Abrasive Air Blast System for Disbonding Ice and Snow from Pavement

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An abrasive air blast system is being developed and tested at the Keweenaw Research Center for disbonding strongly bonded compacted snow and ice from roadways. An investigation was first conducted to determine if abrasive air blasting could be a practicable way to remove ice and compacted snow from paved roads. The study included the use of available off-the-shelf equipment that could be installed on a highway department type of truck. Laboratory experiments were carried out in a cold room using a scaled-down system to remove ice and compacted snow that was bonded to asphalt and concrete road sections. Parametric studies were conducted to determine optimum nozzle height, angle, air pressure, abrasive type, and depth and width of material removal as a function of speed. Maximum speed obtainable in the laboratory was 1.93 km/hr (1.2 mph). A computer model was correlated with experimental data and then extrapolated to the desired speed of 32.2 km/hr (20 mph). Preliminary field tests at up to 32.2 km/hr (20 mph) showed good correlation to the model predictions. The results show that the concept is feasible but requires further development. A new source of funding has been obtained. The new study will use a one-nozzle system mounted on a truck and field-tested under realistic conditions. The main objectives of the new study are to develop a control system for the nozzles to limit road damage and to conduct further parametric field tests to verify earlier laboratory and computer model predictions.

Winter conditions of ice and snow cause serious disruptions in the economies of most states and produce hazardous conditions for the public. For example, typically during a snowstorm the road commission snowplow vehicles plow the main body of snow off of the roadways in a relatively short time. In many instances, traffic on the roads causes some of the snow to pack on the roadways, forming a bond between the compacted snow and the road surface. In other cases, ice storms cover roads with a thin layer of ice. Roads over bridges that may have some water on them tend to form ice faster than main roads. In the northern half of the United States and other northern countries, melt-freeze cycles cause some of the snow to partly melt and refreeze several times, which only strengthens the bond to the road. Scraper blades have been unsuccessful in removing all of the compacted snow and ice.

In these cases it has been the procedure to apply road salt or sand to melt the snow or ice and break the bond to the road surface. There are several problems with this technique. Salt is corrosive, causing deterioration to bridge structures, roadways, and automobiles. Salt is blamed for groundwater contamination in the heavily populated eastern part of the United States. Salt and sand also require time to become effective, and they do not usually work below −12°C (10°F). Currently, calcium magnesium acetate (CMA) is being tested; it appears, thus far, to be environmentally safe and noncorrosive. CMA still requires time to work and does not appear to work at temperatures lower than −12°C (10°F). A system needs to be developed that will effectively remove ice and compacted snow, as soon as possible and without harming the environment, to make the public road system safer and reduce road maintenance costs.

A new system for removing ice and compacted snow from roadways without the use of salt or other chemicals is being developed at the Keweenaw Research Center (KRC). KRC is a research agency of Michigan Technological University with a full-time staff of research scientists and engineers. Results of an early study proved that the system might be feasible but that it would require further development. This paper provides an overview of the early study and a follow-on study, and it presents plans for developing a full-scale abrasive air blast system.

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DEVELOPMENT OF ABRASIVE AIR BLAST SYSTEM

Initially, KRC proposed to study the possibility of using high-pressure, high-volume flow rate air for removing ice and compacted snow from roadways. A literature search revealed that several studies had been conducted with air-pressure or air-assisted-displacement snowplows (*1–4*). Most studies, such as that by Posey (*1*), used low air pressures [34.5 kPa (5 psi)] and high-volume flow rates of air through a slot, but the air was unable to remove the strongly bonded compacted snow or ice. In some of these studies, low-pressure air was forced through a narrow slot, over the width of a road lane and directly behind a plow blade, in an attempt to loosen the ice and snow on the road as the truck was plowing. To the author's knowledge, using high-pressure, high-volume flow rate air through a nozzle had not been attempted before. Later in the study, when investigating a patent for the idea, it was discovered that one person had conceived the idea of scraping the ice to make ice chips, collecting the chips, and then blasting the ice chips to remove the remaining ice off of the roadway. No specific pressures or air flows were mentioned. No papers could be found on this idea, and it is not known how far the ice chip concept has been developed.

