

# Comparative Study of Undercutting and Disbondment Characteristics of Chemical Deicers

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A laboratory study was conducted to determine the undercutting and disbondment characteristic of 10 chemical deicers. The materials included six discrete deicing chemicals and four blends: calcium chloride pellets, calcium chloride flakes, two sodium chloride products, potassium chloride, pelletized urea, sodium chloride with a small amount of carboxymethocellulose, a blend of sodium chloride and potassium chloride sprayed with urea, a blend of sodium chloride and urea, and calcium magnesium acetate. In the undercutting tests, deicer particles were distributed on 6- × 9- × 2-in. concrete slabs covered with a 1/8-in. layer of ice. Tests were conducted at temperatures ranging from 0°F to 25°F in 5°F increments. Results were photographed and subsequently measured with a computerized stylus. The disbondment test apparatus measured and recorded the horizontal and vertical forces required to remove ice from a concrete specimen as it was drawn beneath a stationary blade. Each deicer was applied to the 1/8-in. ice samples and allowed to undercut for 30 min before disbondment forces were recorded. The tests showed that at least a 95 percent-complete undercutting is necessary for ice removal by mechanical disbondment forces of 2.8 lb per inch of blade width.

Removing a layer of ice from a roadway or sidewalk by plowing or shoveling is not an easy task when the ice is firmly bonded to the concrete surface. Only when the ice layer has been sufficiently undercut can it be removed easily. The difficulty holds true for ice bonded to any surface. The application of chemical deicers, however, can help initiate and accelerate the undercutting process and thus facilitate ice removal.

A previous study (1) revealed significant differences in the penetration and melt volume capabilities of several deicing chemicals over a range of selected temperature and time intervals. The goal of subsequent research was to determine the undercutting and disbondment characteristics of the same deicing chemicals.

Ten chemical deicers, including six discrete chemicals and four blends, were studied. The discrete chemicals included

- Calcium chloride ( $\text{CaCl}_2$ ) pellets,
- $\text{CaCl}_2$  flakes,
- Sodium chloride ( $\text{NaCl}$ , two products tested),
- Potassium chloride ( $\text{KCl}$ ), and
- Pelletized urea.

The blended products consisted of

- $\text{NaCl}$  with traces of carboxymethocellulose,
- Mixture of  $\text{NaCl}$  with  $\text{KCl}$  and urea,
- Mixture of  $\text{NaCl}$  and urea, and
- Calcium-magnesium acetate (CMA).

## TEST PROCEDURES

Undercutting is a physically complex process dependent on a number of variables, including type of pavement surface, pavement porosities or irregularities, heat transfer rates, brine concentration, density gradients, and chemical species diffusion rates. The experimental procedures were designed to minimize as many of the variables as possible to elicit easily reproducible data.

Concrete test specimens measuring 6 in. wide, 9 in. long, and 2 in. thick were prepared according to ASTM specifications (ASTM C109-84). Figure 1 shows a typical specimen with an ice-leveling iron.

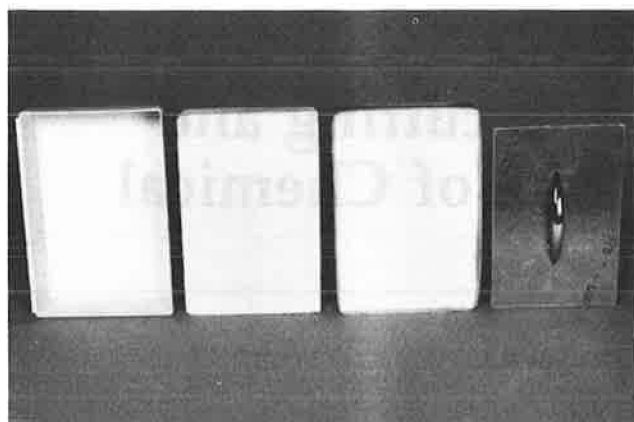
After setting for 60 to 90 min, each concrete specimen was lightly broomed along the 9-in. dimension to simulate the roughened surface of a highway or sidewalk. The surfaces were scribed with small grooves, approximately 0.2 cm apart and 0.1 cm wide at the top. All specimens were then cured for 28 days. Throughout the study, care was taken to prevent contamination of the cured specimens by dust or body oils, and specimens were handled without touching the broomed surface. To hold water on the surface, a 1/4-in.-high lip of acrylic latex caulk and duct tape was applied along the outer perimeters of the concrete specimens, forming a leakproof dam.

A series of initial tests was conducted to determine the appropriate freezing rate and mode of freezing (bottom up or top down) to yield ice-and-concrete specimens with a uniform 1/8-in. ice thickness, a smooth ice surface, reasonably stress-free ice, and uniform and reproducible bonding between the ice and concrete. The tests revealed that the desired characteristics could be achieved in all disbondment and undercutting tests by using the following procedures.

