APPLICATION OF HOT SAND FOR WINTER ICE CONTROL

LABORATORY PHASE

FINAL REPORT

By

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May 1984

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in cooperation with

U.S. Department of Transportation
Federal Highway Administration

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1. INTRODUCTION

Sand applied to ice-covered roads is an effective skid-control agent when the temperature of the sand and ice is close to the melting point. But at low temperatures the sand does not penetrate the ice surface and is easily removed from the roadway by vehicles in motion or by wind. Applying preheated sand to a cold ice surface causes the sand to penetrate the ice by melting, and thus increases the amount of sand retained on the surface. The purpose of this project was to determine the skid-resistance characteristics of an ice surface to which preheated sand had been applied. Full-scale tests were conducted using the Pennsylvania Transportation Institute Circular Track Apparatus installed in a cold room operated by the Department of Mechanical Engineering at The Pennsylvania State University.

The tests were run with crushed and uncrushed sands graded into the ranges #16 to #200, #4 to #16, and 3/8 in. to #4. Sand application temperatures were 180°F (82°C), 130°F (54°C), 70°F (21°C), and the ambient temperature of the cold room. Room temperatures were 30°F (-1.1°C), 20°F (-6.7°C), 0°F (-17.8°C), and -12°F (-24.4°C).

After preparation of the ice surface, the sand was applied and trafficked for a period of five minutes, with the test wheel rolling freely. The locked wheel sliding skid resistance of the sanded surface was then measured continuously over a period of 50 seconds. At low sand application temperatures, relatively little melting occurred after the sand had come into contact with the ice surface. The bond formed between the sand and the ice after the melted water had refrozen was therefore weak and subsequent trafficking and sliding detached most of the stones from the ice and swept them from the wheel track. Under these conditions, the sand provided very little permanent improvement in skid resistance and, in some cases, resulted in a significant reduction in performance. But at the high sand application temperatures, significant melting occurred and a strong bond was formed after refreezing. Particularly strong bonding was evident with large-to-medium grade sands applied at high temperature to low temperature ice. The skid resistance of the surfaces measured under these conditions was substantially higher than the skid resistance of a bare ice surface.

2. TEST EQUIPMENT

The two major pieces of equipment used in the tests were the circular track apparatus and the cold room with its associated refrigeration plant. A complete description of the circular track is given in Reference 1. The cold room is a relatively standard installation and will not be described in detail. Other equipment and supplies included the test tire, sand, an oven for heating the sand, scales for weighing the sand, an insulated container used to apply the sand, and transducers with associated instrumentation.

2.1 CIRCULAR TRACK APPARATUS

Figure 1 is a schematic of the circular track apparatus showing the general layout and dimensions of the machine. A 50-hp motor and eddy current speed controller (7)* drive a gear reducer and 90-degree transfer box (6). The transfer box shaft is connected to, and turns, the two pivoted arms (13) and (22). The right-hand wheel (9) runs on a high friction surface and the test wheel (3) runs on the circular test track. In the machine's normal configuration, the two wheels are connected through a continuously variable vee belt drive (20) with the slip of the test wheel controlled by varying the velocity ratio of the belt drive. Also, the shaft (14) is connected to the test wheel axle via a chain drive enclosed in the case (4), and wheel torque is measured with a torque transducer mounted in the shaft (14). However, at low cold room temperatures the transmission efficiency of the chain drive decreased sufficiently that accurate wheel torque measurements could not be made. The shaft (16) and the chain drive were therefore removed and a torque arm fixed to the wheel axle. Wheel torque was measured by fixing the free end of the torque arm to a force transducer. The torque arm could be removed to run the trafficking phase of the test procedure.

In the normal configuration, load is applied to the test wheel by the air cylinders (18). But at low room temperatures the air lines had a tendency to freeze up and the air cylinder seals to leak. The load air lines were therefore removed and dead weights mounted on the frame above the test wheel

* Numbers in parentheses refer to locations on Figure 1.

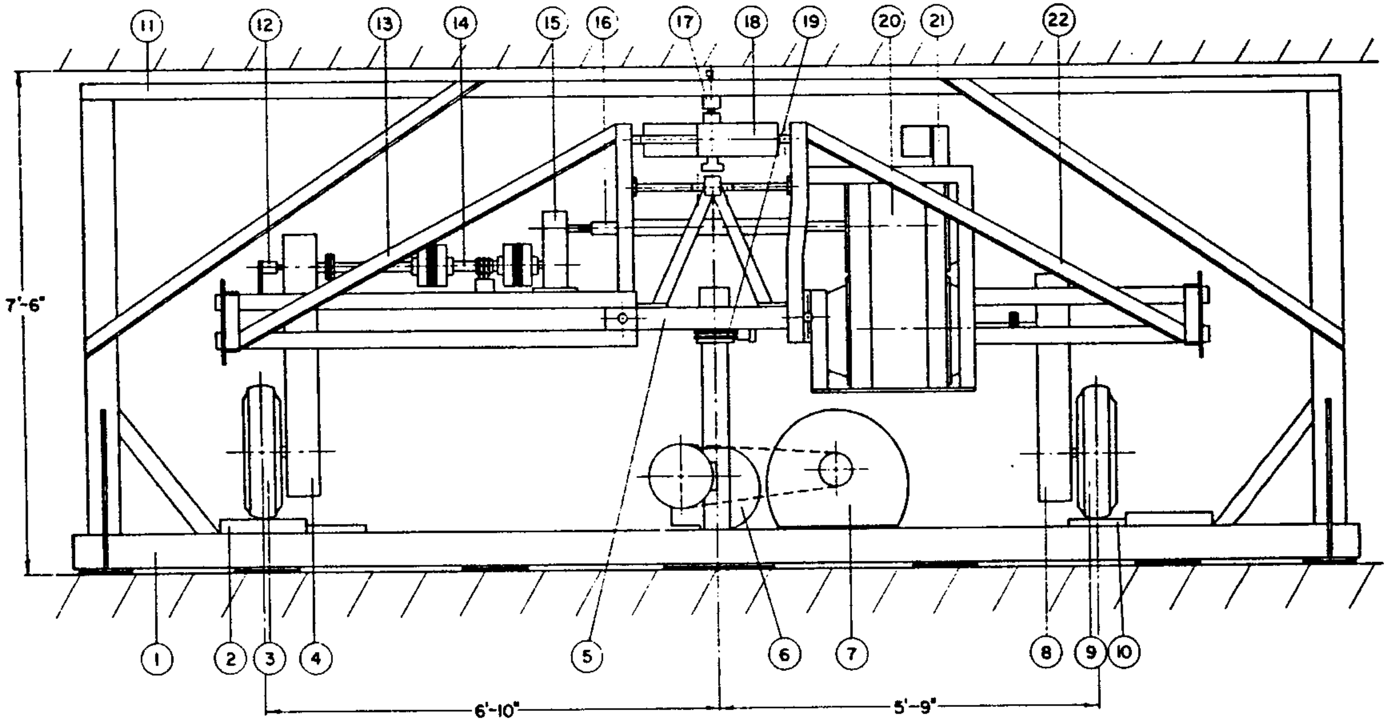


Figure 1. Circular track apparatus - layout and dimensions.

to bring the test load to 675 lb (3,000 N). Figure 2 is a photograph of the circular track as installed in the cold room for the tests.

2.2 COLD ROOM

The cold room measures 18 ft (5.5 m) wide by 17 ft (5.2 m) deep by 7.5 ft (2.3 m) high and is cooled by circulating the air in the room through a heat exchanger. Room temperature is controlled automatically to within ± 1°F (0.55°C) of the set point by injecting hot gas into the refrigerant flow in the heat exchanger coils. Originally it was planned to run tests at a room temperature of -20°F (-28.9°C). But an auxiliary liquid refrigerant pump, required to run the room at low temperature, broke down and the lowest sustainable room temperature which could be reached was -12°F (-24.4°C). This was the lowest temperature used in the tests.

2.3 TEST TIRE

A C70-14 bias-ply tire with a highway tread was used in all of the tests. A great deal of damage was done to the tire tread when sliding on a surface with firmly embedded stones, in some cases almost completely wearing away the two center ribs. Roughening the surface of a tire tends to increase locked wheel sliding performance on ice, but the effect is small compared to the skid resistance levels measured on the best of the sanded surfaces. The effect was therefore ignored and it was possible to use the same tire throughout the testing. To distribute wear around the tire, the wheel was turned on the hub carrier by one stud spacing when wear became excessive.