Preliminary Tests

A preliminary test was run using a small air compressor and sandblaster to examine the potential of using air alone, CMA as an abrasive, and a common abrasive (Black Beauty, a ground slag that is a by-product of coke furnaces). The tests were conducted in late spring. The high-pressure air did remove some compacted snow, but it also left some snow and removed no ice. The CMA, which comes in a light, round pellet form, removed more compacted snow than air alone, but it appeared to bounce off the ice or break as it hit the ice. Black Beauty, which has sharp edges and is somewhat more massive than CMA, removed the compacted snow and some of the ice. This led to the conclusion that air alone and CMA would not work but that the hard, coarse Black Beauty or a similar abrasive could be successful.

Information Study

A literature study was conducted to gather information about current types of air compressors, abrasive air blasters, abrasives, and nozzles available on the market. At the same time, a small-scale laboratory study was initiated to determine the optimum parameters required for removing ice and compacted snow.

From the results of the literature study it was determined that a compressor producing 689 to 1206 kPa (100 to 175 psi) of pressure with a very high volume air flow rate (depending on the nozzle used) would be best for the abrasive air blast system. Compressors of this size are generally powered by diesel engines and have an operating life of 10 years or longer, if properly maintained.

Several sandblasting companies were contacted. The pressures used for most sandblasters are in the range of 413.4 to 826.8 kPa (60 to 120 psi). Some have used pressures as high as 1206 kPa (175 psi) for removing paint from bridges. Most sandblasting tanks, the part that is pressurized, are rated for 1378 kPa (200 psi) per the ASME code. This is a strict code because as the pressures increase in a sandblasting system, the wear rate of the tank and other components (i.e., hoses, valves, etc.) increases exponentially, possibly resulting in a dangerous situation for the operator or people near the sandblaster. If a sandblaster is used in a cold environment, a heater and air-water separator should be used to prevent the formation of ice, which may block orifices and hoses. When air is compressed, the temperature increases and, in a cold environment, moisture will condense out of the air and freeze.

Information was also obtained on abrasives. Some of the abrasives considered for this project were glass beads, aluminum oxide, silicon carbide, steel shot, steel grit, plastics, ice chips, silica sand, Black Beauty, and solid carbon dioxide. Most of the abrasives listed first are expensive. Ice chips and solid carbon dioxide require special equipment to produce and a special system for introducing into the compressed air stream. It was decided to conduct the initial laboratory tests with three types of abrasive: steel grit, silica sand, and Black Beauty. As a result of the preliminary tests, it was desired to use an abrasive that had a large mass and sharp edges. Each of the abrasives has advantages and disadvantages.

Steel grit has sharp edges and high mass, but it may be too expensive. The steel grit used for the laboratory tests was a 50-mesh grit and cost $52/45 kg (100 lb). Steel grit may rust and bond to the road, leaving an undesirable appearance. Silica sand is less expensive [$15/45 kg (100 lb), 45-mesh grit] but may cause silicosis when used in an enclosed area. Black Beauty is inexpensive [$4/45 kg (100 lb), 12- to 40-mesh grit] but may be carcinogenic if used in an enclosed area. If Black Beauty did work well, a flint rock abrasive may be used in its place as it has very similar characteristics and costs about the same. Bulk quantity prices are assumed to be proportionally lower for each of the three abrasive materials.

In most body shops or other places where small-scale sandblasting is done, ceramic converging-type nozzles are common. Air velocities through a converging-type nozzle may approach Mach 1 speeds. For projects requiring large areas to be blasted and heavy materials to be removed, a converging-diverging or venturi-type nozzle is used. When enough volumetric flow rate is available, the venturi nozzle will develop air and particle velocities up to Mach 3, which would assist removal of the compacted snow and ice. The venturi nozzles are made of tungsten carbide, cost $135 each, and last approximately 300 hr, depending on the abrasive. A venturi nozzle could not be used in the laboratory because there was not enough air flow available from the compressor used in the tests.

LABORATORY TESTS

A series of laboratory tests was conducted in a cold room to determine optimum parameters for removing ice and compacted snow from roads.