## ICE PREPARATION

A 17- × 18- × 15-in. freezing chamber was constructed to permit controlled, bottom-up freezing of the specimens. Before being placed in the freezing chamber, the concrete blocks

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**FIGURE 1** Concrete form, concrete block, duct-taped concrete block, and ice-leveling iron.

(with duct tape sidewalls in place) were flushed with deionized water, presoaked with approximately 50 ml of water, and placed in a refrigerator overnight at 35°F to 38°F. An inventory of deionized water was cooled to 35° to 38°F.

After precooling, specimens were removed and any excess water was poured off. Two or three concrete blocks at a time were placed in the freezing chamber, and 115 ml of cooled, deionized water was poured onto the surface of each. The blocks were then cooled from an initial temperature above 32°F to each test temperature. To prevent freezing at the surface of the water, the blocks were cooled from below and the air temperature was kept above 32°F until the ice was frozen from the bottom up.

Because the ice resulting from this process was uneven and granular, the surface was partially melted with a metal iron, and the specimens were returned to the cold room for refreezing. The ice-and-concrete specimens were then inserted in plastic bags, placed in a temperature-regulated cold box at the specified test temperature, and allowed to equilibrate.

### UNDERCUTTING TESTS

Undercutting tests of the 10 deicers were conducted at six temperatures: 0°F, 5°F, 10°F, 15°F, 20°F, and 25°F. Dual-pellet tests were conducted for the blend of NaCl and urea. Pellets were separated and tested individually for the blend of NaCl and KCl sprayed with urea, resulting in a total of 11 undercutting tests, all replicated five times at each of the six test temperatures.

Particles from each of the 10 deicers were sieved and individually weighed before the tests. The average weights of the -6 mesh, +8 mesh fractions selected for use in the tests were as follows: the CaCl<sub>2</sub> flakes, urea, and CMA weighed 15 mg; the CaCl<sub>2</sub> pellets weighed 21 mg; the NaCl, KCl, NaCl-KCl blend, and NaCl with carboxymethocellulose weighed 31 mg; and the urea pellets from the NaCl-urea blend weighed 2.5 to 3.0 mg.

A 20-pellet grid pattern was laid out on each of three ice blocks and was marked with a small amount of dye. Weights of the individual deicer particles were recorded on data sheets numbered to correspond to the marked positions on the blocks

of ice. After allowing the deicer samples to equilibrate to the test temperature, the first set of 10 was placed on the ice and a timer was activated. The second set of 10 deicer particles was placed on the ice 5 min after the first. Figure 2 shows a typical pellet placement.

As melting commenced, a surface film spread over the surface of the ice. The initial dye pattern on the surface slowly faded in intensity at its extremities, leaving an intensely colored circular core denoting the path of penetration. After the deicer penetrated the ice, further melting yielded a roughly circular film of brine between the ice and the substrate.

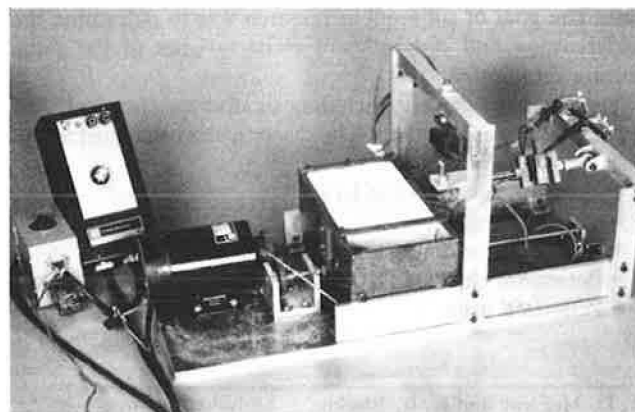
The undercutting process for each set was recorded on slide film with a 35-mm camera 5, 10, 15, 20, 25, 30, 45, and 60 min after placement. After projecting the slides on a glass plate, the lens was adjusted to yield a 1:1 image. The researchers traced the undercut areas on onionskin paper, enlarged them to twice their original size on a copier, and took measurements with a computerized stylus.

### DISBONDMENT TESTS

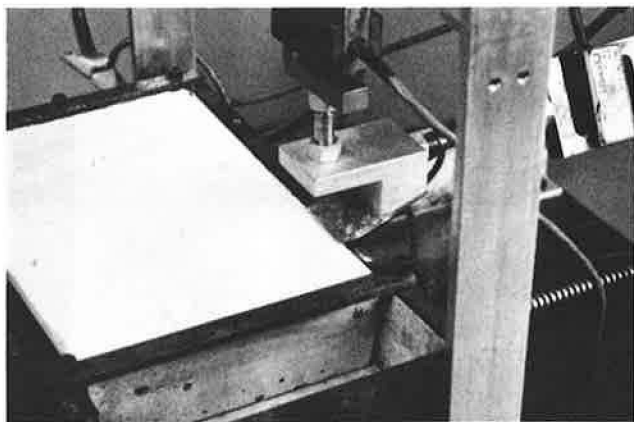
The principal objective of the disbondment tests was to obtain reproducible data that would permit reliable comparisons between deicers and an evaluation of the effects of time or other variables on disbondment. An ice disbondment apparatus was constructed to measure the horizontal and vertical forces generated as an ice-covered concrete specimen was pulled beneath a stationary blade mounted close to the ice-concrete interface (Figures 3 and 4). The forces measured

