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New Methods and Materials for Molding and Casting Ice Formations

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NEW METHODS AND MATERIALS FOR MOLDING AND CASTING ICE FORMATIONS

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SUMMARY

This study was designed to find improved materials and techniques for molding and casting natural or simulated ice shapes that could replace the wax and plaster method. By utilizing modern molding and casting materials and techniques, a new methodology was developed that provides excellent reproduction, low-temperature capability, and reasonable turnaround time. The resulting casts are accurate and tough.

INTRODUCTION

E-3673

Recording the shapes of delicate ice accretions on aircraft components (fig. 1) has always been a difficult task. Until now, ice formations were recorded primarily by using ice tracings (fig. 2) or hot wax moldings. The use of tracings to record ice formations results in a loss of three-dimensional detail. Hot wax molding preserves much three-dimensional detail, but introduces new problems.

The hot wax method calls for dipping a piece of ice (removed from the body on which it has accreted) into a container of molten beeswax. After a sufficient layer of wax has accumulated and after the ice has completely melted, the mold is opened and the water is drained. The mold is then filled with casting plaster that is allowed to harden. When the cast is solid, the wax is melted away, leaving a casting of the ice shape (fig. 3). This technique does not solve all the problems of molding and casting ice formations and even presents a few problems of its own. First, it is necessary to have a rather large piece of ice because the ice must be removed from the site on which it has accreted. This not only destroys information about the location of the ice formation relative to the body on which it was produced, but often damages the ice itself (which can be extremely fragile) and destroys any ice remaining on the body. Dropping a piece of ice into molten wax also has some effect on the ice shape. Second, using plaster as the casting material limits the value of the cast because its coarseness causes some surface texture and detail to be lost. Plaster is also inherently brittle, thus preventing the casts from being used in dry wind tunnel test programs for studying aerodynamic performance degradation due to icing.

The goal of the work being reported herein was to achieve excellent reproduction of ice formations by utilizing modern molding and casting materials and techniques in place of hot wax and plaster. To do this, the mold must cure below 0 °C within a reasonable time, and the ice must also be allowed to remain on the body on which it has accreted. To ensure no ice melt, the curing process must not be at all exothermic. Temperature dependency is important in selecting a molding material. Molding materials are designed to cure at room temperature and may not cure below 0 °C. The cast produced must retain all the detail of the original ice formation and must be tough and machinable to allow its use in dry wind tunnel testing.

TESTS

Standard Handling Techniques

Techniques for handling ice. - As stated previously, the ice that is to be molded can often be extremely fragile. Any of the delicate horns associated with glaze ice, or the feathers associated with rime or mixed ice, are easily broken. Therefore, it is preferable not to handle the ice at all, but to mold it at its accretion site (fig. 4). Another advantage of this method is that it preserves all the information about how the ice was oriented upon the body on which it was accreted. This method of molding at the site allows one to mold a small ice accretion, or even frost, that cannot be removed intact from the accretion site. When the ice cannot be molded at the site, great care must be taken to preserve as much ice detail as possible. If the ice has been accreted on a relatively small model, it would probably be best to remove and mold the entire model. The last resort would be to attempt to remove the ice from its accretion site and then mold only the ice itself. This can be done by slightly heating the body from which the ice is to be removed. If the mold cannot be poured immediately, the model should be placed in a plastic bag to prevent any sublimation and then placed in a freezer. A common picnic cooler containing dry ice can be used as a freezer. During handling, extreme care should be taken so as not to damage the ice.

Techniques for molding. - In molding, all materials must be kept below 0 °C at all times. This requires a freezer large enough to keep all supplies refrigerated and also periodically recooling materials being handled at room temperature. A digital scale for measuring the materials to be mixed is also useful. The proportions of the various mold components are critical. Even a slight change in the mixing ratio can greatly affect the properties of the mold.