Test Fixtures

A fixture was fabricated such that a sandblasting nozzle could be fixed above a table at various heights and angles. Four 0.3- × 0.61-m (1- × 2-ft) road surfaces were formed following ASTM specifications and procedures; two were concrete and two were asphalt. A mold similar to an aluminum cake pan was fabricated to freeze water on top of the simulated road surfaces and form ice layers to desired thicknesses. The table was designed such that the road surface could be pulled at a constant speed underneath the nozzle. Speed could be varied from 0 to 1.93 km/hr (1.2 mph) to allow a relationship to be established for depth of ice removal versus traverse speed. Ice was used for most of the tests since it was understood to be more dense and difficult to remove. Some tests were run using compacted snow but only to determine how much deeper the cut would be than that of ice. The tests were run with a small compressor and sandblaster. The pressure was generally 999 kPa (145 psi) at the compressor, and the volume flow rate was 0.28 m^3/m (10 ft^2/m) or less. A ceramic converging-type nozzle with a 6.35-mm (0.25-in.) orifice was used. Figure 1 is a photograph of the laboratory test fixture.

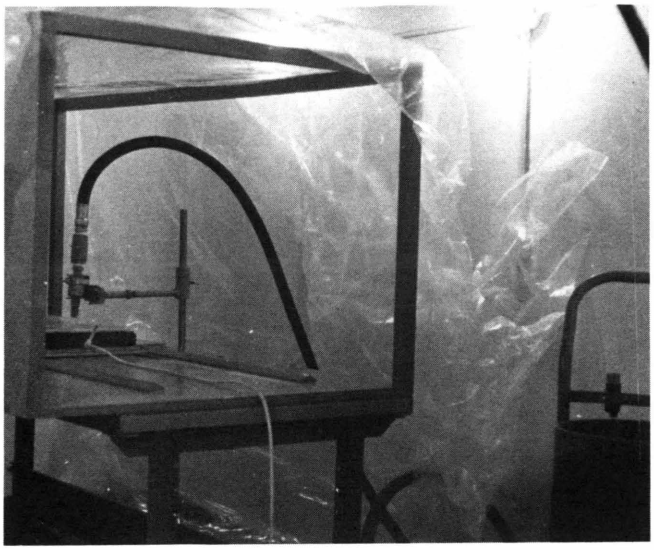

FIGURE 1 Photograph of laboratory test fixture.

Test Descriptions and Data

Tests were conducted to determine optimum air pressure, nozzle height, abrasive type, traverse speed, and nozzle angle versus depth of cut into the ice.

The first series of tests was conducted with a slab of ice 6.35 mm (0.25 in.) thick on the road surface and, because of the slow traverse rate, the abrasive cut through the ice and into the substrate material. Some aggregate was exposed. This occurred equally for the concrete and the asphalt road surfaces. The abrasive air jets tend to wear the ice away rather than disbond it from the road surface, which led to the reasoning that ice samples up to 51 mm (2 in.) thick could be used because only the depth of cut into the ice was important.

Initial tests with the nozzle in the vertical position (90 degrees from the horizontal) and in the 60-degree position showed that the cuts were deeper in the vertical position. Keeping in mind that these first tests were at very low traverse rates, from 0.08 to 0.37 km/hr (0.05 to 0.23 mph), it can be seen that at low speeds the nozzles should be fixed vertically. At traverse rates up to 32.2 km/hr (20 mph), it has yet to be determined if the nozzle will perform better at a slight angle because of the vehicle speed and abrasive velocity relationship.

The laboratory system was set up to run at speeds up to 0.37 km/hr (0.23 mph). Later in the study the system was modified to run at speeds up to 1.93 km/hr (1.2 mph). Some of the results in this paper were run at the lower-speed range only. In some cases it was not necessary to conduct the tests in the higher-speed range.

Tests for air pressure versus depth of cut into the ice were run with silica sand as the abrasive. Tests were all run at a 76.2-mm (3-in.) nozzle height and at 0.37 km/hr (0.23 mph) with the nozzle at 90 degrees; the temperature was −11.6°C. The data are presented in the following table and show that as the pressure increases, the depth of cut increases, but at a decreasing rate.

Air Pressure (kPa)	*Depth of Cut (mm)*
689	6.35
827	12.70
999	14.00

From these laboratory tests it is difficult to determine if increasing the air pressure higher than 999 kPa (145 psi) would significantly improve the depth of cut, but it is assumed that the component wear rate would increase and not be very safe.