1	2	3	4
5	6	7	8
9	10	1	2
3	4	5	6
7	8	9	10

**FIGURE 2** Typical pellet placement.



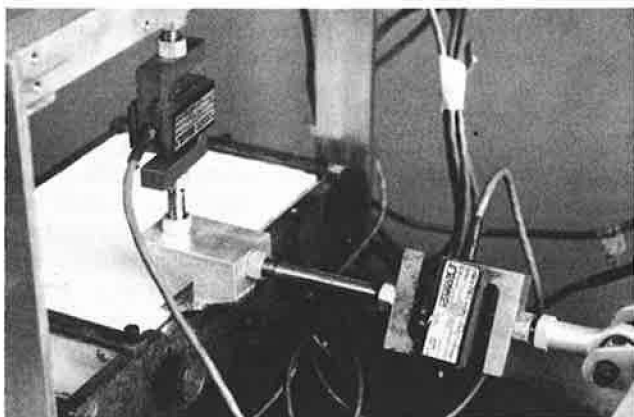
**FIGURE 3** Ice disbondment apparatus.



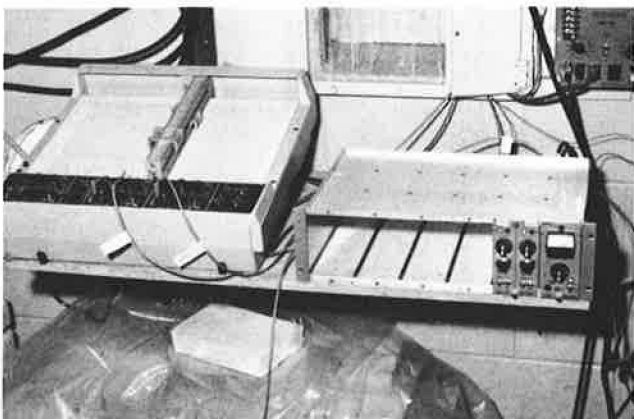
**FIGURE 4** Positioning of disbondment blade relative to concrete surface.

with the apparatus were the same as those that would be recorded if the ice-covered specimen were stationary and the blade was moved through the ice coating.

The disbondment apparatus was equipped with a 1.5-in.-wide blade mounted on two 200-lb-load cells (one horizontal and one vertical), which were connected to a two-pen recorder (Figures 5 and 6). The dimensions of the ice-and-concrete specimen and the blade permitted two tests per specimen.



**FIGURE 5** Load cell arrangement.



**FIGURE 6** Disbondment force recorder.

A disbondment test procedure was developed from a study of deicer placement. These results are discussed in the following section.

### DEICER PELLET PLACEMENT

In order to ensure reproducible results, the deicer pellets had to be of equal weights and spaced uniformly on the ice-and-concrete specimens. Accordingly, pellet dispensers were constructed to apply 3 oz/yd<sup>2</sup> of 15-, 21-, and 31-mg pellets. Hole dimensions were adjusted to permit pellets of varying dimensions to be dispensed.

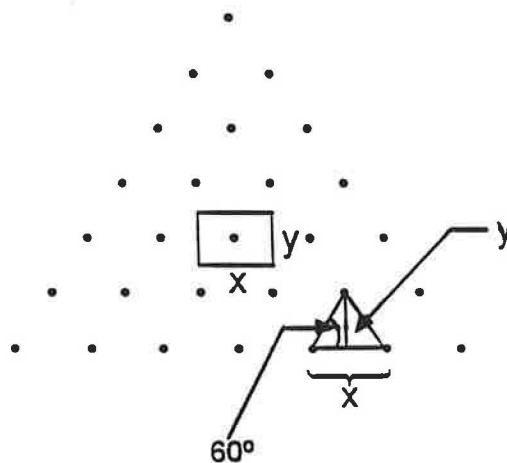
Initial disbondment tests indicated that the application rate of 3 oz/yd<sup>2</sup> was not high enough for all deicers to complete undercutting at 25°F and substantially insufficient at lower temperatures. Therefore, the tests were reevaluated with the following guidelines: (a) pellet placement arrays should provide maximum opportunity to completely undercut the ice, and (b) pellet-loading rates should be adjusted upward and varied with temperature to permit the essentially complete undercutting required for ice removal with reasonable forces.

Because undercutting data for CMA indicated little undercutting after 60 min at 25°F and no undercutting at lower temperatures, CMA was excluded from disbondment testing. The second NaCl deicer and the NaCl deicer with a small amount of carboxymethocellulose added were excluded to avoid redundancy.

