the data presented. The contents do not necessarily reflect the official views or policies of the state of Louisiana or the Federal Highway Administration. This paper does not constitute a standard, specification, or regulation.

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# Motor-Vehicle Corrosion from Deicing Salt

**FRANK O. WOOD**

**The benefits and costs of road deicing and its resultant effects on motor vehicles are discussed. A dollar figure cannot be put on benefits such as lives saved in quicker response time to medical and fire emergencies and lives saved by reduced traffic accidents. Even without these factors, the benefit/cost ratio justifies the use of deicing salts. A carefully designed and executed test reported by the American Public Works Association appears to indicate that it is not possible to inhibit salt. Chemicals other than salt and nonchemical methods that have been considered for ice control are briefly described. Other methods, in addition to alternate deicing compounds, include Verglimit, hydrophobic substances, electrically heated pavements, earth-heated pavements and geothermal heating, urethane foam and styrofoam insulation under bridge decks, air-jet plows, high-velocity sprays of deicing chemicals, infrared heating lamps, and underbody-bladed trucks. Salt, however, continues to be the least expensive deicer. Current techniques of corrosion protection in automobile manufacture are described.**

A report by the Institute for Safety Analysis on the benefits and costs of road deicing, issued in November 1976, indicates the following annual economic benefits and costs (1):

| Category | Annual Economic Benefits ($000 000s) |
|---|---|
| Reduced wage losses | |
| Lateness to work | 7 600 |
| Work absenteeism | 3 000 |
| Reduced production losses | 7 000 |
| Reduced losses in goods shipment | 600 |
| Reduced fuel costs | 200 |
| Total | 18 400 |

| Category | Annual Costs of Road Salting ($000 000s): Institute for Safety Analysis Study (1) | Abt Associates Study (2) |
|---|---|---|
| Utilities | 2 | 10 |
| Vehicle corrosion | 643 | 2000 |
| Highway bridge decks | 160 | 500 |
| Trees and vegetation | 0 | 50 |
| Water supplies | 10 | 150 |
| Salt and application | 200 | 200 |
| Total | 1015 | 2910 |

Among the benefits of road salting that cannot be given a dollar figure is reduced fuel consumption. The Institute for Safety Analysis report (1) cites a saving of 0.37-1.2 billion gal/year. It has been calculated, based on a study by Claffey (3), that automobiles in the Milwaukee area would consume an additional 6 million gal of gasoline per year if the streets were not maintained during the wintertime. This calculation was made in response to a proposal by Milwaukee officials that the amount of salting be reduced by 50 percent to save 200 000 gal of gasoline used to operate salt-spreader trucks.

Other benefits of deicing include the lives saved by quicker response time to medical emergencies--e.g., heart attacks, burns, poisonings, home accidents, and work accidents--and fire alarms.

Lives saved because of a reduction in traffic accidents are also not given a dollar figure. Although no precise cost can be placed on this, the Institute for Safety Analysis report (1) quotes research that shows that about 26 percent of all noninstantaneous traffic fatalities have a potential for survival. If medical care for critically injured accident victims is delayed 1 h, the percentage of those likely to survive drops to about 6.25 percent and to less than 2.5 percent in 3 h.

The estimated annual cost of vehicle corrosion in the United States is $643 million. The study by Abt Associates (2) estimates this cost to be $2 billion/year.

The traditional cost of $100/vehicle/year has been largely discounted. In fact, a task group report of the National Association of Corrosion Engineers (4) states the following:

> It has been widely quoted that corrosion damage devalues the average automobile by about $100.00 annually. The widespread use of this number is regrettable because it is not derived on the basis of an economic study. The $100.00 annual loss was simply estimated and should not have been construed in any way as being quantitative or even semi-quantitative.