Tests were conducted for nozzle height versus depth of cut for all three types of abrasive. The tests determined which abrasive performed the best and how nozzle height affected the depth and width of cut. Pressure was 999 kPa (145 psi), traverse rate was 0.37 km/hr (0.23 mph), temperature was −11.6°C, and nozzle angle was 90 degrees. The results showed that Black Beauty was the most effective abrasive; the best results were obtained at a 76.2-mm (3-in.) height in the vertical position, above the ice surface. Although the steel grit was more dense, the Black Beauty was slightly larger in size and appeared to have a more erosive effect. These data are presented in Table 1; Figure 2 is an example of the abrasive cut into the ice.

Toward the end of the laboratory tests (when the higher-speed tests were run), tests were run at 76.2- and 25.4-mm (3- and 1-in.) nozzle heights with Black Beauty at 999 kPa (145 psi) of pressure and 1.93 kPa (1.2 mph). There was no difference in depth of cut, but width of cut was reduced using the 25.4-mm (1-in.) nozzle height. Therefore, for these conditions, the 76.2-mm (3-in.) nozzle height was the most effective.

Another set of tests was made using compacted snow on the simulated road pavements. These were run for both the 90- and 60-degree nozzle angles, at the four highest rates of speed (for the laboratory tests). Black Beauty was used as the abrasive, at 999 kPa (145 psi) of pressure and at a 76.2 mm (3 in.) nozzle height. The results are presented in Table 2. Again, even at the relatively higher speeds, the 90-degree position proved to be the most effective. Figure 3 shows the effect of the abrasive air jets on compacted snow.

The final data gathered during the laboratory tests were traverse speed versus depth and width of ice cut. The tests were carried out using Black Beauty at 999 kPa (145 psi) of air pressure and a 76.2-mm (3-in.) nozzle height at 90 degrees and at −11.6°C. Data generated from these tests are presented in Table 3 and shown graphically in Figure 4. These

TABLE 1 Nozzle Height Versus Depth and Width of Cut

Abrasive Type	Nozzle Height (mm)	Depth (mm)	Width (mm)
Silica Sand	76.2	19.1	25.4
Silica Sand	152.4	16.0	31.8
Silica Sand	228.6	12.7	50.8
Steel Grit	76.2	20.6	25.4
Steel Grit	152.4	17.5	31.8
Steel Grit	228.6	16.0	50.8
Black Beauty	76.2	22.4	25.4
Black Beauty	152.4	20.6	47.8
Black Beauty	228.6	19.1	66.8

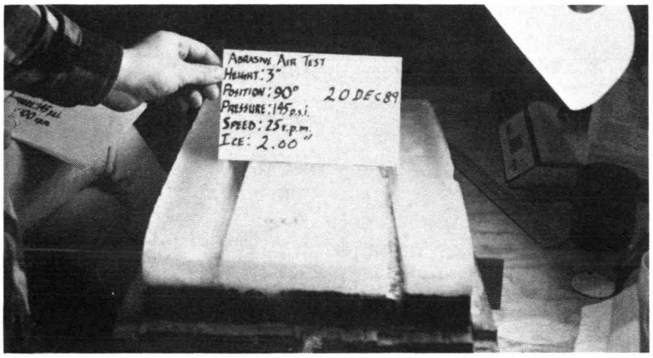

FIGURE 2 Typical abrasive air jet results on ice.

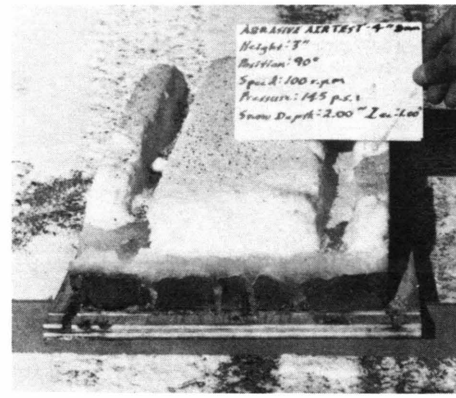

FIGURE 3 Typical abrasive air jet results on snow.

data show that as traverse speed increases, the depth of cut decreases.

In summary of the laboratory tests, it was found that the most effective results for the conditions tested occur when Black Beauty is used as the abrasive at a 76.2-mm (3-in.) nozzle height, in the vertical position, at an air pressure of 999 kPa (145 psi). These results were used to calibrate the analytical model and then extended to predict the depth of cut at 32.2 km/hr (20 mph). The model work is discussed in the next section.