With pellets of equal weights and idealized perfect-circle undercutting patterns, the optimum pellet array involved the placement of pellets at the corners of equilateral triangles, in a pool ball rack arrangement (Figures 7 and 8). On the basis of data derived from the undercutting research, the loading rate required to completely fill void spaces was calculated to be 1.21 times an idealized loading rate.

With the preceding considerations in mind, the disbondment testing protocol was revised as follows:

- Thirty minutes was selected as the disbondment time.
- Areas undercut per unit weight of deicer at each temperature for 30 min were multiplied by 1.21 to determine loading rates and to calculate pellet spacings.



**FIGURE 7** Schematic representation of pellet array for ice disbondment tests.

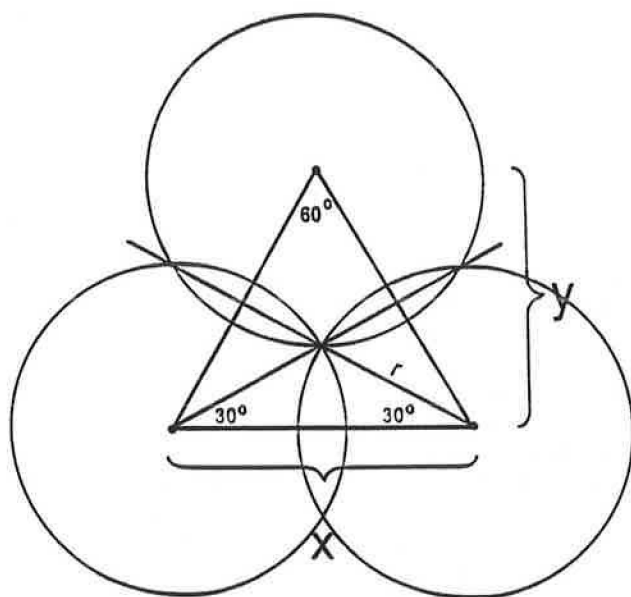


FIGURE 8 Idealized representation of undercutting with pellet arrays in ice disbondment test, with overlapping circular undercutting patterns.

• Pellet dispensers were constructed to permit application of deicers at the specified rates. The pellet arrangement was a pool ball rack configuration (see Figures 7 and 9).

## DISCUSSION AND RESULTS

The deicer parameters (loading rates in ounces per square yard, pellet weights, and number of pellets) used in the disbonding tests are presented in Table 1. To permit visual observation of the undercutting, approximately 2 to 3 mg of Rhodamine B dye was added to each deicer sample and distributed by shaking. The  $\text{CaCl}_2$  deicers (flake and pellet forms) were taken into the cold room, cooled, and loaded into dispensers

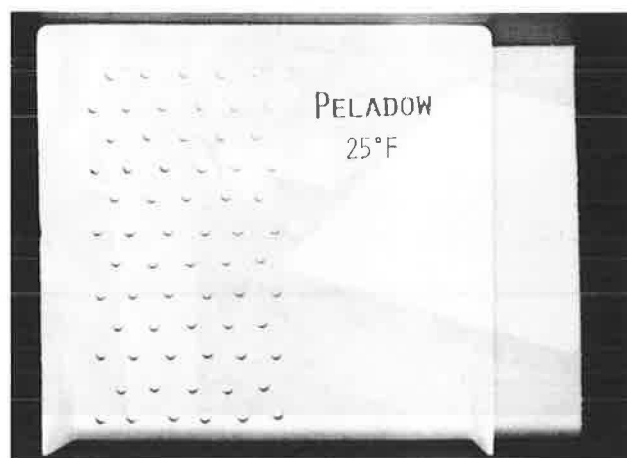


FIGURE 9 Pellet dispenser for disbondment tests.

immediately before the disbondment tests. The remaining deicers were loaded into dispensers in the laboratory and transferred to the cold room 15 to 20 min before the tests.

Pellet dispensers were positioned over the ice specimens and held in place with one hand. The dispenser tray was moved so that pellets dropped through the holes onto the ice surface. The timer was started immediately after the drop. Pellets that did not drop through their respective holes were forced through with forceps, and the dispensing tray was removed. Pellets that rolled or were dropped significantly out of position were repositioned. (Although considerable effort was expended in attempts to uniformly distribute the  $\text{CaCl}_2$  flakes, distribution was judged to be less than satisfactory.)