The Institute for Safety Analysis study estimates that the damage to bridge decks was $160 million based on actual repair costs, whereas the Abt Associates study estimates $500 million based on repair costs and estimated time loss during bridge repair in the summertime. However, the Abt Associates study estimates that there would be no economic losses as a result of leaving snow and ice on the highways in the wintertime. The Institute

**Table 1. Chemicals that have been used in ice control.**

| Chemical | Eutectic Temperature[a] (°F) | Concentration at Eutectic Temperature[a] (%) | Cost per Ton[b] ($) |
|---|---|---|---|
| Sodium chloride | −5.8 | 23.8 | 1 |
| Potassium chloride | +13 | 19.5 | 4 |
| Ammonium sulfate | −2.2 | 38.3 | 6.5 |
| Calcium chloride | −67 | 29.8 | 6.7 |
| Fertilizers | | | |
| Magnesium chloride | −28 | 21.6 | 14 |
| Methanol | −144 | 100 | 14 |
| Aluminum chloride | −65 | 25.3 | 18 |
| Urea | +11 | 32.6 | 26.7 |
| Urea/Ca formate (2:1) | −3 | 42.5 | |
| Urea/Ca formate/formamide (1:1:1) | <−8 | 42 | |
| Ethylene glycol | −59.8 | 60 | 53 |
| Propylene glycol | | | |
| Tetrapotassium pyrophosphate | −38 | 60 | 79 |
| Lithium chloride | −112 | 25.3 | 294 |
| Calcium and magnesium acetates | | | |

[a]From Lange (6, p. 1191).
[b]From Chemical Marketing Reporter, April 16, 1979.

for Safety Analysis study estimates that there would be no cost for trees and vegetation and a $10 million cost for water supplies, whereas the Abt Associates study estimates a cost of $50 million and $150 million, respectively, for these items. These are small costs and will not be debated in this paper.

The main point is that the benefit/cost ratio of road salting is 6.3:1 if one uses the Abt Associates figures and 18.1:1 if one uses the Institute for Safety Analysis estimates. It would certainly appear, even with incomplete figures, that the benefits justify the cost.

## TEST OF A SALT INHIBITOR

The only way in which the salt industry can assist in alleviating corrosion would appear to be through the development of an inhibitor or inhibitors that would be sprayed on the salt prior to shipping to inhibit the action of salt on metal. During the three winters from 1967 to 1970, the American Public Works Association sponsored a field test in Minneapolis to determine how much corrosion is caused by salt and how effective inhibitors are. This three-year test was completed and reported in September 1970 (5).

The testing procedure consisted of driving nine Ford Falcons on three routes in the Minneapolis area that are approximately the same length and have approximately the same vehicle traffic. Three of the Falcons were driven over a route maintained with abrasives, three were driven over a road maintained with salt, and three were driven over a road maintained with Carguard, an inhibited salt that has given excellent results in alternate immersion tests, in vehicle simulators where a tire was rotated in a 3 percent salt solution treated with the proportionate amount of Carguard, and in field tests in which automobiles were driven through the inhibited salt solution in the morning and afternoon to simulate travel to and from work. The test was evaluated by placing coupons under the front bumper and in the grill area of the cars and corrosometer probes under the fenders, by inspection by trained Ford field observers, and finally by "can opening",--that is, cutting the cars completely apart to show corrosion on the interior of door panels, etc.

The conclusion was that the abrasives caused the least amount of corrosion and that there was no difference between straight salt and inhibited salt. The explanation for the excellent results with Carguard in the earlier tests and the lack of inhibition in this final road test appeared to be that the inhibitor was applied at regular intervals in all preceding tests whereas, under actual test conditions, the salt was applied to the road only when it was needed for deicing. The winters during the test were fairly mild, and there were long periods of time when the inhibited deicing salt was not used. There appear to be very few situations in which the need for inhibited salt would be as great as the need for deicing. This would appear to be true of almost any inhibitor, and the salt industry is very discouraged at the prospect of approaching the inhibition of corrosion from deicing salts in this manner.