In all tests, the tire pressure was set at 24 psi (165 kPa) with the tire at the ambient temperature of the room.

2.4 INSTRUMENTATION

The locked wheel braking force acting on the tire was found by measuring wheel torque and dividing by the effective radius of the tire. Coefficient of friction was then calculated by dividing the tire force by the dead weight acting on the tire.

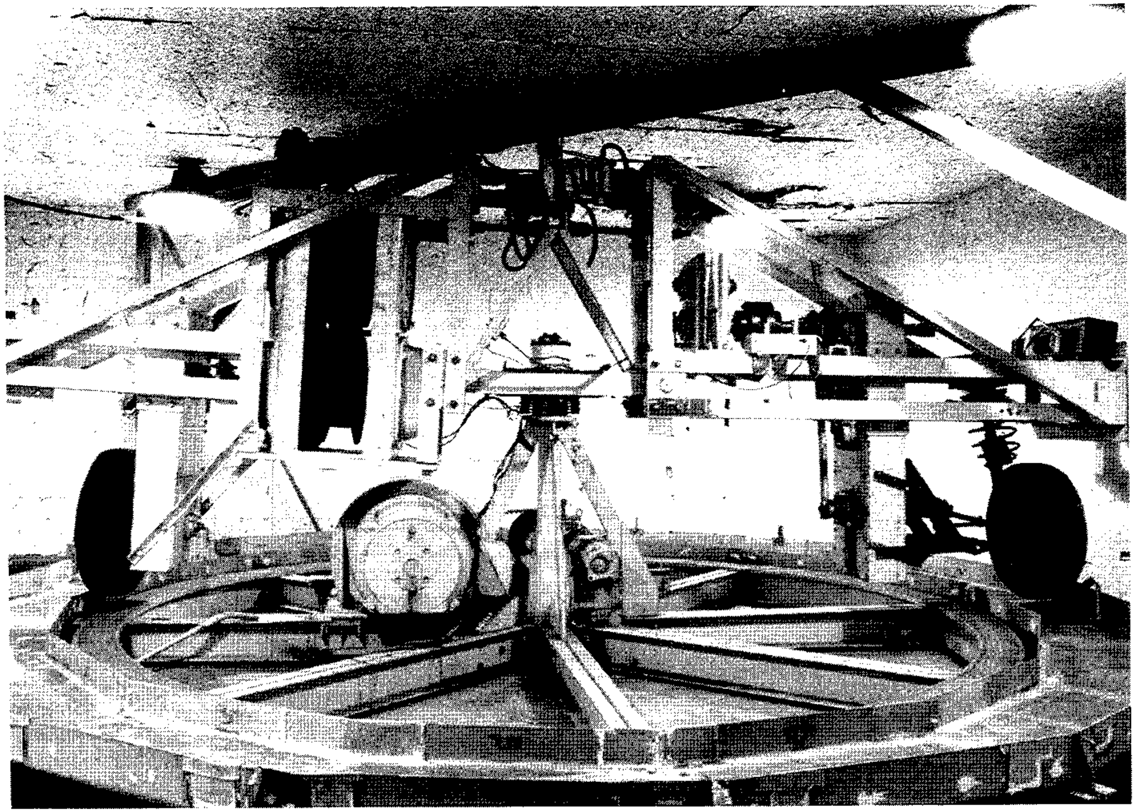


Figure 2. Circular track apparatus - as installed in the cold room.

A strain gauge force transducer was used in the measurement of wheel torque. Instrumentation for bridge excitation and amplification of the output voltage signal was located close to the transducer on the rotating arm of the track apparatus. The amplified signal was then passed through a voltage-to-frequency converter (V/F) and the resulting frequency signal measured with a counter located in the room adjacent to the cold room. The V/F approach was chosen because it has high noise immunity and gives a direct measure of the average transducer output over the chosen count period. High noise immunity was required because of the presence of two 50-hp electric motors (one driving the track and one driving the refrigeration compressor) and various other small electrical machines. Slip-rings were also required for the signal to pass from the rotating arm to the cable connected to the counter; a frequency encoded signal is effective in rejecting slip-ring noise. The counter was set up to count the number of pulses from the V/F converter over a five second period. The complete system was calibrated by applying dead weights to the transducer, counting the number of pulses for each increment of load, and fitting a straight line to the resulting plot.

Track speed was measured with a tachometer generator driven from the shaft of the track motor. Room temperature was measured with a mercury thermometer visible through an inspection window in the wall of the cold room. Bulk ice temperature was measured with a solid-state, current output, temperature transducer which was frozen into the ice while preparing the ice surface. The solid-state device gave adequate accuracy with good noise immunity and ease of use. No attempt was made to measure the surface temperature of the ice.

2.5 SAND

Three grades of sand were required in both crushed and uncrushed form. The sands were obtained from a number of sources, as follows:

Uncrushed (from Lycoming Sand and Gravel, Pa.)

3/8 in. to #4	roofing gravel
#4 to #16	roofing gravel
#16 to #200	concrete sand

Crushed

3/8 in. to #4	Pennsylvania DOT specification IB anti-skid
#4 to #16	Pennsylvania DOT specification IB anti-skid
#16 to #200	Lycoming Sand and Gravel mortar sand

After obtaining the sand in bulk, it was washed, dried, and sieved to the required gradations. It was then bagged ready for use.

3. TEST PROCEDURES

The general procedure followed throughout the testing was as follows:

1. Set room temperature.

2. Prepare a fresh, clean ice surface.

3. Measure the sliding friction performance of the clean, bare ice.

4. Apply sand at room temperature.

5. Traffic the surface for five minutes.

6. Measure the sliding friction performance of the trafficked surface until the coefficient of friction reaches a constant value.

7. Restore the ice surface.

8. Repeat sand application, trafficking, friction measurement, and surface restoration with sand temperatures of 70, 130, and 180°F (22, 54, and 82°C).

9. Repeat at a new room temperature or with a different sand type.

Because of the wide range of operating conditions covered by the tests and the complex nature of sliding friction on contaminated ice, details of the individual steps in the test procedure should be known to correctly interpret the results and to make valid comparisons with the results of tests run by other agencies. Important aspects of the procedures are described separately below.

3.1 INITIAL PREPARATION OF THE ICE SURFACE

After bringing the temperature of the cold room to below the required test temperature, water was poured into the track to a depth of approximately

3/4 in. (19 mm) and allowed to freeze. Ice formation proceeded from the outside surfaces to the center of the water layer. As the water expanded on freezing, unfrozen water was forced up through the top surface at intervals around the track, forming a rough fully frozen ice surface. A further layer of water approximately 1/4 in. (6 mm) thick was then applied to cover the irregularities. This usually resulted in a surface smooth enough for testing. Completely flat surfaces can be produced, if desired, by further applications of warm water in thin layers.

After the final water layer had frozen, the room temperature control was adjusted to the desired test temperature and the ice allowed to soak until the bulk ice was at the test temperature. Soak times of one-half to one-and-a-half hours were required.

3.2 RESTORATION OF THE ICE SURFACE

At the end of each test, the ice surface and tire tread were contaminated to varying degrees depending on the sand grade used, its temperature, and the temperature of the ice. Ideally, a completely fresh surface should have been prepared for each test by applying a new layer of water and allowing it to freeze. But this would have been overly time-consuming and a number of different surface restoration methods were used according to the amount of contamination produced by a test.

When no melting occurred after application of the sand, trafficking and skidding generally removed most of the sand from the wheel track. In this case the tire was cleaned, the remaining loose sand swept up, and the next test run with no further surface preparation. Some residual contamination inevitably remained, but the next test was almost always run with the same sand at a higher sand temperature and any effect on the results was minimal.

The uncrushed sands tended to produce a large amount of fines during trafficking and skidding, particularly with the smallest gradation. If the combination of ice temperature and sand temperature caused melting after application of the sand, the fines were ground into the ice during skidding. When this occurred, the surface could not easily be cleaned and a new surface was prepared by applying a thin layer of warm water and allowing it to freeze. Fines, which were brought into suspension by the melting of the original ice surface as the warm water was applied, settled out before the new ice surface had formed. When the level of contamination from fines was not severe, the surface was cleaned by applying small amounts of warm water and wiping the surface clean.