Just before activating the disbondment blade, a visual estimate of the completeness of undercutting was made. When 30 min had elapsed, the recorder traverse mechanism was activated, and the forward switch for the blade drive of the disbondment apparatus was immediately activated. Typically, the blade was stopped when it reached the far edge of relatively nonundercut ice. The completeness of ice removal was

TABLE 1 DEICER PARAMETERS FOR DISBONDMENT TESTS

Deicer	Active Ingredient (% by wt)	Temperature (°F)	Time (min)	Application Rate (oz/yd <sup>2</sup> )	Average Pellet Weight (mg)	No. of Pellets per Test
1. $\text{CaCl}_2$ pellets	91.0 $\text{CaCl}_2$	25	30	4.36	21	66
		20	30	5.42	21	91
		15	30	6.93	21	113
		10	30	9.38	21	145
2. NaCl	99 NaCl	25	30	4.02	31	55
		20	30	6.20	31	72
		15	30	10.36	31	113
3. NaCl-urea blend <sup>a</sup>	92 NaCl, 8 urea	25	30	4.49	35	55
		20	30	7.24	36	72
		15	30	11.89	36	113
4. $\text{CaCl}_2$ flakes	77.5 $\text{CaCl}_2$	25	30	5.87	15	—
5. Urea	100 urea	25	30 and 60	9.00	15	190
6. KCl	99-100 KCl	25	30	6.42	31	72
7. NaCl-KCl-urea blend	44-45 NaCl, 54-55 KCl, 1 urea	25	30 and 60	5.36	26.8 <sup>b</sup>	72

<sup>a</sup>Testing involved using equal numbers of rock salt and urea pellets and placing a rock-salt crystal next to a urea pellet.

<sup>b</sup>Testing involved using equal numbers of rock salt and potassium chloride—sprayed with urea—alternately placed on ice surface.

estimated visually, and the dislodged ice was then removed from the specimen.

### Undercutting

Table 2 presents the average undercut areas (in square centimeters per gram) for the various deicers at each of the six test temperatures. The results express the average of five replicates.

Table 3 presents the application rates (in ounces per square yard) for complete undercutting of 1/8-in.-thick ice after 30 and 60 min at temperatures from 0°F to 25°F. The application rates presented in Table 3 are idealized, in that circular undercutting patterns and areas are mathematically converted to touching, but not overlapping, perfect squares. Several deicers were not tested at the lower temperature limits, because these limits are below the eutectic temperature of the chemical.

### Undercutting Observations

1. At the highest temperature (25°F) and the longest time (60 min), the most effective deicers and a fixed application rate of 3 oz/yd<sup>2</sup> produced 85- to 90-percent-complete undercutting.
2. The undercutting process was essentially complete in 60 min, and little or no benefit was gained by extending the time period.
3. At all temperatures, the CaCl<sub>2</sub> pellets began undercutting the ice specimens more quickly than the other deicers tested.
4. The rapid undercutting action of the CaCl<sub>2</sub> pellets became more pronounced, comparatively, as the temperature was lowered.
5. At 25°F, NaCl-based deicers undercut more slowly than CaCl<sub>2</sub> pellets in short time intervals. At longer intervals (45 to 60 min), the NaCl deicers undercut more extensively by factors of 1.05 and 1.10.
6. Urea and KCl deicers exhibited no undercutting of 1/8-in. ice at temperatures lower than 20°F.
7. The undercutting behavior of CMA paralleled its ice penetration behavior (i.e., slight undercutting occurred at 25°F after 60 min, and none occurred at lower temperatures).

### Disbondment

Table 4 presents disbondment results of deicers after 30 min at 10°F, 15°F, 20°F, and 25°F. Table 5 presents the average disbondment results for each deicer over all test temperatures and times.

### Disbondment Observations

1. The CaCl<sub>2</sub> pellets exhibited the best disbondment results. Compared to the averages for NaCl (the deicer with the second-best performance), the averaged results for CaCl<sub>2</sub> pellets at each temperature and for all temperatures show that

CaCl<sub>2</sub> pellets yielded greater degrees of undercutting and ice removal, and that less force was required to remove the ice.

2. The average disbondment force (over all temperatures) for CaCl<sub>2</sub> pellets was 9 lb/in. The other average disbondment forces were as follows: NaCl, 16 lb/in.; NaCl-KCl-urea blend, 22 lb/in.; NaCl-urea blend, 27 lb/in.; KCl, 31 lb/in.; urea, 32 lb/in.; and CaCl<sub>2</sub> flakes, 56 lb/in.

3. At least 95-percent-complete undercutting is indicated as being necessary for ice removal by mechanical disbondment forces of 2.8 lb per inch of blade width.

4. The high disbondment forces required for CaCl<sub>2</sub> flakes, urea, KCl, and the blended products are attributed to extensive surface melting. The extent of surface melting appeared to be considerably greater with the closely spaced pellets in the disbondment tests than with isolated pellets in undercutting tests. Urea and CaCl<sub>2</sub> flakes exhibited the greatest surface melting, causing the disbondment blade to slide over large portions of the ice surface.

5. The data indicate that an increase of approximately 10 percent in nonundercut areas is accompanied by a 10-lb/in. increase in the average resultant force requirement for disbondment.