MATHEMATICAL FLOW MODEL CORRELATION

A mathematical flow model for water/abrasive jets, developed by Hashish (*5*), was modified for the study of abrasive air jets. The model is fairly complex and considers the input parameters that follow:

- For the abrasive
  - Particle radius
  - Particle mass
  - Young's modulus
  - Poisson's ratio
  - Particle density
  - Abrasive mass flow rate
  - Initial particle velocity
  - Moment of inertia
  - Particle roundness
- For the ice
  - Flow stress
  - Coefficient of friction
  - Yield strength
  - Poisson's ratio
  - Young's modulus
  - Flow stress coefficient
- For the cutting system and air
  - Traverse rate
  - Jet diameter
  - Air jet velocity at nozzle exit
  - Loading ratio
  - Air density
  - Air pressure
  - Air flow rate
  - Particle velocity
  - Mixing efficiency

Some of the parameters were estimated, and some were converted from water to air since the model was originally developed for water.

First, the model data were correlated to the experimental data given in Table 3 for speeds up to 1.93 km/hr (1.2 mph). Figure 5 shows the model and experimental data for depth of cut versus traverse rate. After the model was developed to correlate at speeds up to 1.93 km/hr (1.2 mph), it was extrapolated to 32.2 km/hr (20 mph) to predict depth of cut into the ice. This is presented in Figure 6, which shows that at 999 kPa (145 psi), approximately 1.59 mm (0.0625 in.) of ice could be removed at a speed of 32.2 km/hr (20 mph). Because the depth-of-cut curve tends to decrease at a lower rate, at vehicle speeds greater than 16.1 km/hr (10 mph), it appears that ice removal may be possible at speeds greater than 32.2 km/hr (20 mph).

TABLE 2 Traverse Rate Versus Depth and Width of Cut

Traverse Rate (km/h)	Nozzle Angle = 90° Depth/Width (mm)	Nozzle Angle = 60° Depth/Width (mm)
0.48	88.9/38.1	76.2/38.1
0.97	50.8/38.1	28.7/38.1
1.45	31.8/31.8	25.4/31.8
1.93	28.7/31.8	23.9/25.4

TABLE 3 Traverse Speed Versus Depth and Width of Cut

Traverse Rate (km/h)	Depth of Cut (mm)	Width of Cut (mm)
0.08	31.91	50.8
0.15	25.4	25.4
0.26	19.1	22.4
0.37	14.1	19.1
0.97	9.7	25.4
1.45	7.9	31.9
1.93	6.4	25.4

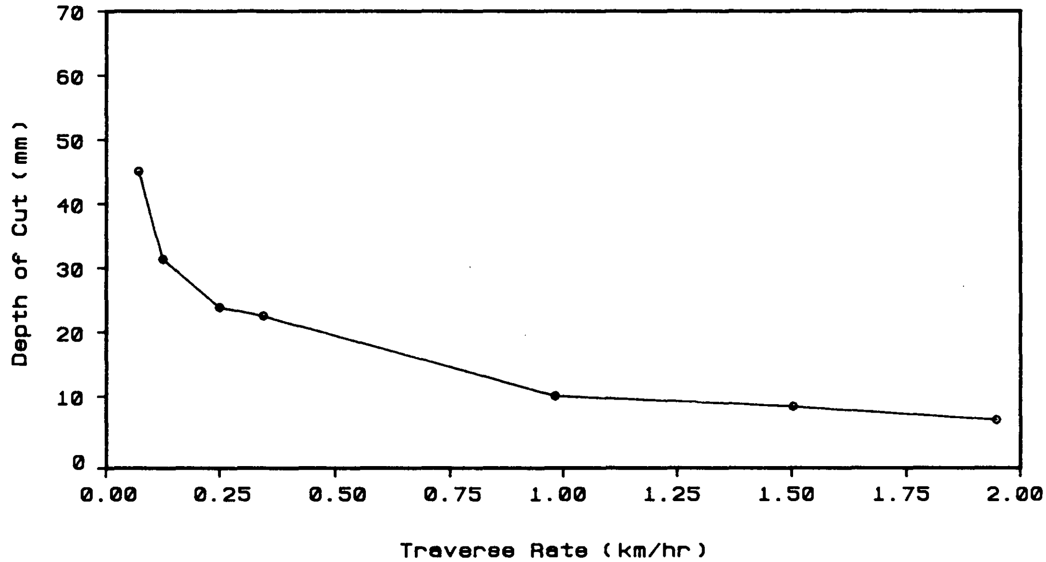

FIGURE 4 Depth of cut versus traverse speed, experimental data.

