMOD4
1	97.6	123.0
2	108.0	117.0
3	79.7	124.0
4	51.1	150.0
5	82.2	92.0
Average Shear Force	83.7	121.2

Figure 6 shows the variation in shear force that various coatings exhibited during the tests. The materials that showed the greatest potential as icephobic coatings (listed below) failed to pass the rain erosion (water spray) tests:

a. Cationic Silicone E-2460

b. Silicone Grease G635

c. HM0D4

d. REPCON

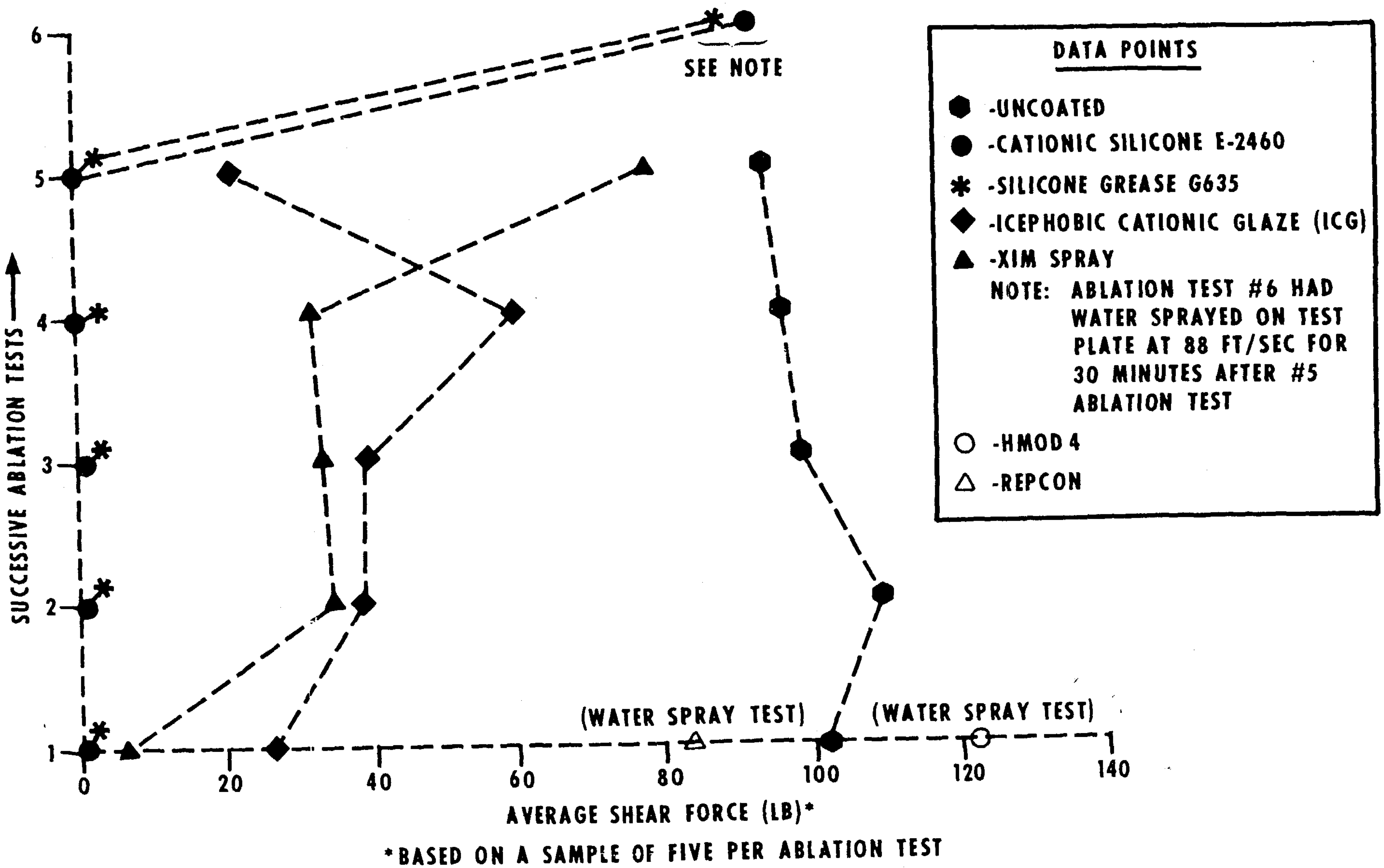

Figure 6. Average shear force per ablation test.

CONCLUSIONS

On the basis of the data presented and analyzed in this report, it is concluded that:

a. The coatings evaluated in this program represent the best coatings that industry has available at this time which exhibit potential icephobic properties. However, the coatings do not successfully function as icephobic coatings at -4°F.

b. None of the coatings examined under this program show adequate icephobic properties for use on Army helicopters.

RECOMMENDATIONS

Based on the results and conclusions of this program, it is recommended that:

a. The materials evaluated under this effort not be used as icephobic coatings on Army helicopters.

b. Due to a rapidly changing state of the art of chemical technology, a periodic reexamination be made of potential icephobic materials or coatings which might be used on Army helicopters.