### CONCLUSION

Although actual field conditions vary considerably from those of the controlled laboratory environment under which these tests were conducted (e.g., laboratory-developed ice-pavement bond strength may have been greater than that occurring on highways), some general conclusions regarding the undercutting and ice disbondment characteristics of the tested deicers can be drawn. The distinctly different undercutting and disbondment characteristics exhibited by different chemical deicers over a range of times and temperatures have important implications for personnel responsible for clearing ice and snow from roads and highways, sidewalks, and steps.

Clearly, the faster and more complete the degree of undercutting a deicer provides, the more efficiently road crews will be able to moderate hazardous conditions. For situations where rapid ice removal is critical to safety, CaCl<sub>2</sub> pellets appear to be the deicer of choice, regardless of temperature. At temperatures 25°F and higher, where time intervals of 45 to 60 min are available, NaCl can be expected to provide sufficient undercutting to facilitate ice removal. At the other extreme, on the basis of its poor performance in the undercutting tests at all times and temperatures, CMA can reasonably be characterized as an inefficient disbondment facilitator.

### PRODUCT INFORMATION

Information on materials 3 through 8 obtained in 1986 in a study reported elsewhere (1).

1. PELADOW (registered trademark, Dow Chemical Company)  
 Manufacturer: Dow Chemical U.S.A.  
 Principal ingredient: Calcium chloride  
 Lot number: ML861006  
 Assay: 91.0 percent CaCl<sub>2</sub> by ASTM Method E-449; 2.16 percent KCl; 1.7 percent NaCl; 0.03 percent MgCl<sub>2</sub>



TABLE 2 UNDERCUT AREA COMPARISONS

	Undercut Area (cm <sup>2</sup> /g)												
Time (min)	CaCl <sub>2</sub> Flakes	CaCl <sub>2</sub> Pellets	NaCl	NaCl with Carboxymetho-cellulose	NaCl + Urea	NaCl	NaCl-KCl-Urea Blend				Urea	CMA	
							NaCl	KCl	NaCl + KCl <sup>a</sup>	KCl			
25°F													
60	63	86	93	91	88	89	94	66	79		68	51	21
45	62	82	95	92	85	86	94	61	76		65	46	0
30	61	82	89	87	79	79	85	48	65		56	40	0
25	61	82	83	78	74	72	79	41	58		48	35	0
20	59	79	74	67	63	60	67	33	48		38	0	0
15	59	72	53	52	52	47	52	23	36		27	0	0
10	52	57	34	31	29	27	33	8	19		12	0	0
5	32	33	15	12	13	9	14	0	6		0	0	0
20°F													
60	49	70	68	61	61	63	71	32	49		31	33	0
45	46	67	66	56	60	61	67	27	45		25	27	0
30	46	66	58	45	49	50	58	18	36		18	21	0
25	47	63	50	37	41	44	53	16	33		14	0	0
20	43	59	41	30	35	36	42	14	27		13	0	0
15	43	53	30	22	27	28	31	3	16		0	0	0
10	38	40	20	17	21	24	18	0	8		0	0	0
5	8	17	0	0	12	0	7	0	3		0	0	0
15°F													
60	44	55	52	51	51	50	53	0	24		0	0	0
45	41	55	46	45	43	45	48	0	21		0	0	0
30	40	51	34	33	30	30	33	0	15		0	0	0
25	40	51	28	26	23	26	27	0	12		0	0	0
20	40	46	21	21	19	19	20	0	9		0	0	0
15	38	38	16	16	12	13	13	0	6		0	0	0
10	31	25	—	—	0	0	0	0	0		0	0	0
5	0	0	0	0	0	0	0	0	0		0	0	0
10°F													
60	31	40	29	24	26	26	28	0	13		0	0	0
45	27	38	23	19	22	20	21	0	10		0	0	0
30	24	38	16	14	15	14	18	0	8		0	0	0
25	21	36	15	10	12	12	17	0	8		0	0	0
20	24	34	15	11	10	12	15	0	7		0	0	0
15	10	29	14	4	13	9	12	0	5		0	0	0
10	0	20	5	0	0	0	0	0	0		0	0	0
5	0	0	0	0	0	0	0	0	0		0	0	0
5°F													
60	25	31	12	12	14	11	15	0	7		0	0	0
45	25	29	10	10	11	10	11	0	5		0	0	0
30	21	26	8	8	10	8	10	0	5		0	0	0
25	18	23	7	7	7	8	9	0	4		0	0	0
20	17	20	5	4	—	6	9	0	4		0	0	0
15	13	18	0	—	0	0	0	0	0		0	0	0
10	0	18	0	0	0	0	0	0	0		0	0	0
5	0	0	0	0	0	0	0	0	0		0	0	0
0°F													
60	21	25	11	8	10	9	11	0	5		0	0	0
45	22	25	10	6	9	9	9	0	4		0	0	0
30	22	21	8	5	8	6	8	0	4		0	0	0
25	14	17	—	0	—	0	—	0	0		0	0	0
20	23	16	0	0	0	0	0	0	0		0	0	0
15	—	14	0	0	0	0	0	0	0		0	0	0
10	—	—	0	0	0	0	0	0	0		0	0	0
5	0	0	0	0	0	0	0	0	0		0	0	0

NOTE: Data based on average of five replicates.