Applying the larger sand gradation at a high temperature resulted in a large number of stones adhering firmly to the ice. During skidding or when cleaning the ice surface after the test, the stones often became detached from the bulk ice still adhering to a portion of the surface ice, causing considerable damage. Under these conditions, the surface was restored by removing all of the stones and applying a thin layer of water.

3.3 SAND APPLICATION

Sand was applied to the ice surface by hand from an insulated container. The application rate was 0.2 lb/ft^2 (0.978 kg/m^2) for all grades. The correct amount of sand to cover the wheel track over the full circumference of the ice surface was first weighed out and placed in a container. It was then heated to the desired temperature in a small oven outside the cold room, or, if the application temperature were to be the ambient temperature of the cold room, left to soak in the cold room. The heated sand was applied to the prepared ice surface by shaking it through a small opening in the top of the insulated container from a height of approximately one foot. Some nonuniformity of application rate occurred around the track during each application and from test to test, but this was minimized by having the same operator apply the sand in all of the tests.

Because a constant application rate by weight was used for all grades of sand, the fine sands gave higher area coverage than the coarse grade sands. Figure 3 shows the coverage obtained with a #16 to #200 sand. The area of coverage and typical levels of nonuniformity can be seen. Figure 4 shows the coverage with a 3/8 in. to #4 sand. When applying the large grade sands, the stones tended to bounce on the surface and to spread over a wider area than the fine sands, as can be seen in Figures 3 and 4.

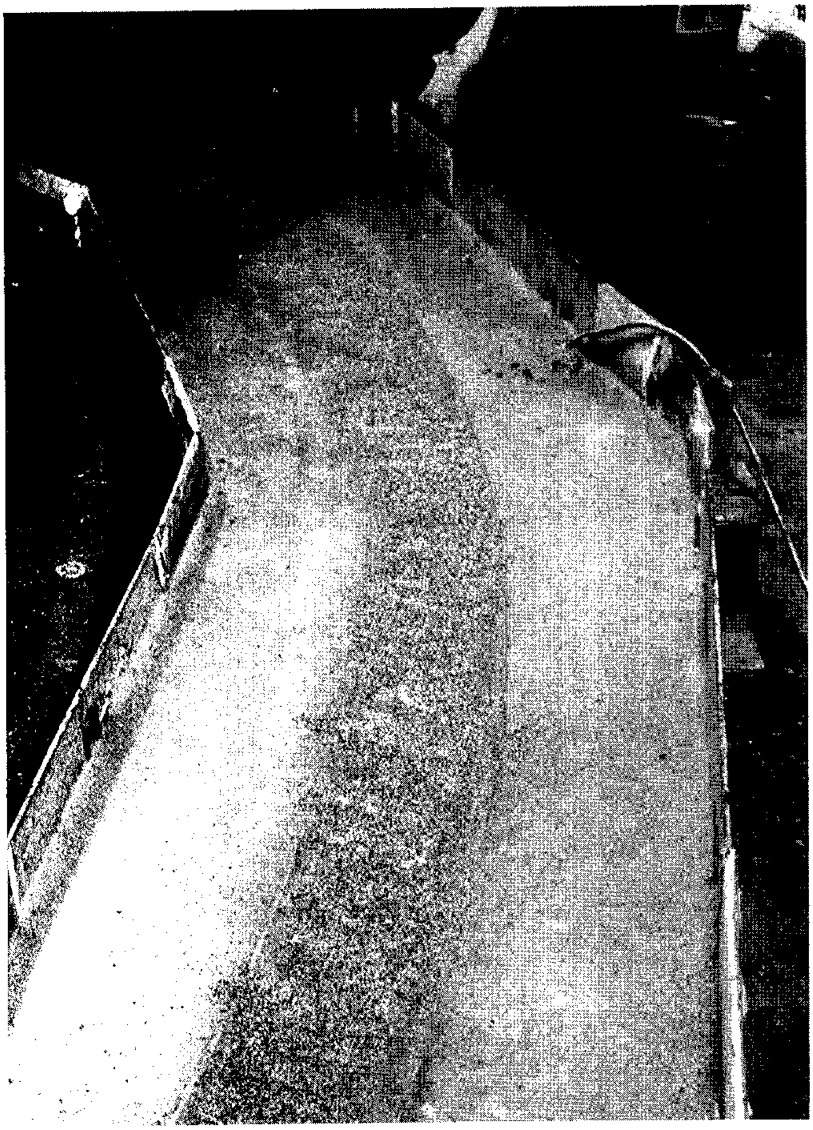


Figure 3. Coverage obtained with #16 to #200 sand.

Figure 4. Coverage obtained with 3/8 in. to #4 sand.

With application at low sand temperatures, there was little or no melting of the surface ice. At the highest sand temperatures, however, there was considerable melting and the sand became firmly fixed to the bulk ice when the melted water refroze. The high area coverage of the fine sands caused melted water to permeate the sand layer, resulting in a layer of sand bound in a matrix of ice and adhering to the bulk ice. The stones in the large grade sands simply melted into the ice and were individually bonded to the ice when it refroze. The amount of time between sand application and subsequent trafficking was sufficient, in all cases, for refreezing to have occurred before trafficking commenced.

After the sand application procedure had been completed, the test wheel was lowered onto the surface and trafficking performed for a period of five minutes. During trafficking, the wheel was rolling freely and the test speed was 10 mph (16.1 km/h). Even though a freely rolling tire generates (almost) the lowest levels of shear stress within the tire footprint area for any set of operating conditions, large longitudinal shear stresses are still present if the tire is rolling freely with no lateral or yaw velocity components. Adding a yaw component to the longitudinal motion of the tire, as occurs on the circular track apparatus, superimposes lateral shear stresses on the already present longitudinal stresses. Furthermore, significant amounts of sliding can occur within the tire footprint area if the tire is rolling on a surface with a low coefficient of friction. These effects indicate that weakly bonded stones are likely to be displaced by tires operating under even the least severe condition of straight-line free rolling. The additional yaw motion generated by the circular track means that the trafficking performed does not simulate the conditions produced by a free traffic stream. The conditions are probably closer to those produced by vehicles accelerating or decelerating at normal levels (less than 0.3 'g').

At the test speed of 10 mph (16.1 km/h), each section of ice was subjected to 102 wheel passes during trafficking. When no melting had occurred during sand application, trafficking removed almost all of the sand from the wheel track. In most cases, the remaining sand comprised fines produced by crushing and grinding the stones between the tire and the ice. When significant melting and refreezing had occurred, very few stones were removed by the trafficking. Fines were still produced, with some of the uncrushed grades generating large amounts. At intermediate levels of melting and refreezing, the proportion of stones remaining after trafficking varied between the two extremes of none or almost all.

3.4 MEASUREMENT OF SLIDING FRICTION

The performance of the sanded surfaces after application and trafficking was determined by locking the test wheel and measuring the coefficient of friction (μ) for locked wheel sliding. The procedure used to measure locked wheel sliding friction was, in all tests, as follows:

1. Raise the test wheel and lock the wheel axle to the torque transducer.

2. Bring the rotating arm to the test speed (10 mph) with the wheel raised.

3. At the beginning of a five-sec measurement period, open the air cylinder valve to start lowering the wheel.

4. Read and record the torque transducer measurement value at the end of each five-sec measurement period.

5. Continue until the torque measurement has reached a constant value or until a period of 50 sec has elapsed, subjecting each section of ice to a maximum of 17 wheel passes.

The time elapsing between opening the air valve to lower the wheel and the wheel load reaching its nominal test value varied with the temperature of the cold room. At all temperatures, however, the elapsed time was less than 5 sec. The first five-sec measurement period therefore did not give a valid measurement of the friction produced by the surface, whereas the second measurement period did. In many tests the friction varied rapidly with time at the beginning of the test, and the maximum friction level was probably significantly higher at some point during the period between 2.5 and 7.5 sec after closing the valve than the measured average value during the second 5-sec measurement period. To account for these factors, the data were reduced by discarding the first measurement and extrapolating back for 2.5 sec from a smooth curve drawn through all of the other measurement points. The first point shown on the test data plots is therefore an estimate of the maximum performance of the surface obtained by extrapolation.