INITIAL FIELD STUDIES

In an attempt to verify removal of ice at 32.2 km/hr (20 mph), a large portable air compressor [10.5 m^3/m (375 ft^3/m) at 689 kPa (100 psi)] and a 272.4-kg (600-lb) pot sandblaster, including a 9.5-mm (0.375-in.) venturi nozzle, were borrowed from a local sandblasting company. For this test, ice 25.4 mm (1 in.) thick was formed on 0.61- × 1.22-m (2- × 4-ft) wooden sheets that were carried outside from the cold rooms for testing. A short series of tests was carried out at 8.1, 16.1, 24.2, and 32.2 km/hr (5, 10, 15, and 20 mph). The sandblaster was placed in the back of a pickup truck, and the air compressor was towed behind the truck. At 8.1 km/hr (5 mph), a layer of ice 6.4 mm (0.25 in.) thick was removed. At 16.1, 24.2, and 32.2 km/hr (10, 15, and 20 mph), a layer of ice 1.59 to 3.18 mm (0.0625 to 0.125 in.) thick was removed. As the model predicted, there was not much difference in the depth of cut between 16.1, 24.2, and 32.2 km/hr (10, 15, and 20 mph). These tests were conducted at 689 kPa (100 psi), and if a system were built, 999 kPa (145 psi) of pressure would be used, enhancing the ice removal process. Also in this test, the compressor was pulled behind a pickup truck and 7.6-m (25-ft) air supply lines and sandblasting lines were used. In a field unit the compressor and sandblaster would be mounted in the back of the truck where shorter supply lines and hoses could be used to ensure more efficient use of the air being supplied by the compressor, because the line losses can be significant, especially in a multinozzle system. Figure 7 shows

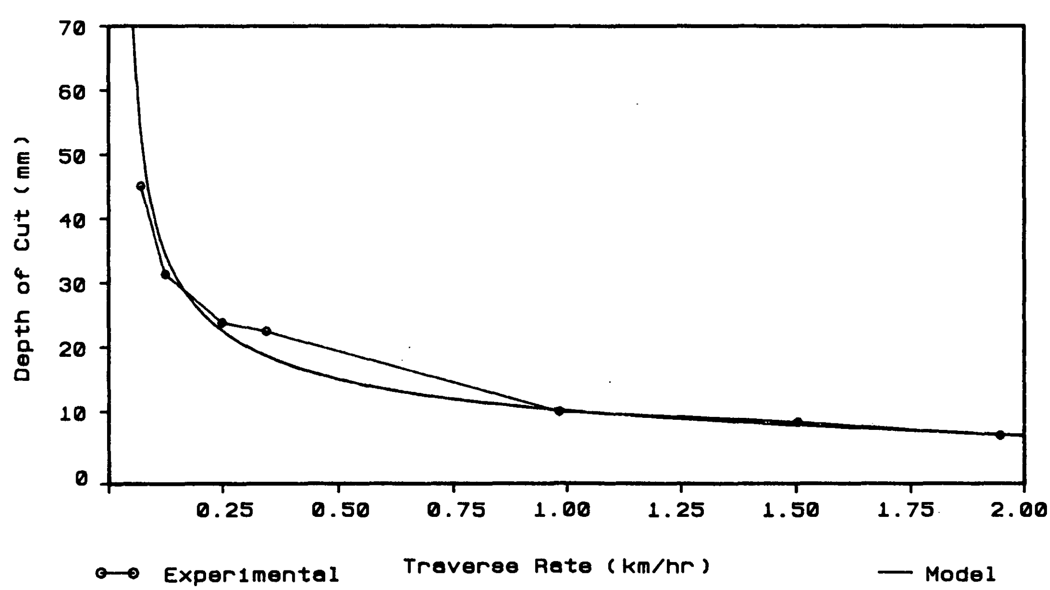

FIGURE 5 Model versus experimental data up to 1.93 km/hr.