All the molding materials tested included a base material and a catalyst. Because these materials were being handled below their design temperatures, many became thick and difficult to handle. This necessitated using a thinning agent that allowed the materials to be poured while not interfering with their curing actions. During all testing, the procedures suggested by the material suppliers were followed, including

(1) Using a high-quality digital scale for weighing proper amounts of base, curing agent, and thinner
(2) Mixing all materials with a slow-speed electric-motor-driven impeller or a flat-bladed spatula to minimize air entrapment
(3) Deaerating all mixed compounds in a vacuum belljar to remove air entrapped during mixing
(4) Pouring the prepared molding compound carefully in order to avoid entrapping air

Every effort was made to minimize the exposure time at room temperature. The filled mold boxes were cured in the freezer at -5 °C to retain all ice sample details. A freezer temperature of -5 °C was used for all molding operations. (It was later concluded that a more suitable arrangement would be to carry out all molding activities in a "cold room" held at approximately -5 °C.)

The base was mixed with the thinner first to allow the mixture to be recooled after handling without any curing taking place since the catalyst had not yet been added. After this mixture was recooled to below freezing, the required catalyst was added. Immediately after the catalyst was added and mixed thoroughly with the base and the thinner, the mixture was placed inside a belljar and degassed for approximately 3 to 4 min or until little or no bubbling was taking place. These last two steps must be done skillfully for optimal results. The mixing must be done in such a way that as little air as possible is introduced to the mixture so as to minimize the time required for degassing. The time is important since the mixture will be warming throughout the mixing and degassing and will need to be recooled. The mixture will also be starting to cure. In the rare case in which a large amount of air is introduced to the mixture and a lengthy degassing is necessary, the materials may be cured to the point where they can no longer be poured by the time the mixture is recooled to below 0 °C.

After the compound is mixed, degassed, and recooled, the mold may be poured. A mold box must have already been constructed to contain the molding materials. If the sample is a small one that is being molded away from its accretion site, care should be taken to prevent air from being trapped when the mold is poured. This may happen if a fairly severe glaze ice formation is to be molded and the sample is oriented in the box with the leading edge down. The area between the horns of the ice shape could trap air and thus render the mold useless. This can be prevented by simply orienting the sample so that the leading edge is pointing up. The mold should be poured carefully to help prevent mixing in any more air.

Another problem may arise when the ice is removed from its accretion site. The sample must be physically held within the molding material or it will tend to float to the surface and ruin the mold. This can usually be done by placing several small rods across the mold box below the point to which it will be filled. To mold a small sample, the mold box should be immediately returned to the freezer after the mold has been poured. The freezer may be reset to hold a temperature of just below freezing and the mold should remain undisturbed until cured.

If the molding materials have been properly mixed, the condition of the entire mold can be determined by touching an exposed surface. If the mold seems solid to the touch, it may be removed from the freezer or the testing area and allowed to warm. After a reasonable time (usually about 2 hr) the mold may be pulled away from the test body. A small sample mold may be cut open to expose the area of the sample. Before casting a reproduction of the sample, allow the mold to dry thoroughly.

<u>Techniques for casting</u>. - Creating the cast is much simpler than producing the mold because there is no longer a need to keep the materials cold. The cast may be produced at any temperature. For many casting materials, heating the cast shortens curing time and strengthens the cast. Since temperature is no longer a prime concern, more care can be taken in mixing the casting materials. As with the molding materials, mixing the correct proportions of the various cast components is important, and a digital scale should be used. Equally important is ensuring a complete and thorough mixing of the cast components.

Several problems occur in the casting process. Since many of the materials are slightly toxic in their uncured state, they must be handled under an exhaust hood. Another possible problem is the distortion of the final cast because of incorrect orientation of the flexible mold during the cast cure. This problem is solved by returning the mold to the mold box within which it was cured.

The cast may be removed from the mold after the specified curing time for the given cast material. If the mold is to be used for another casting, extreme care should be used in removing the cast from the mold. Because of the roughness of the ice sample, it is often difficult to remove the cast without tearing the mold slightly. Although some damage cannot be completely avoided, it can be minimized by careful handling at this stage. At this point, an accurate model of the original ice formation has been obtained. This model can be used simply as a way of storing the geometry of the ice or as a test model in further studies of the icing phenomenon.

Materials Considered and Why

In selecting new materials that might be suitable for molding and casting operations, prior work in this area (refs. 1 and 2) was considered. Silicone rubber compounds were chosen for molding operations, and epoxy and urethane compounds for casting operations. The properties sought in these materials and the benefits derived from these properties are given for both the molding and casting materials in table I.