Before starting the tests, the test speed to be used was determined by measuring locked wheel sliding friction over a range of sliding speeds. The criteria for selecting the test speed were that the speed should be as low as possible while maintaining friction on clean ice at a value close to the minimum (asymptotic with speed) value. Figure 5 shows the results of tests run on clean ice at temperatures of 0°F (-17.8°C) and 20°F (-6.7°C). The results were obtained by locking the wheel, running the track at constant speed, and measuring the coefficient of friction. Speed was then changed and a new measurement made. The results of Figure 5 are from averages of measurements made with speed increasing and speed decreasing. A test speed of 10 mph (16.1 km/h) was chosen as meeting the stated selection criteria.

As a check on the fundamental accuracy and applicability of the measurement and test procedures, coefficient of friction was measured at the selected test speed on ice at four different surface temperatures. The results, shown in Figure 6, are comparable with measurements made elsewhere under similar conditions (see, for example, References 2 and 3).

Figure 7 shows typical results from friction measurements made at four sand temperatures and two room temperatures with #16 to #200 sand. A notable aspect of the results shown is that reduction in performance relative to clean ice occurred when the application temperature was low. Extremely low levels of performance are evident for application temperatures of 30°F (-1.1°C) and 70°F (21.1°C) at a room temperature of 30°F. During the tests it was observed that the water melted by frictional heating mixes with fines produced by trafficking and skidding, forming a slurry which accumulates in the tire footprint area. Under suitable conditions, the slurry film becomes continuous and accumulates to such a degree that direct contact between the tire and the ice is lost. The photographs in Figures 3 and 8 through 10 show the ice surface after application, trafficking, and skidding, respectively, with #16 to #200 sand applied at 180°F and a room temperature of 30°F. When little or

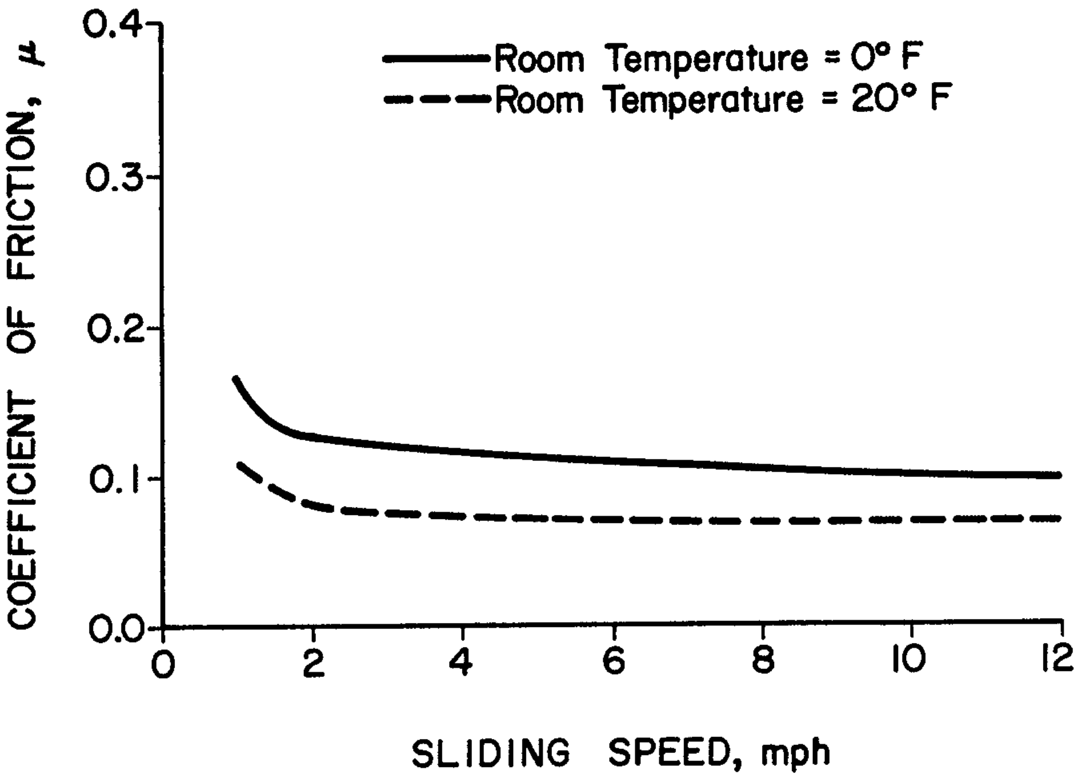


Figure 5. Locked wheel sliding coefficient of friction measured on clean ice versus sliding speed.

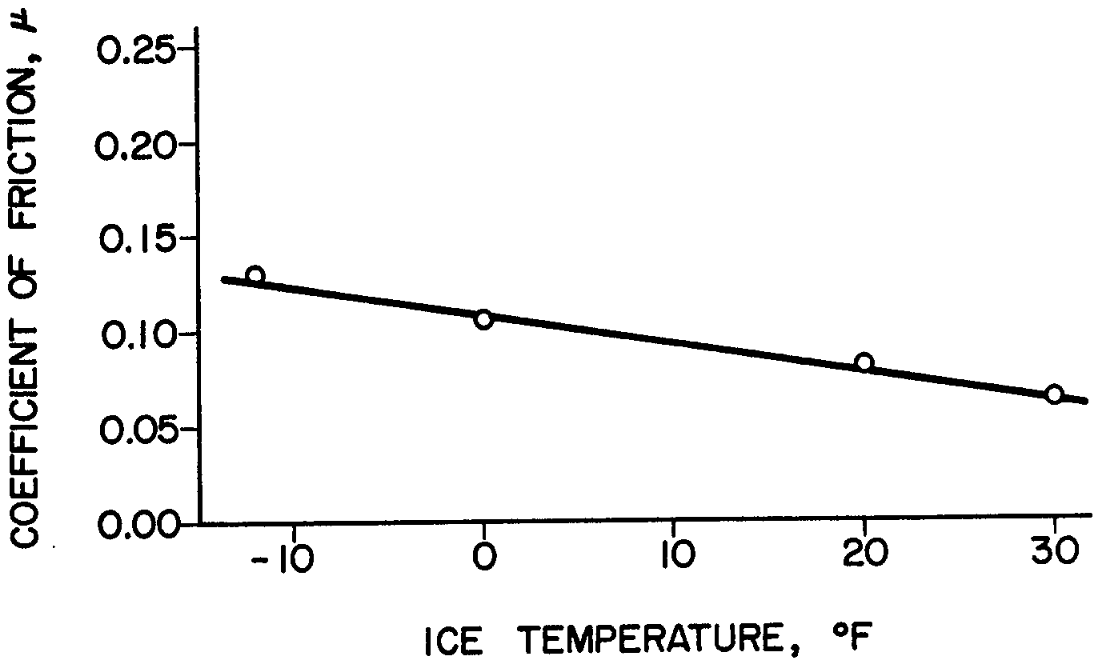
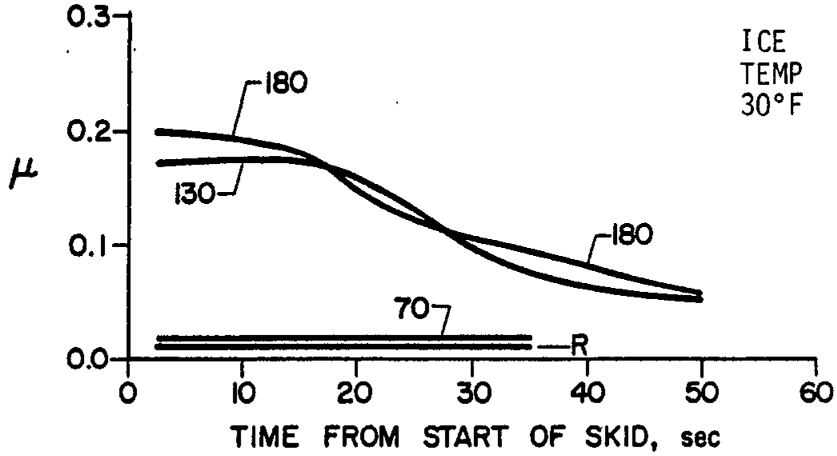
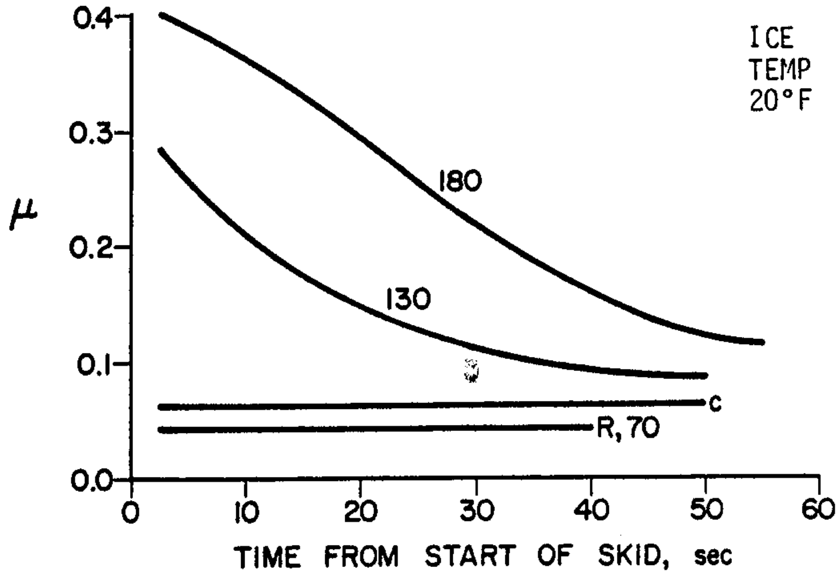


Figure 6. Locked wheel sliding coefficient of friction measured on clean ice at 10 mph versus ice temperature.