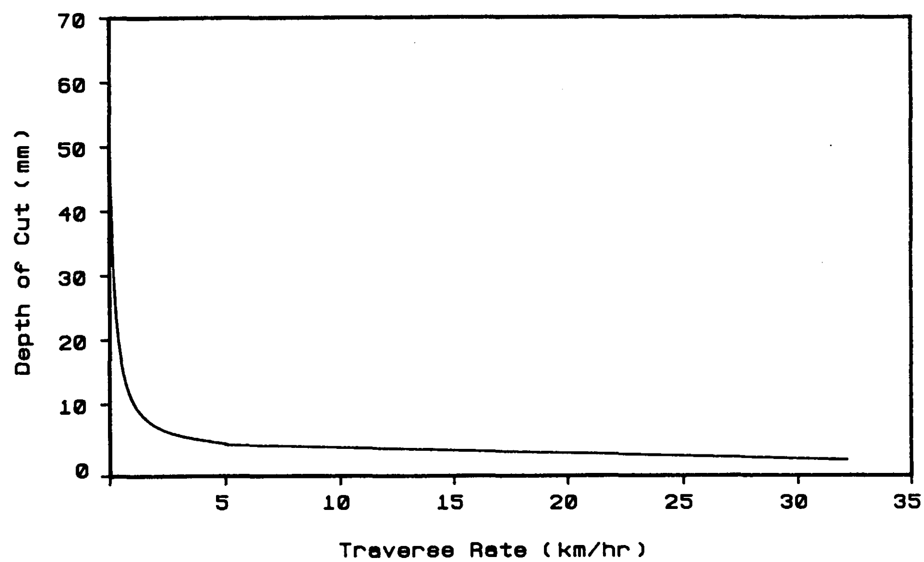

FIGURE 6 Model data extrapolated to 32.2 km/hr.

the plot of final depth of cut versus traverse speed for Black Beauty with both experimental and computer model data up to 32.2 km/hr (20 mph).

OTHER CONSIDERATIONS

Although it has been shown that an abrasive air blast system can remove ice at traverse rates of 32.2 km/hr (20 mph), more research needs to be conducted. A field unit needs to be developed with multiple nozzles for removing wide sections of roadway. The original tests were conducted with a small compressor and converging-type nozzle, so tests should be conducted to determine optimum nozzle size, abrasive type and size, and nozzle control for a large-scale system and venturi nozzle. Tests should be carried out on actual roadways with ice and compacted snow. Operator or automatic control systems need to be developed for the nozzles and air compressor to obtain maximum removal without pavement damage under all road conditions.

Pavement damage is currently being studied. It may appear to be a problem, but when tests were conducted at KRC at speeds of 8.1, 16.1, 24.2, and 32.2 km/hr (5, 10, 15, and 20 mph), some of the abrasives were blasted at the asphalt pavement in the parking lot with no apparent damage. The problems will most likely occur at intersections when the vehicle slows or stops.

There are two ways to effectively control snow and ice removal: one is to raise or lower the nozzles and the other is to control nozzle output through a shut-off valve at the nozzle. There are essentially two areas of concern for controlling system performance without pavement damage. One is the

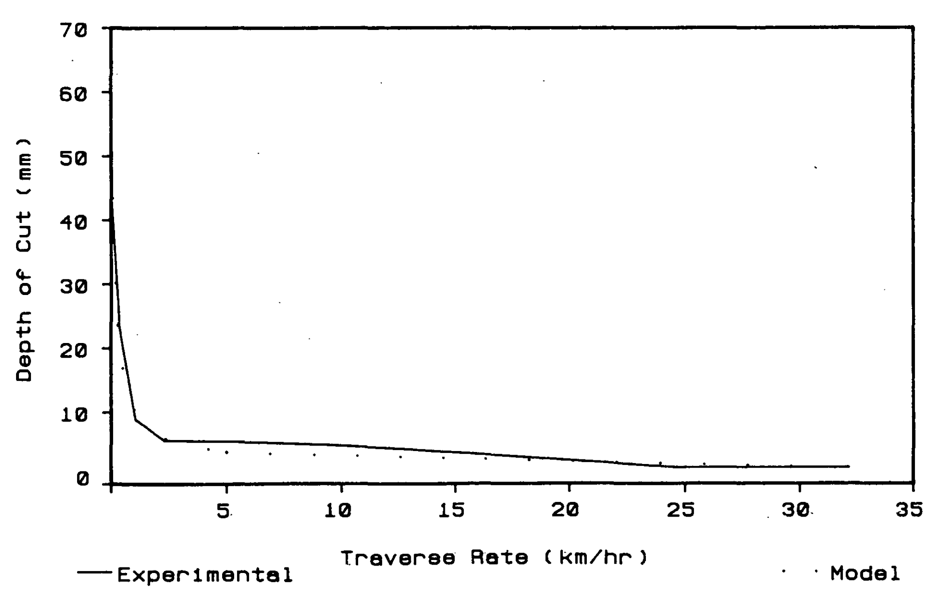

FIGURE 7 Model and experimental data at speeds to 32.2 km/ hr.