The most current information on these properties was obtained from Dow Corning Corp. and General Electric Co. for their respective mold-making compounds and from Ciba-Geigy Corp. and Hexcel Corp. for epoxy and urethane casting materials. Candidate silicone rubber molding materials and their properties and candidate epoxy and urethane casting materials and their properties are displayed in tables II and III, respectively.

Test Techniques for Molding

A matrix of experimental mixtures was established by considering the recommendations of the molding material suppliers and the fact that the curing time for the mixed base material and catalyst is longer at lower temperatures. This matrix (table IV) included various combinations of base materials and catalysts, with variations in the ratio of base to catalyst and in the amount of silicone fluid (thinner) used. The ratio of base to catalyst was varied in order to investigate the effect on the working and curing times at a mixture temperature of -5 °C. It was assumed that a lower ratio (5 vs 10 as recommended) would accelerate the cure, thereby offsetting the effect of temperature.

During the course of the investigation, the matrix of experimental mixtures was expanded to include additional combinations of base, catalyst, and thinner. The amount of silicone fluid (thinner) in the final compound was varied to investigate how it affected the pourability (viscosity) of the molding compound and the physical properties of the final molds. Each experimental molding mixture was evaluated qualitatively by close observation of

(1) The ease (pourability) in filling the mold box
(2) The condition of the molding mixture during initial curing and after complete cure

(3) The general properties of the final mold

To aid in this evaluation, a small amount of the molding mixture was kept in the mixing container and was observed carefully during initial curing under the same conditions as the experimental mold. The general pourability of the mixture at -5 °C and the ease with which it flowed into small cavities in the sample were observed and noted during mold filling. The condition of the experimental curing mixture was readily determined by observing thin sections that were easily removable (if cured) from the mixing container or the mold box. The time for partial or complete cure was noted in each case and the quality of the final cured compound was determined by observing and noting the following conditions:

(1) The fidelity of the sample reproduction in the mold box (or the mixing container)
(2) The degree of elongation prior to failure
(3) The comparative basic strength at failure
(4) The degree of hardness
(5) The degree of air entrapment, both in the basic compound and at the interface with the sample

Test Techniques for Casting

Testing casting materials was much easier than testing molding materials because no temperature dependency was involved. Since all casting materials could be tested in their designed environments, they were judged on the following qualities:

(1) Their ease of handling
(2) Their final reproduction quality
(3) Their final strength
(4) Their final machinability

RESULTS AND DISCUSSION

Molding Results

As the testing progressed, much was learned of basic material requirements and general techniques. Many of the materials investigated were immediately discarded because of unacceptable characteristics at the temperatures required for molding ice formations. As shown by the mold experiment results (table V), many of the tested materials behaved poorly.

The overall results of each series of tests are discussed here. Six tests were made with the General Electric RTV 700 base and the Beta 4 catalyst at various temperatures and mixture ratios. This combination was abandoned because it would not cure at the low temperatures required. In three tests at various mixture ratios, the Dow Corning Silastic E compound also did not cure at low temperatures. At this point it became clear that the properties of the final mold could be altered by adjusting the ratio of base to catalyst. If no evidence of curing was present after several days, the material was probably incapable of curing at any mixture ratio. On this basis, the next few materials were quickly rejected. The Dow Corning Silastic J was unable to cure at low temperatures even after a full week. This was also true of the General Electric RTV 664 and RTV 660 bases with their matched catalysts.

Tests of the General Electric RTV 700 base with the Beta 2 catalyst produced more promising results. Three molds at various mixture ratios yielded an excellent reproduction of the ice sample. However, the curing time of over 2 days was considered unreasonably long and the compound was rejected.

The Dow Corning 3110 base combined with catalyst 4 appeared to be a good candidate for this work. After six tests, curing times at low temperatures were reduced to less than 1 hr and reproductions of the ice samples were excellent. Similar results were produced with the Dow Corning 3112 base combined with catalyst 4. Although these two molding materials seemed to solve the problems of curing time and reproduction quality, they were fairly brittle and broke rather than stretched.