Legend:

μ = coefficient of friction in locked wheel sliding.

R = sand applied at the same temperature as the room ambient.

Curve labels = sand application temperature in degrees Fahrenheit.

c = clean ice.

Figure 7. Typical test results for #16 to #200 uncrushed sand, showing the range of measured coefficients of friction.

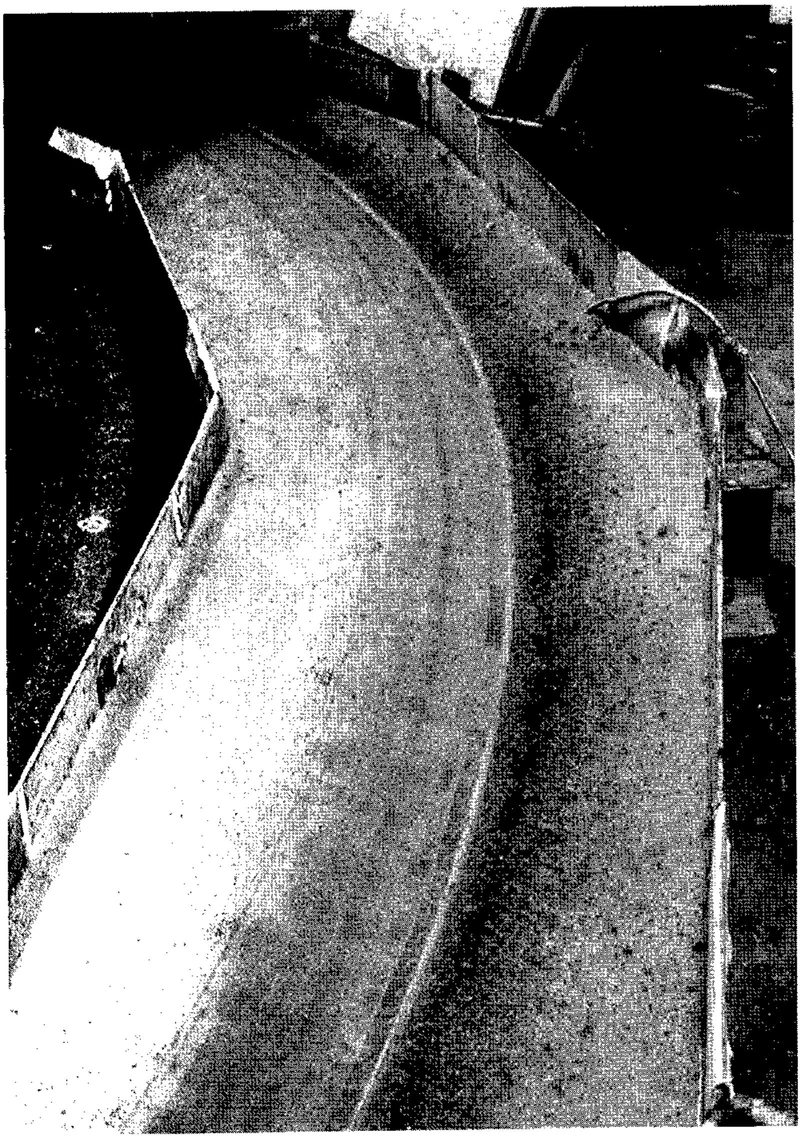


Figure 8. #16 to #200 sand applied at 180°F on 30°F ice, after trafficking.

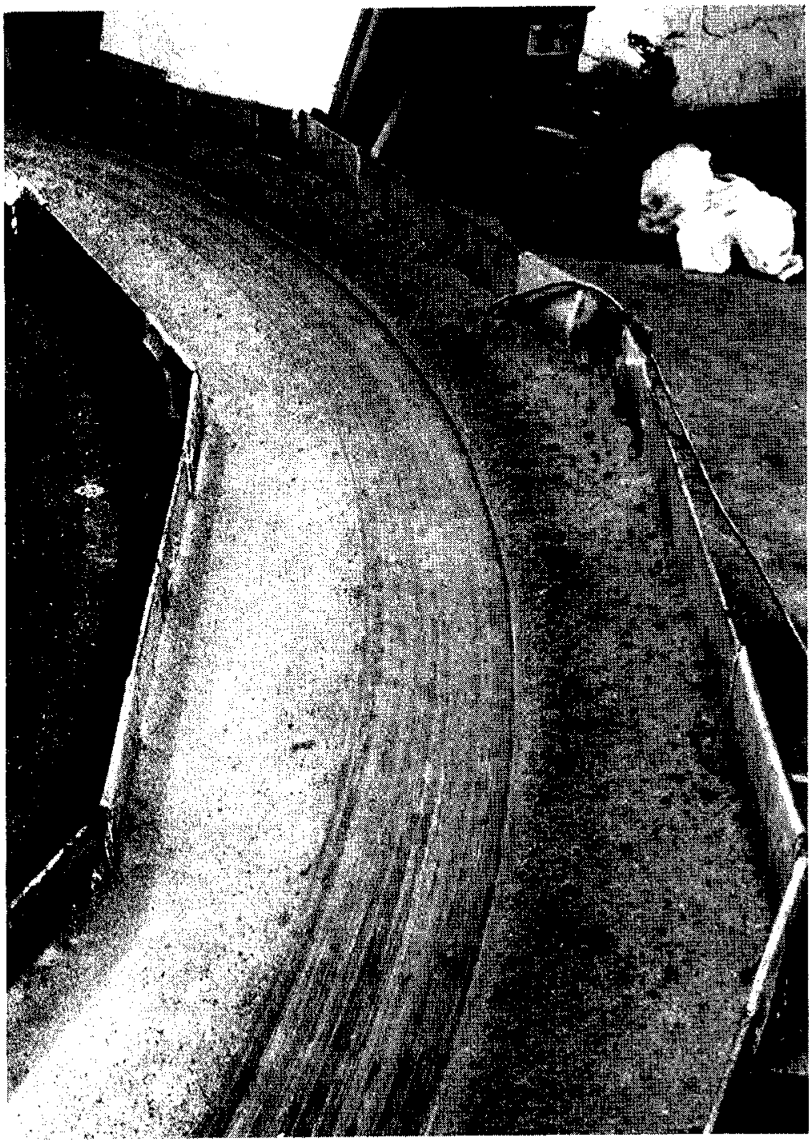


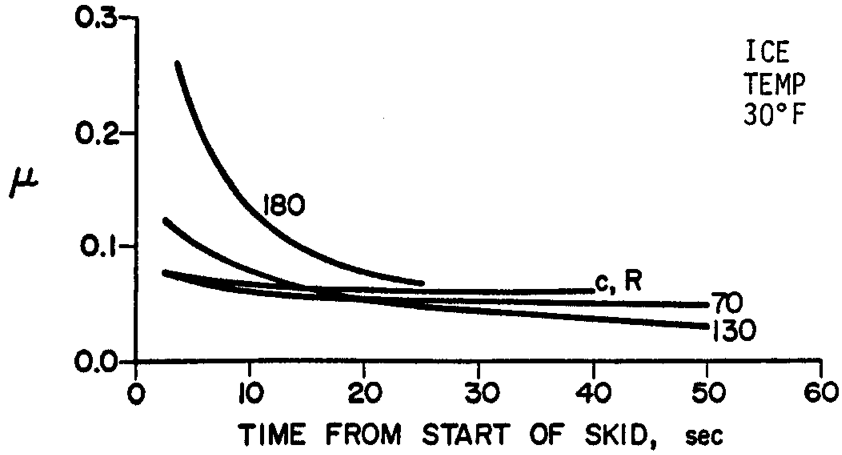
Figure 9. #16 to #200 sand applied at 180°F on 30°F ice, after skidding.