method of sensing snow and ice thickness or the absence of snow and ice, and the other is that of controlling nozzle height and operation.

Currently, KRC has a research grant to design and build a single-nozzle system with a control system to prevent pavement damage. The nozzle control system will consist of a hydraulic cylinder positioning servosystem with sensors such that nozzle height may be adjusted to avoid pavement damage.

Determining the conditions under which pavement damage occurs is a crucial step in designing the control system. Pavement damage will occur when the nozzles are at a height such that the depth of cut is deeper than the existing snow or ice thickness or when no snow or ice is present. For example, since pavement damage occurs at slower speeds, nozzle height must increase when the vehicle comes to a stop at an intersection. The control system is being designed to avoid these conditions and will operate in either a manual or an automatic mode. In the manual mode, the nozzle position will be set by a manually controlled transducer (potentiometer). In the automatic mode, the nozzle height will be adjusted automatically by discrete control.

Friction sensors are being designed such that the friction on the road surface and thickness of the snow or ice is continuously measured before and after the nozzles. It is well known that the coefficient of friction for a tire on dry pavement is about .7; on snow, .3 to .4; and on ice, .01 to about .2. Each friction-measuring system will consist of a set of wheels connected by gears and chains so that one wheel will be driven at vehicle speed while the other wheel will be driven at a speed approximately 12 percent slower when on dry pavement. This will result in a generation of torque on the second wheel that can be converted into a frictional force between the pavement and the tire. On snow and ice the torque will be reduced because of the slippage between the tire and the ice or snow surface. Tests will be run to set up the parameters for when ice, snow, or pavement is present. Two sets of the wheel friction-measuring device will be used: one ahead of the nozzle banks and one following the nozzle banks. Each set of wheels will also have a vertical displacement–measuring device for determining height differences between the front and rear sets of friction-measuring wheels. This will determine the depth of cut. The combination of depth of cut and friction measurement after the nozzle bank will determine if the cut is sufficient. The information will be continuously input to a microprocessor unit, which will control the hydraulic cylinders that raise or lower the nozzle banks, making continuous adjustments as the vehicle travels down the roadway.

During the 1992–1993 winter, tests will be conducted with the single-nozzle system and the control system. The tests will be conducted to set up the parameters for on-road use. In addition, since venturi-type nozzles can now be used, parametric studies can be conducted to develop new curves for the depth of cut versus traverse speed, nozzle angle, and type and size of abrasive for optimum removal.

FUTURE DEVELOPMENT

After the successful development of a control system for a single-nozzle system, KRC plans to seek funds to design, fabricate, and test a full-scale system that would include full-size compressors and sandblasting pots. The research has shown that one 44.8-m^3/m (1,600-ft^3/m) compressor will run four nozzles continuously all day long. An appropriate system could have eight nozzles and, depending on the nozzles used, could cover most of a road lane. Each compressor would have a corresponding 7264-kg (8-ton) sand pot that would contain enough abrasive to last an 8-hr shift. There are also air heaters and dryers available that would be incorporated into the system.

Another aspect that should be investigated is the vac-blast concept. After tons of sand are blasted on roadways all winter, the sand must be removed. Although current estimates for the amount of sand applied by the abrasive air blast system are about 90.8 kg (200 lb)/lane-mi versus the currently used 181.6 kg (400 lb) that is spread (not blasted) on roads in Michigan, the abrasive material will build up over time and will have to be removed. The vac-blast concept consists of a vacuum head and hose integral with the nozzle. The vacuum head surrounds the nozzle so that very little abrasive is left on the surface being blasted. The system has merit and needs to be investigated. The vac-blast system may be capable of removing most of the debris and would also contain the abrasive such that it is not blasted toward people or cars behind the abrasive air blast truck.

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