At this point, the results of the molding investigation were sufficiently developed to be useful in a concurrent icing research program (ref. 3) for documenting ice accretions on a helicopter rotor blade. The molding composition (Dow Corning 3110/catalyst 4/DC 200 thinner) and techniques recommended for that program successfully captured the details of a variety of ice shapes quickly and accurately.

The final molding material tested seemed to solve the problem of insufficient stretching. In six tests, the Dow Corning HS RTV base with its matched catalyst produced excellent molds with good detailed reproduction (fig. 5) and elongation of the end product sufficient to ensure good cast handling. At a mixture ratio of 10 parts base to 1 part catalyst with Dow Corning DC 200 thinner added (10 wt %), the curing time at approximately -5 °C was close to 17 hr.

Casting Results

Selecting a casting material was much simpler than selecting a molding material primarily because there were no unusual requirements as to how the cast should be produced. The selection of a casting material only necessitated following the manufacturers' instructions and then deciding which of the resultant casts was preferred.

As can be seen from the cast experiment results (table VI), some of the casting materials had undesirable qualities. The Hexcel Uralite 3124, the Ciba-Geigy 506-956 combination, and the Ciba-Geigy 502-956 combination all produced casts filled with air bubbles both in the interior and on the surface. The surface bubbles rendered the cast too rough to be considered an accurate representation of an ice sample. The Ciba-Geigy casts were also extremely exothermic. The Hexcel Uralite 3125 cast stuck to the mold after curing, and the mold had to be destroyed in order to remove the cast.

The two remaining materials, Hexcel Uralite 7250 (fig. 6) and Hexcel Epolite 3306 (fig. 7), produced excellent casts. Each material has certain advantages over the other. The urethanes are generally easier to mix that the thicker epoxies. Uralite is tougher and easier to handle than Epolite but must be cured in an oven for optimal results. Epolite can be cured at room temperature. Although it is more brittle, it is more easily machined than Uralite. These two final casts were cut and drilled. The holes were later measured to test the machinability of the materials. The Uralite hole was found to be too small because the material stretched while being machined and then bounced back. Although this elasticity makes Uralite tough, it is a disadvantage if the material is to be machined.

CONCLUDING REMARKS

Excellent detail of ice formations can be reproduced in molds by using the proper materials and techniques. The experiments described demonstrated that it is possible to use a silicone rubber molding material below 0 °C and still have reasonable curing times. It has also been shown that an accurate, tough, and machinable permanent model of ice formations can be cast from previously produced molds through the use of selected urethanes and epoxies.

Dow Corning HS RTV was chosen as the best material for molding at low temperatures. It achieved good reproduction of surface features, demonstrated the required elongation, and required reasonable curing time. The final mixture ratio used was 10 parts base to 1 part catalyst with 10 wt % of 20-centistoke-viscosity DC 200 silicone fluid.

For casting, the choice of an ideal material depends upon the desired application. For a tough cast, the best material would be Hexcel Uralite 7250 (100 parts 7250A to 38 parts 7250B). For a cast that must be machined with relatively tight tolerances, the best material would be Hexcel Epolite 3306 (100 parts resin to 10 parts hardener).

REFERENCES

1. Lundstrom, G.: Ice and Landing Surface Demoulding: Replica Fabrication. FFA Memorandum 90, The Aeronautical Research Institute of Sweden, 1973.

2. Anon: A Technique for Producing a Permanent Replica of an Ice Formation Accreted on an Aerofoil Section. Note from National Gas Turbine Establishment (NGTE), England.

3. Lee, J.D.; Harding, R.; and Palko, R.L.: Documentation of Ice Shapes on the Main Rotor of a UH-1H Helicopter in Hover. NASA CR-168332, Jan. 1984.

TABLE I. - PROPERTIES OF MOLDING AND CASTING MATERIALS

(a) Molding materials

Property sought	Benefit
Low pouring viscosity	Fills small cavities
Low shrinkage	Maintains exact shape of master
High tear strength, high elongation, and high tensile strength	Allows small-cross-section mold material to be removed from master without tearing
Reasonable working time and pot life	Allows adequate time for de-airing and handling
Freedom from toxicity	Safety in handling
Lack of exothermic reaction during curing	Protects ice accretion details for reproduction
Reasonable curing time at ~-5 °C[a]	Preserves details of ice shapes

(b) Casting materials

Property sought	Benefit
Low pouring viscosity	Fills small mold details
Low shrinkage	Maintains exact shape of mold
High flexural and tensile strength	Withstands aerodynamic loads generated during wind tunnel testing of cast reproductions
Reasonable working time and pot life	Allows adequate time for mixing and handling
Compatibility with mold material	Produces acceptable castings without destroying details
Reasonable curing time (~24 hr)	Allows practical handling
Freedom from toxicity	Provides safety in handling
Lack of exothermic reaction during curing	Protects mold details

[a]Of primary consideration.