## SUBSTITUTE FOR SALT

Many people inquire as to whether chemicals other than salt or nonchemical methods have been considered for ice control. The answer is yes. A large number of reports have been issued and continue to be issued on this subject. Not only have a number of alternate deicing compounds been considered but so have other methods for ice control, such as Verglimit, hydrophobic substances, electrically heated pavements, earth-heated pavements and geothermal heating, urethane foam and styrofoam insulation under bridge decks, air-jet plows, high-velocity sprays of deicing chemicals, infrared heating lamps, and underbody-bladed trucks. These will be discussed later in this paper.

## ALTERNATE DEICING COMPOUNDS

Any chemical that dissolves in water will lower the freezing point. As more and more chemical is added to water, the freezing point will decrease to a certain level and then begin to increase. The lowest temperature at which the chemical will melt ice is known as the eutectic. A list of the chemicals that melt ice would be almost endless and completely meaningless.

Therefore, some criteria must be chosen for preparing a list of possible deicing chemicals. Table 1 gives a list of deicing chemicals that have been tried and provides for each three critical values: the eutectic temperature, the concentration (required to melt ice) at the eutectic temperature, and cost per ton. The chemicals are arranged according to increasing cost.

The deicing of highways is a dynamic rather than a static situation: The ice-melting chemical should therefore not be expected to melt ice at the eutectic temperature but at a temperature approximately 15°F above the eutectic. For example, sodium chloride would not be expected to remove ice from a highway at -6°F but probably would perform satisfactorily at 10°F.

Potassium chloride will not melt ice at as low a temperature as sodium chloride and is more expensive. It is a chloride and therefore should have the same corrosion characteristics. Ammonium sulfate is less corrosive to automobiles but cannot be used because it attacks concrete. Calcium chloride will work at lower temperatures than sodium chloride, but it is not sufficiently better to justify the higher cost and it has approximately the same corrosion characteristics as sodium chloride.

Mixtures of 75 percent sodium chloride and 25 percent calcium chloride and of 80 percent sodium chloride and 20 percent calcium chloride have been used. Currently, 8-10 gal of a 32 percent solution is being added to a ton of salt either by applying it to an entire truckload or by spraying it on at the spinner. Fertilizers have been considered to minimize damage to grass and trees, but they cause population explosions of algae in rivers and lakes. Since magnesium chloride has a higher eutectic temperature than calcium chloride and approximately the same corrosion characteristics, if the economics do not justify calcium chloride, they certainly do not justify magnesium chloride.

Methanol and calcium and magnesium acetates have been suggested in a recent report (7). The Federal Transport Ministry of Germany has tried alcohol and has found that it poses a serious fire hazard and has a limited action time because of evaporation (8).

Aluminum chloride not only is corrosive but also undergoes a violent reaction with ice. Urea is not as corrosive as sodium chloride, but 1.5 times as much urea would be required (with a higher temperature limitation). This means that it would cost 26.7 times as much to use urea, to melt the same amount of ice, as it would cost to use sodium chloride. Urea is used on airport runways, although the roads to and from the airport are treated with salt or salt and calcium chloride. Urea has also been used selectively on bridge decks.

The urea/calcium-formate composition was suggested by the Research Institute of the Illinois Institute of Technology (9) as the result of an investigation performed under the auspices of the Highway Research Board. Although this paper was widely circulated, the cost of the mixture, which would certainly be greater than the cost of urea, has discouraged all highway departments from considering its use. As the urea/calcium-formate mixture was an attempt to propose a salt substitute, the urea/calcium-formate/formamide mixture was an attempt to propose a substitute for calcium chloride. It, too, proved to be too expensive for consideration by highway departments.

Ethylene glycol and propylene glycol have been used by various highway departments. The following comment has been made concerning their use (8): "Applications resulted in slippery conditions, a dark coloration, and a wet appearance of the surface of the bridge decks."