<sup>a</sup>Deicer, calculated undercutting, based on 45 percent NaCl and 55 percent KCl sprayed with urea.

TABLE 3 DEICER APPLICATION RATES FOR COMPLETE UNDERCUTTING, 1/8-IN.-THICK ICE

Deicer	Application Rate (oz/yd <sup>2</sup> ) by Temperature and Time											
	25°F		20°F		15°F		10°F		5°F		0°F	
	30 min	60 min	30 min	60 min	30 min	60 min	30 min	60 min	30 min	60 min	30 min	60 min
CaCl <sub>2</sub> pellets	3.6	3.4	4.4	4.2	5.7	5.3	7.8	7.4	11.0	10.0	14.0	12.0
NaCl	3.3	3.2	5.1	4.3	8.6	5.7	18.0	10.0	36.0	25.0	39.0	27.0
CaCl <sub>2</sub> flakes	4.9	4.7	6.4	6.0	7.3	6.7	13.0	9.5	14.0	12.0	13.0	13.0
NaCl with carboxymethocellulose	3.4	3.3	6.5	4.8	8.9	5.8	22.0	12.0	37.0	24.0	57.0	36.0
NaCl + urea	3.7	3.3	6.0	4.8	10.0	5.8	20.0	11.0	29.0	21.0	38.0	31.0
NaCl	3.7	3.3	5.9	4.7	10.0	5.9	22.0	11.0	39.0	27.0	54.0	32.0
NaCl	3.7	3.3	5.9	4.7	10.0	5.9	22.0	11.0	39.0	27.0	54.0	32.0
NaCl-KCl-urea	4.4	3.7	7.7	5.7	18.0	11.0	34.0	21.0	60.0	39.0	74.0	53.0
KCl	5.3	4.3	16.0	9.5	—	—	— <sup>a</sup>	— <sup>a</sup>	— <sup>a</sup>	— <sup>a</sup>	— <sup>a</sup>	— <sup>a</sup>
Urea	7.4	5.8	14.0	8.9	—	—	— <sup>a</sup>	— <sup>a</sup>	— <sup>a</sup>	— <sup>a</sup>	— <sup>a</sup>	— <sup>a</sup>
CMA	—	14.0	—	—	—	—	—	—	—	—	— <sup>a</sup>	— <sup>a</sup>

NOTE: Deicer application rates in this table are those (see Figure 8) for idealized perfect square undercutting.

<sup>a</sup>At 10°, 5°, and 0°F, urea and NaCl-KCl are below eutectic temperatures. At 0°F, CMA is approximately at the CMA eutectic temperature.

TABLE 4 DISBONDMENT TEST RESULTS

Deicer	Time (min)	Concentration (oz/yd <sup>2</sup> )	Average Force (lb/1.5 in.)		Resultant Force			Visual Estimates	
			Horizontal	Vertical	Pounds per 1.5 in.	Pounds per Inch	Angle (degrees)	Percent Undercut	Percent Removed
25°F									
CaCl <sub>2</sub> pellets	30	4.36	2.1	4.8	5.3	3.5	66	95	95
CaCl <sub>2</sub> pellets	30	4.36	4.0	3.4	5.3	3.5	41	95	95
NaCl	30	4.02	10.2	16.7	19.6	13.0	59	80	85
NaCl	30	4.02	5.9	12.7	14.0	9.3	65	90	90
NaCl	30	4.02	7.2	13.4	15.2	10.1	62	90	90
NaCl + urea	30	4.49	8.3	21.1	22.7	15.1	68	80	70
NaCl + urea	30	4.49	19.8	28.0	34.0	22.7	55	70	75
KCl	30	6.42	22.4	42.4	48.0	32.0	62	75	60
KCl	30	6.42	20.0	41.0	46.0	31.0	64	80	85
NaCl-KCl-urea	30	5.36	15.0	30.0	33.0	22.0	64	75	80
NaCl-KCl-urea	60	5.36	6.8	8.5	11.0	7.3	52	90	95
CaCl <sub>2</sub> flakes	30	5.87	18.0	73.0	75.0	50.0	76	50 <sup>a</sup>	50 <sup>a</sup>
CaCl <sub>2</sub> flakes	30	5.87	28.0	89.0	93.0	62.0	72	50 <sup>a</sup>	50 <sup>a</sup>
Urea	60	9.0	25.5	55.0	61.0	41.0	65	50 <sup>a</sup>	50 <sup>a</sup>
Urea	30	9.0	24.0	42.0	48.0	32.0	60	50 <sup>a</sup>	50 <sup>a</sup>
20°F									
CaCl <sub>2</sub> pellets	30	5.42	12.4	8.3	14.9	9.9	34	90	90
CaCl <sub>2</sub> pellets	30	5.42	11.5	13.7	17.9	11.9	50	90	90
NaCl	30	6.20	11.0	17.1	20.3	13.5	57	85	90
NaCl	30	6.20	9.9	14.4	17.5	11.7	55	85	90
NaCl + urea	30	7.50	21.6	29.6	36.7	24.5	54	80	80
NaCl + urea	30	7.50	11.0	22.0	24.5	16.3	63	85	85
15°F									
CaCl <sub>2</sub> pellets	30	6.94	10.4	19.6	22.0	14.7	62	80	80
CaCl <sub>2</sub> pellets	30	6.94	18.8	22.7	29.5	19.7	50	85	85
CaCl <sub>2</sub> pellets	30	6.94	12.0	16.0	20.0	13.3	53	85	85
NaCl	30	10.36	18.2	21.5	28.2	18.8	50	60	60
NaCl	30	10.36	22.4	33.0	40.0	26.7	56	60	60
NaCl	30	10.36	21.0	40.0	45.0	30.0	62	80	85
NaCl	30	10.36	19.0	35.6	40.0	26.7	62	85	85
NaCl + urea	30	10.8	28.8	66.4	72.4	48.3	66	60	60
NaCl + urea	30	10.8	21.2	46.8	51.3	34.2	66	65	60
10°F									
CaCl <sub>2</sub> pellets	30	9.38	9.0	4.5	10.0	6.7	27	90	95
CaCl <sub>2</sub> pellets	30	9.38	6.5	4.0	7.6	5.1	32	95	95