TABLE II. - CANDIDATE MOLDING MATERIALS

Material	Viscosity, cP	Cured hardness, shore A	Shrinkage, percent	Tear strength, lb/in.	Tensile strength, lb/in.^{2}	Elongation, percent	Curing time at 77 °F, hr
Dow Corning:							
Silastic E	120×10^3	35	(a)	90	700	400	24
Silastic J	100	60	(a)	85	800	250	24
Silastic L	120	33	(a)	45	500	370	24
3110	14	45	0.4	15	350	180	2
3112	30	60	.3	30	600	120	5
HS RTV[b]	45	20	.5	135	880	410	24
General Electric:							
RTV 700	50×10^3	30	0.2	125	600	400	24
RTV 664	110	60	0	100	800	220	18
RTV 630	180	70	.2	85	800	200	24
RTV 660A	60	33	0	110	600	360	24

[a]Nil.
[b]Added during investigation.

TABLE III. - CANDIDATE CASTING MATERIALS

Material	Mixed viscosity, cP	Cured hardness, shore D	Shrinkage, percent	Flexural strength, lb/in.^{2}	Tensile strength, lb/in.^{2}	Curing time, hr	Curing temperature, °F
Epoxy:							
Ciba-Geigy Araldite 506	600	--	0.03	18 000	10 000	72-168 2-8	(a) 212
Ciba-Geigy Araldite 502	2100	--	.01	14 000	8 300	24 2-3	(a) 212
Hexcel Epolite 3306	6000	86	.05	8 200	6 300	16	(a)
Urethane:							
Hexcel Uralite 3124	6400	75	0.05	------	4 280	16 2	(a) 175
Hexcel Uralite 3125	5800	80	.08	------	8 000	24 2	(a) 175
Hexcel Uralite 7250	2600	60	.14	------	2 600	18-36 1-2	(a) 175

[a]Room temperature.

TABLE IV. - CANDIDATE MIXTURES

(a) General Electric products

Base	Catalyst	Ratio of base to catalyst[a]	Thinner, wt %	Base	Catalyst	Ratio of base to catalyst[a]	Thinner, wt %
RTV 700	Beta 4	10 10 10 7 7[b] 7 15 15	0 10 25 10 15 25 10 25	RTV 630	Matched catalyst	10 10 7 7 15 15	10 25 10 25 10 25
	Beta 2[b]	7 5 3	10 10 15		660B[b]	30 30	10 25
RTV 660A[a]	660B[b,c] 660B[d] 660B[d]	7 10 7	0 25 10	RTV 664	664B	10 10 7 7 15 15 30 30 30	10 25 10 25 10 25 0 10 25

(b) Dow Corning products

Base	Catalyst	Ratio of base to catalyst[a]	Thinner, wt %	Base	Catalyst	Ratio of base to catalyst[a]	Thinner, wt %
3110	Catalyst 1	5 5 5 10 10 10	0 10 25 0 10 25	3112	Catalyst 1	5 5 5 10 10 10	0 10 25 0 10 25
	Catalyst 4	100 100 100 200 200 200 400 400 400 150	0 10 25 0 10 25 0 10 25 0		Catalyst 4	100 100 100 200 200 200 400 400 400	0 10 25 0 10 25 0 10 25
Silastic E	Matched catalyst	10 10 7 7 7 15 15	10 25 0 10 25 10 25	Silastic J	Matched catalyst	10 10 7 7 15 15 [b]5	10 25 10 25 10 25 25
HS RTV[b]	Matched catalyst	10 20 15 7	10 10 10 10	Silastic L	Matched catalyst	10 10 7 7 15 15	10 25 10 25 10 25

[a]All ratios measured by weight.
[b]Added during investigation.
[c]Slow cure.
[d]Fast cure.