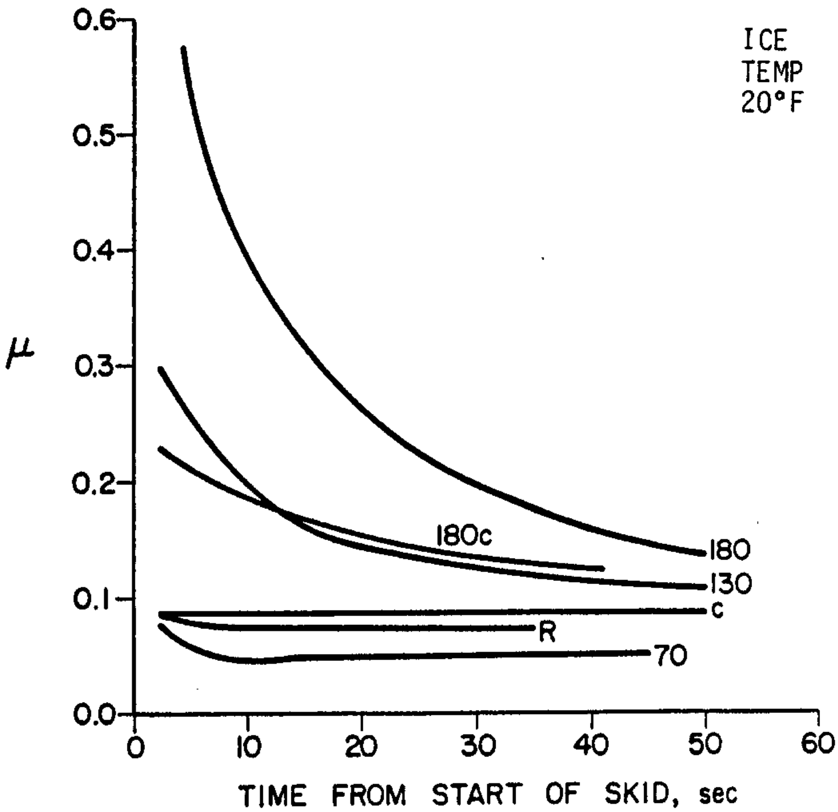
Figure 10. #16 to #200 sand applied at 180°F on 30°F ice, contact patch after skidding.

no sand is adhering to the ice surface, the slurry film that builds up is presumably capable of generating only very low coefficients of friction. Although it seems certain that the slurry film causes the low friction, an explanation cannot be given of how it does so. It also is not known to what extent this behavior would be present in field applications of the sands.

Figure 7 also shows that sand applied at high temperature, when significant melting and refreezing occurs, provides a considerable improvement in friction performance at the start of sliding. The decrease in performance as the time of sliding increases can be attributed to removal of sand adhering to the ice and to formation of a slurry film in the tire footprint. That both effects are significant is shown in Figure 11, where the curve marked 180 is for friction measured during the normal test procedure and the curve marked 180c is for friction measured in an immediate continuation of the 180 test but with the tire footprint area cleaned of contamination prior to starting the new test.

Figure 12 is a further illustration of the effects of contamination on friction force generation on ice. The figure shows results from tests run after completion of a normal test series. First, the tire footprint area was cleaned and a locked wheel sliding test run on the contaminated surface, giving curve (a). The surface was then cleaned and the contaminated tire run on the clean ice, curve (b). Finally, cleaning both the tire and the surface restored the coefficient of friction to normal fresh ice levels, curve (c).





Legend:

μ = coefficient of friction in locked wheel sliding.

R = sand applied at the same temperature as the room ambient.

Curve labels = sand application temperature in degrees Fahrenheit.

c = clean ice.

Figure 11. Test results for #4 to #16 uncrushed sand, showing the effect of cleaning the contact patch (curves 180 and 180c).

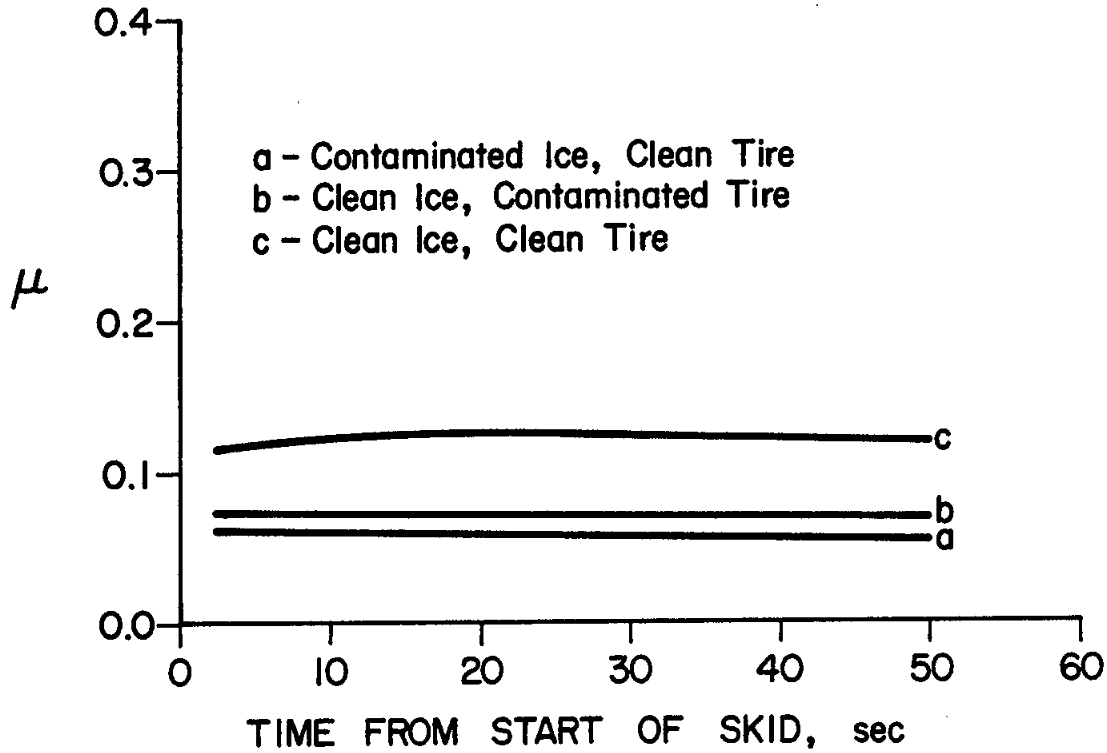


Figure 12. Coefficients of friction (μ) measured with various levels of contamination of the ice surface.

4. SUMMARY OF RESULTS

A complete set of results is given in the appendix for all room temperatures, sand application temperatures, and types of sand included in the tests. Tables A.1 through A.7 list numerical values of the individual coefficient of friction measurements made during each test. Figures A.1 through A.7 are plots of the tabulated data. In order to clearly show the general trends in the results, none of the figures in the appendix have individual data points plotted, but, in general, the scatter about the curves drawn was small. Figure A.12 and Figure 13 are identical except that Figure 13 includes the data points. The curve marked 180 (application temperature = 180°F) in Figure 13 has the largest amount of scatter about the smoothly drawn curve of any of the data sets from the test measurements. The other curves in the figure are typical of the majority of the test results.