<sup>a</sup>Approximate.

TABLE 5 DISBONDMENT RESULTS: AVERAGE OF ALL TESTS AT ALL TEMPERATURES WITH EACH DEICER

Deicer	Resultant Force (lb/in. blade)	Percent Undercut	Percent Removed
CaCl <sub>2</sub> pellets	9.0	90	91
NaCl	16.0	81	84
NaCl + urea	27.0	74	72
Urea	32.0	50	50
CaCl <sub>2</sub> flakes	56.0	50	50
KCl	31.0	78	72
NaCl-KCl-urea	22.0	75	80

## 2. DOWFLAKE (registered trademark, Dow Chemical Company)

Manufacturer: Dow Chemical U.S.A.  
 Principal ingredient: Calcium chloride  
 Lot number: ML870925  
 Assay: 77.50 percent CaCl<sub>2</sub>; 2.62 percent KCl; 1.49 percent NaCl; 0.04 percent MgCl<sub>2</sub>

## 3. HALITE (I)

Manufacturer: Diamond Crystal Salt Company  
 Principal ingredient: Sodium chloride  
 Assay: 99 percent NaCl by chloride analysis

## 4. ICE FIGHTER PLUS (I)

Manufacturer: Morgro Chemical Company  
 Principal ingredient: Sodium chloride with Propolyice (registered trademark of Morgro Chemical Company)  
 Assay: 99 to 100 percent NaCl by chloride analysis

## 5. SAFE-STEP ICE MELTER (I)

Source: Koos, Inc.  
 Principal ingredient: Sodium chloride and potassium chloride  
 Assay: 44 to 45 percent NaCl, 54 to 55 percent KCl by chloride analysis; 51.5 percent KCl, 48.5 percent NaCl; 1.0 percent urea by physical segregation of particles

## 6. SUPERIOR SNO-N-ICE MELTER (I)

Manufacturer: CP Industries (Chemopharm)  
 Principal ingredient: Sodium chloride and urea  
 Assay: 92.0 percent NaCl by chloride analysis; 8.0 percent urea by urea nitrogen analysis

## 7. UREA (I)

Distributor: Lange Stegmann  
 Assay: Fertilizer grade, spherical particles  
 100 percent urea by nitrogen analysis  
 Principal impurity product specifications: 1.8 percent biuret

## 8. ZERO ICE MELTING CRYSTALS (I)

Source: Howard Johnson Enterprises, Inc.  
 Principal ingredient: Potassium chloride  
 Assay: 99 to 100 percent KCl by chloride analysis

## 9. CMA (CALCIUM MAGNESIUM ACETATE)

Manufacturer: Chevron Chemical Company  
 Principal ingredient: Calcium acetate and magnesium acetate  
 Assay: 49.25 percent calcium acetate; 46.42 percent magnesium acetate; 2.45 percent moisture; 1.88 percent water insolubles pH 8.97 at 20 percent weight solution.

## 10. PREMIERE ICE MELTER

Manufacturer: CP Industries (Chemopharm)  
 Principal ingredient: Sodium chloride  
 Assay: 99 percent NaCl

## REFERENCE

1. A. D. McElroy, R. R. Blackburn, J. Hagymassey, and H. W. Kirchner. Comparative Study of Chemical Deicers. In *Transportation Research Record 1157*, TRB, National Research Council, Washington, D.C., 1988.

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