TABLE V. - MOLD EXPERIMENT RESULTS

Base	Catalyst	Ratio of base to catalyst	DC 200 thinner, wt %	Comments
RTV 700	Beta 4	10	0	Room temperature; too thick to pour; trapped air
		↓	10	Room temperature; cure time too long
			25	Room temperature; cure time too long
		7	25	No cure at low temperature
		7	15	Too thick to pour
Silastic E	Matched	10	25	No cure at low temperature
		7	10	↓
		7	0	
RTV 700	Beta 4	7	10	
3110	Catalyst 4	170	0	Cure too fast (no pot life)
		250	10	Cure too long (23 hr)
		200	10	Cure too long (3 days)
Silastic J	Matched	5	25	No cure at low temperature
RTV 664	RTV 664B	7	10	No cure at low temperature
3110	Catalyst 4	100	0	Trapped air
		100	10	Curing time, ~50 min; good mold
		150	0	Curing time, ~1.5 hr; good mold
3112	Catalyst 4	100	10	Trapped air; pot life, ~10 min; curing time, ~45 min
RTV 660A	RTV 660B	10	25	No cure at low temperature
RTV 660A	RTV 660B	7	10	No cure at low temperature
RTV 700	Beta 2	7	10	Cure too long (~5 days)
		5	10	Cure too long (~3 days)
		3	15	Cure too long (~2 days)
HS RTV	Matched	10	10	Curing time, <24 hr; good mold
			↓	Curing time, <18 hr; good mold
				Curing time, ~17 hr; good mold; used
HS RTV[a]	Matched	20		Curing time, >24 hr
HS RTV[a]	Matched	7		Curing time, 18 hr
HS RTV[a]	Matched	15		Curing time, >26 hr

[a]Real ice (Icing Research Tunnel sample).

TABLE VI. - CAST EXPERIMENT RESULTS

Casting material	Comments
Uralite 7250[a]	Very good process; needs oven
Uralite 3124	Full of bubbles; needs oven
Uralite 3125	Sticks to mold; needs oven
Epolite 3302	Somewhat exothermic; very good discontinued material
Epolite 3306[b]	Somewhat exothermic; very good
506-956	Very exothermic; needs oven; bubbly
502-956	Very exothermic; needs oven; bubbly
Uralite 7250	Large cast; very good; needs oven
Epolite 3306	Large cast; very good

[a]Uralite is easier to handle than Epolite but it requires an oven.
[b]Epolite 3306 is more machinable than Uralite 7250.

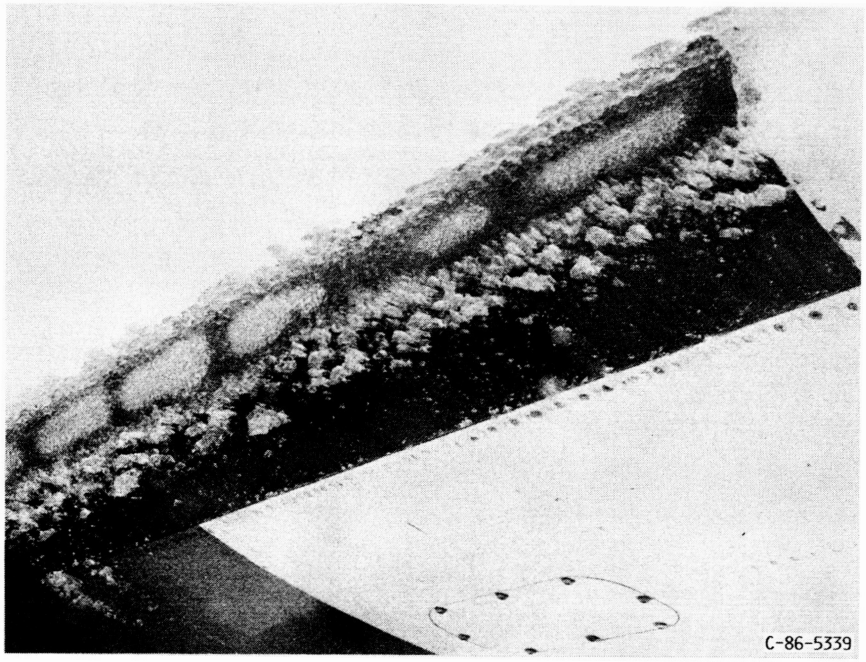

FIGURE 1. - ICE FORMATION ON AIRCRAFT WING.