Tetrapotassium pyrophosphate (TKPP) is used for frost prevention on bridge decks in mildly freezing weather in California. Because of the high cost of TKPP, it is only considered for use on bridge decks in areas that are free of ice and snow and where the temperature rarely falls below 25°F. Although lithium chloride would be a very fast-reacting ice melter, it is still a chloride and probably as corrosive as any other chloride, and the price would certainly prohibit any consideration of its use on highways.

## ALTERNATE METHODS OF DEICING

### Verglimit

Verglimit is a bituminous concrete surface course in which calcium-chloride-coated fines replace the 5 or 6 percent stone fines that would ordinarily be a part of the regular bituminous concrete wearing course. As the surface wears under traffic, the calcium chloride capsules on the immediate surface dissolve and produce a calcium chloride solution between the road surface and the ice.

Conflicting results have been obtained. The fact still remains that Verglimit costs about $900/ton. At this price, it may be used on some bridge decks, hills, curves, and intersections that have a history of winter accidents, but it will certainly not be used for general highway construction. If Verglimit were to be produced in the United States, the cost might be reduced to $200/ton.

### Hydrophobic Substances

The Environmental Protection Agency (EPA), as far back as 1971, designated as one of their projects the development of a hydrophobic substance that would be an alternative to salt by preventing ice from bonding to the pavement. One substance that was developed was a modified traffic paint that contains a room-temperature-curing silicon rubber as a release agent. The other substance developed to be combined with this silicon rubber substance was a silicon resin waterproofing compound.

In 1975, inconclusive tests were conducted on the residential streets of Boulder, Colorado. During the winter of 1977, other inconclusive tests were run on a special track at Washington State. Since then, there have been only sporadic reports from Washington State with no particularly impressive results.

### Electrically Heated Pavements

Probably no alternative to deicing chemicals has been experimented with as much as electrically heated pavements, and the results have been mixed. Electric heating is expensive and is only to be considered for sensitive areas such as bridge decks.

### Earth-Heated Pavements and Geothermal Heating

An experimental pavement that uses earth heat with a heat pump and an earth storage system has been reported in a paper by Winters (10). It would appear from that paper and the paper by Zenewitz (8) that earth heating of pavements is not feasible. Geothermal heating, however, might be a real possibility. It has also been suggested that heated water be piped from nuclear reactors to heat pavements, but, after the Three Mile Island incident, it would not appear that anyone would care to experiment with nuclear reactors under varying heat loads.

### Urethane Foam and Styrofoam Insulation

Both urethane and styrofoam insulation have been tried on the underside of bridge decks in order to maintain the deck at a temperature similar to that of the approach pavement. The state of Nebraska has reported that sometimes it works and other times it does not. The state of New Hampshire has reported trying it without success, and the state of Wisconsin has also reported that this technique failed to control ice formation.

### Air-Jet Plows

The state of Connecticut reported that in the early 1970s it experimented with an air-jet snowplow that was able to deliver air at 1000 $ft^3/s$. The plow clogged up, however, and the air tended to take the exit of least resistance--toward the rear, opposite to the desired direction.

### High-Velocity Streams of Deicing Chemical

The state of Connecticut is cooperating in a Highway Planning and Research Program study of the development of a high-velocity spray of deicing brine. They have had some success with this equipment in breaking up snowpack and ice pack. This particular application might reduce the use of salt by approximately 20 percent.

## Infrared Heat Lamps

The state of Colorado has been using infrared heat lamps to heat the underside of a bridge deck to prevent icing. The system, which uses 7 W of electricity per square foot of surface, was found to be inadequate because of excessive lag time and insufficient power. The experimenters felt that a 20-W/ft$^2$ system that costs \$8.90/ft$^2$ to install would give 20 years of satisfactory operation. The effect of insulation, which was included in the study, was found to depend on wind direction. Insulation helped to prevent icing when wind direction paralleled bridge direction and increased chances of icing when wind direction was perpendicular to the bridge direction.