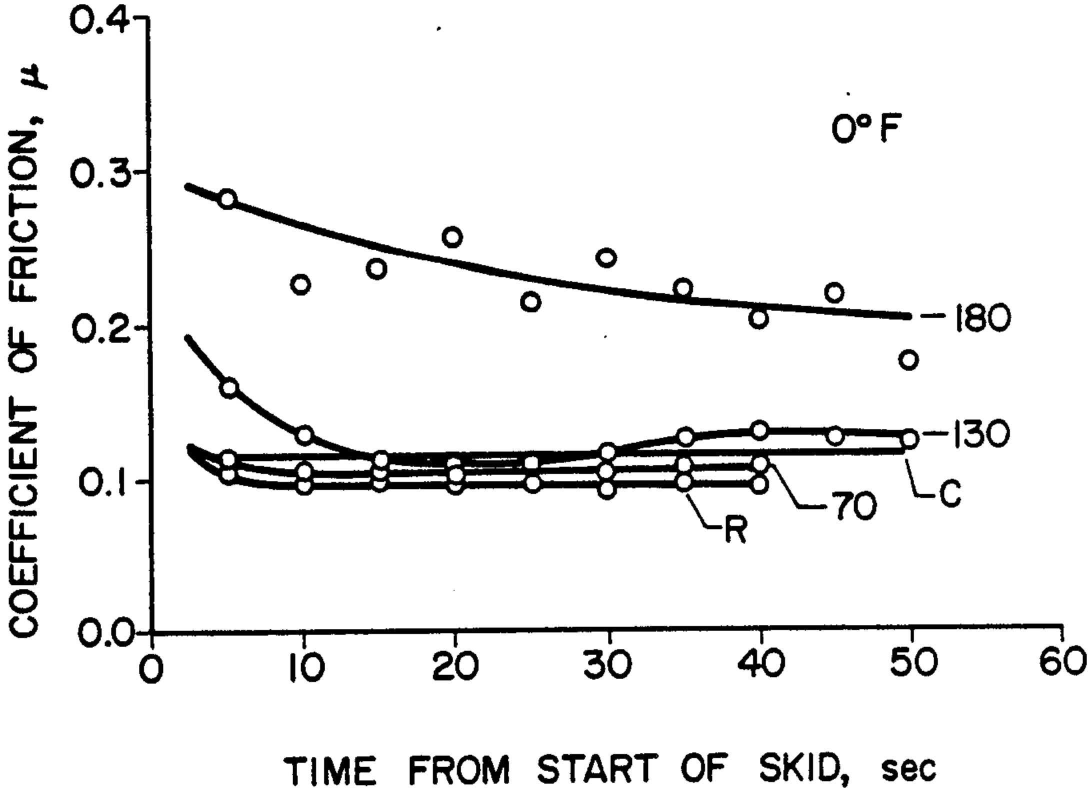
General trends observed in the results are as follows:

1. Locked wheel sliding performance on sanded surfaces with the sand application temperature at the cold room ambient or at 70°F was, in almost all cases, equal to or worse than the performance measured on clean ice at the cold room ambient temperature. In a few cases, some improvement was seen at the start of the test, but the performance always deçreased to a level below clean ice performance after a short period of sliding.

2. In some cases, an application temperature of 130°F gave significantly improved performance over clean ice performance.

3. In all cases, sand applied at 180°F was more effective than sand applied at 130°F.

4. In almost all cases, sand applied at 180°F provided an improvement in performance compared to performance on bare ice at the cold room ambient temperature.



Legend:

μ = coefficient of friction in locked wheel sliding.

R = sand applied at the same temperature as the room ambient.

Curve labels = sand application temperature in degrees Fahrenheit.

c = clean ice.

Figure 13. Sample plot of results for 3/8 in. to #4 crushed sand, showing individual data points.

5. At the highest cold room temperature (30°F), performance increased as sand grade size decreased.

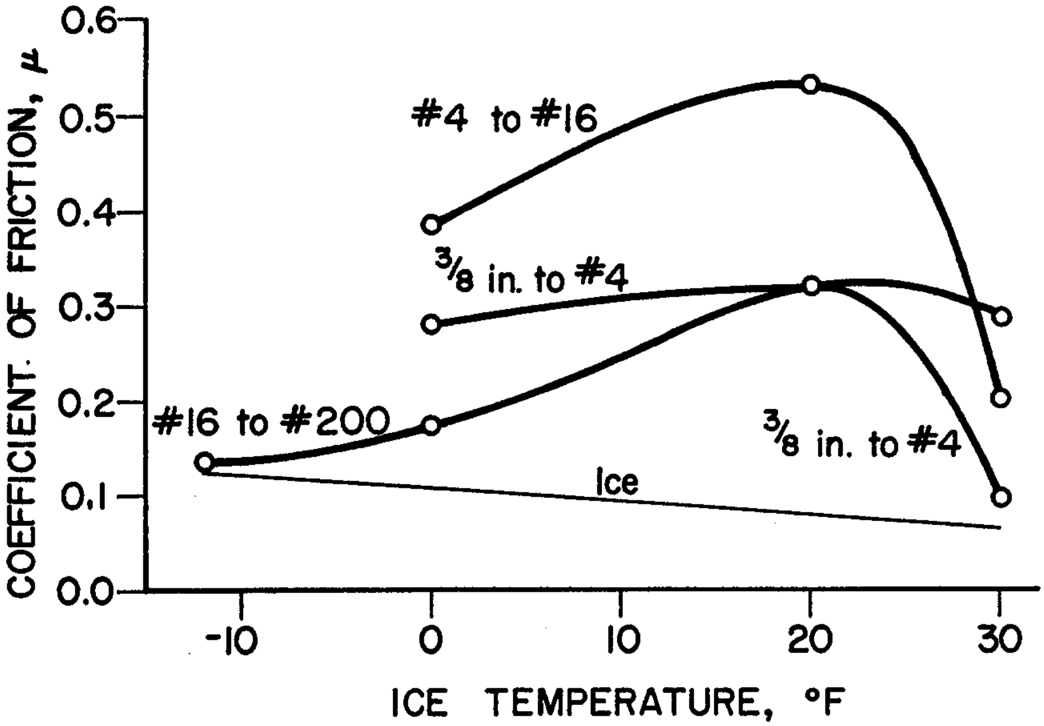
6. At the lowest cold room temperature (-12°F), performance increased as sand grade size increased.

7. At intermediate cold room temperatures, the intermediate sand grade (#4 to #16) was more effective than the other two grades.

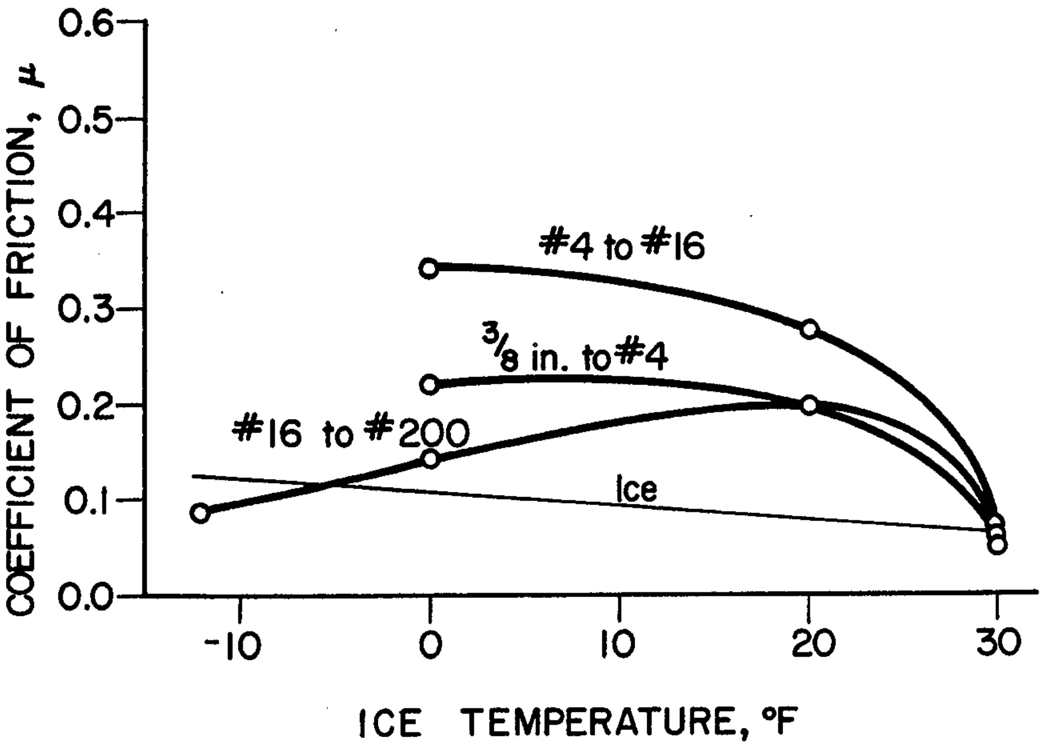
Summary plots of the 180°F application temperature results are shown in Figures 14 (uncrushed sands) and 15 (crushed sands). Coefficient of friction for each sand grade is plotted against ice temperature for (a) measurements made during the first valid measurement period (not the extrapolated estimates of maximum performance) and (b) measurements made 30 sec after starting skidding. The plots illustrate the trends noted above.