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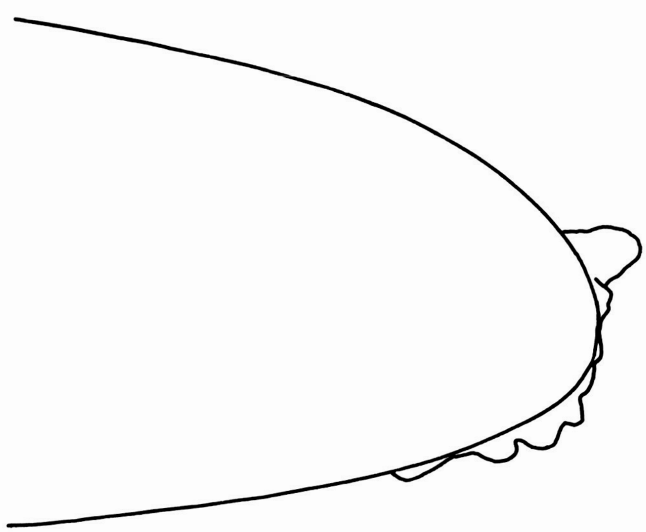

FIGURE 2. - TRACING OF ICE FORMATION ON AIRCRAFT WING.

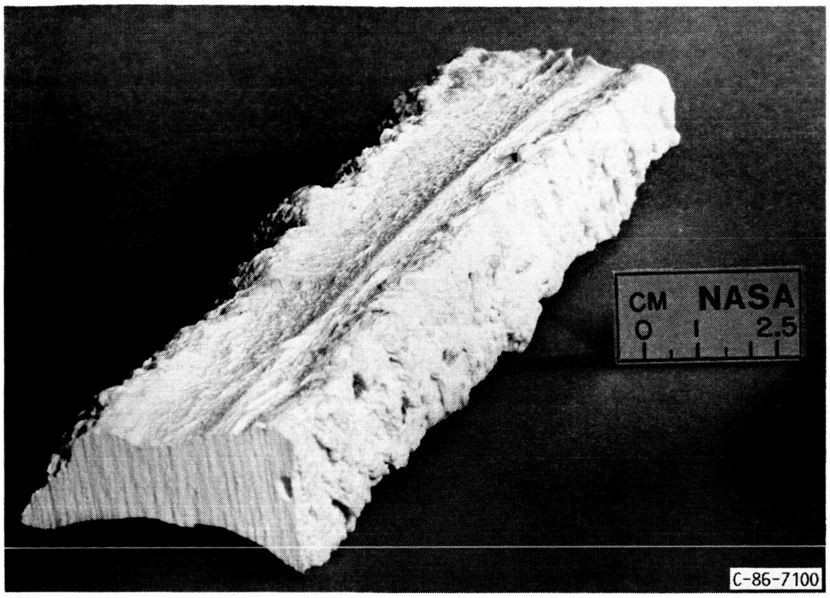

FIGURE 3. - PLASTER CAST FROM HOT WAX MOLD OF ICE FORMATION ON AIRCRAFT WING.

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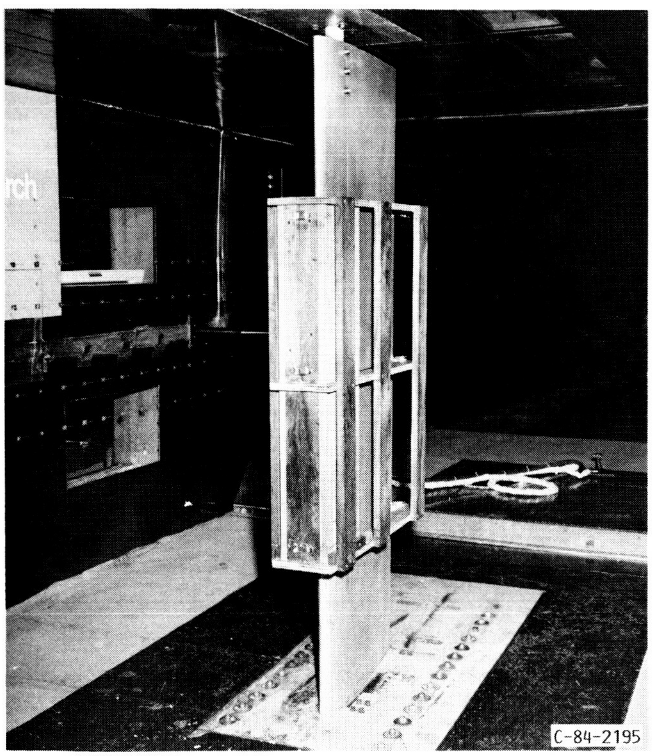