## Underbody-Bladed Trucks

The state of Michigan has been using underbody-bladed trucks to remove ice and snow. The blades are of tungsten carbide and work well except in severe cold. A drawback of the system is that the blade, if used on roads that have up-and-down rolls and resultant depressions, may not reach the ice at the low points. Although these plows have been used in Michigan for many years, their use in other states has never been widespread.

The paper by Zenewitz (8) demonstrates a good understanding of the status of alternate deicing compounds and methods in its summary based on telephone inquiries to state highway departments in the United States and provincial highway departments in Canada. That summary reads, in part, as follows:

> Information obtained in the manner indicated above shows that all the states, provinces, and countries which were contacted are using salt for highway deicing. Most of the on-going research on deicing in the United States is generally concerned with the more efficient storage and use of salt for deicing....The general feeling among questioned highway personnel is that available chemical alternatives are too costly and less effective when compared with sodium and calcium chlorides. This feeling is even more pronounced with respect to the cost of nonchemical alternatives.

## IMPROVEMENTS IN CORROSION PROTECTION OF AUTOMOBILES

Most of the complaints concerning salt and automobile corrosion occurred around the mid-1950s, when automobile designers were given complete free license and built-in sources of corrosion--such as eyebrows over headlights, high tail fins, and rocker panels that formed a trough completely accessible to moisture, dirt, and other corrodents--were permitted. This situation became so serious that the Society of Automotive Engineers (SAE) wrote a standard that set out principles to be included in design to prevent corrosion. Some of the features specified in SAE standard J447A, which was originally adopted in 1957 and later published in a handbook supplement in December 1964 (11), can be summarized as follows:

1. Keep the underbody surface dry. Avoid ledges, flanges, and pockets where dirt can accumulate and hold moisture.
2. Where appearance is of primary importance, use solder-filled, double off-set lap joints.
3. Make joints watertight.
4. Seal joints with a mastic-type compound and cover the entire faying surface and riveted surface.
5. Provide a protective flange for lap joints in line with wheel splash to prevent water and road contaminants from being driven into the area of faying surfaces.
6. To prevent galvanic corrosion, avoid wherever possible the use of dissimilar metals in contact with each other.
7. Use open construction wherever possible. Avoid box sections and closed areas.
8. Provide adequate drainage areas in doors and bodies that have movable windows.
9. When box sections or enclosed areas are used, provide sufficient openings for application and drainage of protective coatings.
10. Keep electrical connections free of moisture.
11. Design fuel tanks and other fuel-containing components to eliminate solder joints and the use of corrosion solder plugs.

Another milestone came in 1963-1964, when the rocker panel, which is the section below the door opening, started to be constructed of galvanized steel rather than steel. This virtually eliminated inside-outside corrosion and perforation at this point.

At that time, a few automobile plants were using whole-body dipping and electrostatic methods to attract paint to all metal surfaces. Since then, new materials such as Zincrometal have become available.

Zincrometal is a trade name for a proprietary zinc-organic coating developed by the Diamond Shamrock Corporation. It is applied to cold-rolled steel right after it comes from the rolling mill. The parts used by automobile plants are stamped out of galvanized steel, plain cold-rolled steel, and steel protected with Zincrometal. Steel coated with Zincrometal is used on the interior surfaces, some parts of the fenders, the inner part of the hood, and the deck lid. Ford Motor Company is using Zincrometal extensively, whereas General Motors uses it selectively.

Plain cold-rolled steel is used in the roofs, which are above the belt line and have very little corrosion. In the mid-1960s, the automobile industry claimed that galvanized steel could not be welded. Today, they have found ways to use Zincrometal-coated steel and galvanized steel in the same way that they used to use cold-rolled steel.

Reinforcement pieces and crossbars are often made more corrosion resistant by using prepainted steel. Frames are coated with a protective wax coating prior to assembly.