FIGURE 4. - MOLD BOX ON MODEL AIRCRAFT WING IN WIND TUNNEL.

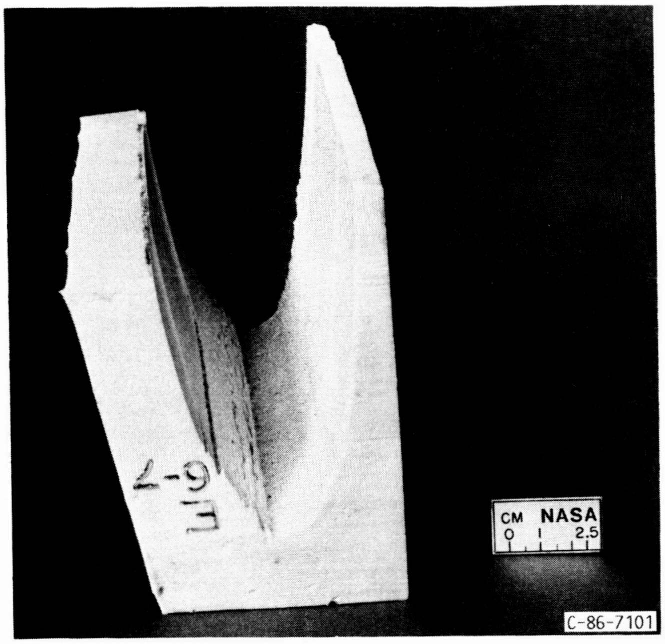

FIGURE 5. - MOLD PRODUCED WITH DOW CORNING HS RTV.

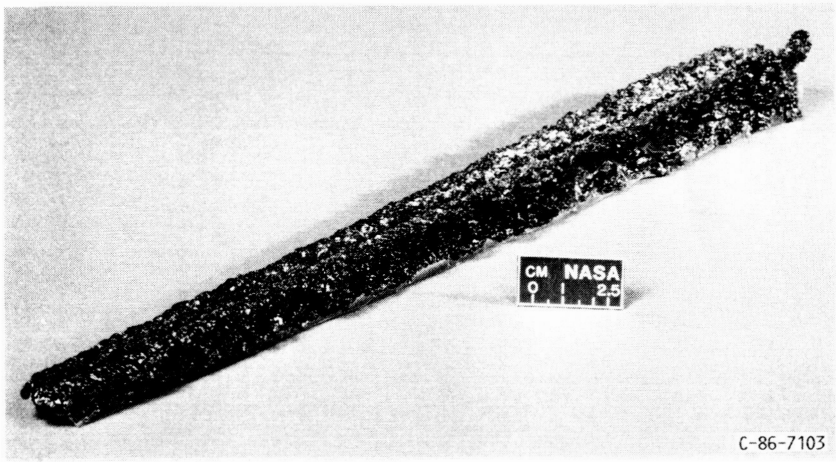

FIGURE 6. - CAST PRODUCED WITH HEXCEL URALITE 7250.

FIGURE 7. - CAST PRODUCED WITH HEXCEL EPOLITE 3306.

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15. Supplementary Notes

16. Abstract

This study was designed to find improved materials and techniques for molding and casting natural or simulated ice shapes that could replace the wax and plaster method. By utilizing modern molding and casting materials and techniques, a new methodology was developed that provides excellent reproduction, low-temperature capability, and reasonable turnaround time. The resulting casts are accurate and tough.

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