The car body is then given an electrophoretic coating by dipping it into a tank of primer paint. The coating is applied by giving the body one charge and the paint the opposite charge. The paint is attracted to the body and deposited on the sheet metal. The virtue of the system is that the paint is particularly attracted to any "holidays" that developed during the coating process so that the entire body is given a uniform coating. The only difference between the electrophoretic coating of the mid-1960s and today's type of coating is that the car body was formerly charged anodic and the paint cathodic but today the body is more often charged cathodic and the paint anodic.

Some Zincrometal parts are given a coating of zinc-rich primer after the stamping operation. The inner panel of the car door, for example, has deep draws in it along the lock facing and the hinge facing. The Zincrometal has a tendency to scrape off as the draw dye closes on the part, and zinc-rich primer is sprayed on these areas, which became unprotected as a result of damage to the coating in the forming operation.

Aluminized waxes are used to repair any damage done to the coating in subsequent operations. For example, after the door and inner door panel are formed and the coating is restored, these two parts are joined together by welding and hemming operations that may break through some of the protective coating applied in the manufacturing process. Aluminized waxes are used to coat all the seams in the bottom 6-8 in of the door. The aluminized wax runs down to fill up the joint. The inside of the door thus has three protective coatings in critical areas. Aluminized waxes are also used where the quarter panel joins the wheelhouse and along the back side of the quarter panel in the pockets on each side of the luggage compartment.

Heavy vinyl sealer is used to paint the insides of the rear wheelhouse. The lower exterior portions of the car--under the quarter panel, under the front fender, and along the rocker panel, for example, where stone damage would cause chipping and corrosion--are also sprayed with this paint. Strips of plastic are also used to line the inside of the fenders. These strips melt and flow into crevices when the car passes through the bake oven. Plastic face-shield panels are used for extensions of the hood, around the grill panel, and around the front headlight area.

Trim materials have also been improved. Research has been conducted to study the physical and chemical properties of multimetal coating systems. The concept of microporous or "cracked" chromium over nickel has led to less coating penetration by pitting. Other changes have added additional years to the durability of electroplated coatings.

The manner of fastening trim materials to the automobile has also been improved. For example, holes that were used for clip attachment of body side moldings and ornaments have been partially eliminated by using externally applied weld studs, thus minimizing the chance for moisture to enter through the hole. The contact of dissimilar metals, which causes galvanic corrosion, has been prevented by using adhesively bonded, plastic body-side moldings and aluminum-clad, stainless-steel moldings. This has prevented the unsightly corrosion of the body steel adjacent to the molding.

These improvements have resulted in Canadian automobile manufacturers announcing a 3-year warranty on cars sold in Canada. American Motors and Ford Motor Company are giving a 3-year corrosion warranty on 1980 models. The objective of General Motors is 5 years without cosmetic exterior corrosion and 10 years without perforation.

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# Durable Pavement-Marking Materials

HENRY J. GILLIS

**Work done by the Minnesota Department of Transportation during the past 10 years to develop and evaluate a durable yet economical road-striping material is described. The development of equipment capable of applying a two-component epoxy resin is discussed. Epoxy, polyester, and thermoplastic resins and their cost-effectiveness are evaluated. Field evaluation of the various materials consisted of visual observations, photographs, macrophotographs, and measurements of retroreflectivity. The available data suggest that epoxy can be placed on a high-volume bituminous or portland cement concrete roadway, at a thickness of 10 mils, and provide adequate delineation for 12 months or longer while remaining as economical as paint. The polyester material did not adhere well to portland cement concrete and the aggregate in the bituminous pavement. Thermoplastic was found to be generally unacceptable because it is too susceptible to removal by traffic and snowplows when placed at the manufacturer's recommended minimum thickness of 30 mils and it does not bond adequately to portland cement concrete.**

For many years traffic and maintenance engineers and industries around the world have worked to improve conditions for the motorist. There is an ongoing search for new delineation materials and devices. The Manual on Uniform Traffic Control Devices (MUTCD) (1) states, "Traffic lane markings have a