Only three sand types (#4 to #16 and 3/8 in. to #16, crushed, and #16 to #200, uncrushed) were run at the lowest room temperature because of difficulties experienced in running the tests at that temperature. The difficulties were mainly caused by leakage in the air cylinders of the wheel lift mechanism, increasing the time required to run a test, and rapid frost formation on the refrigeration heat exchanger coils, increasing the frequency with which the coils had to be defrosted. Performance of the #16 to #200 crushed and uncrushed sands was approximately the same under all conditions for which tests were run. The results for this grade of uncrushed sand at -12°F room temperature are therefore plotted on both of the figures. Different performance characteristics were, however, evident for crushed and uncrushed sands of the other two grades and Figure 14 does not show results for #4 to #16 and 3/8 in. to #4 uncrushed sands at -12°F room temperature.

Figures 14 and 15 effectively show the performance of the sanded surfaces immediately after application and Figures 14 and 15 effectively show the performance of the surfaces after they had been subjected to a great deal of working. At a room temperature of 30°F, almost all benefit from the sanding is lost after working. As ice temperature decreases, the surfaces retain more of their as-applied performance, with very little loss of performance evident

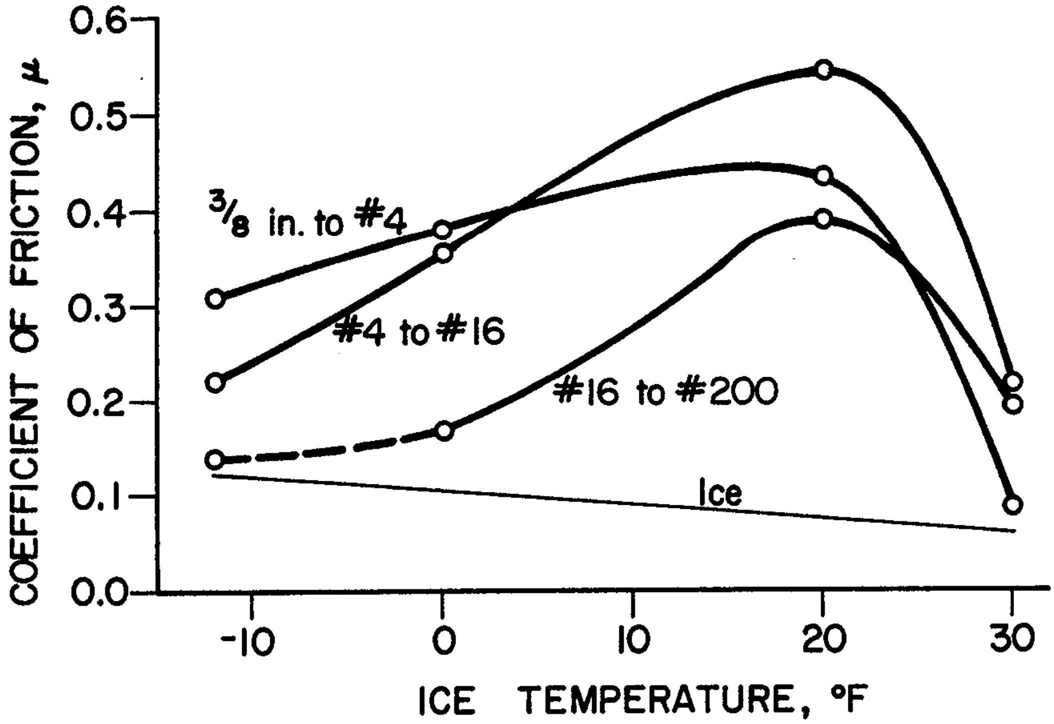


(a) Results for first valid measurement after starting locked wheel sliding tests.

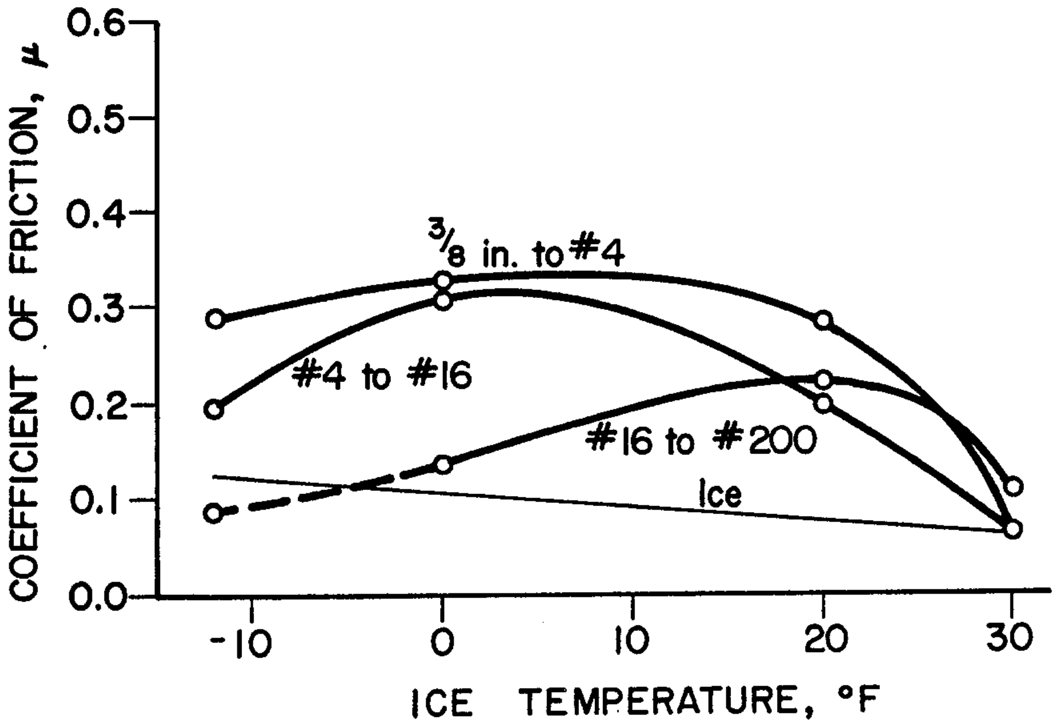


(b) Results for measurements taken 30 sec after starting locked wheel sliding tests.

Figure 14. Summary of results for uncrushed sands at an application temperature of 180°F (82°C).



(a) Results for first valid measurement after starting locked wheel sliding tests.



(b) Results for measurements taken 30 sec after starting locked wheel sliding tests.

Figure 15. Summary of results for crushed sands at an application temperature of 180°F (82°C).

at a temperature of -12°F. Furthermore, the large grade sands show the best performance at low temperatures and the worst performance at high temperatures. This may be due partly to the higher thermal mass per unit surface area of the large stones providing more efficient melting at low ice temperatures. The high strength of ice at low temperatures will also improve the resistance to detachment of the stones as temperature decreases, offsetting the higher detachment forces to which the large stones are subjected as the tire slides over the surface.

5. CONCLUSIONS

From a series of laboratory tests run in a cold room with a full-size test wheel, it has been demonstrated that the skid resistance of ice surfaces treated with anti-skid sands can be increased significantly by heating the sand prior to application.

The tests included a trafficking period between sand application and skid testing, and therefore approximated conditions likely to be met in the field. Three aspects of the tests which may cause differences to occur between the measured test results and field experience are: (1) the sand was thoroughly washed and dried before application, (2) ice thickness was large compared to the size of the stones, and (3) the sands were applied by hand at slow speed and little heat was lost from the stones between leaving the container and coming to rest on the ice surface.

The highest application temperatures (180°F) used in the tests gave the best performance for all sand grades at all ice temperatures. Large grade sands tend to be the most effective at ice temperatures below 0°F.

6. IMPLEMENTATION

The testing program described in this report is the first phase of an investigation of the feasibility of applying heated sand to icy roads to provide improved traction. This testing program has shown that heated sand can provide significantly greater friction between tires and icy surfaces than cold sand can provide, particularly at very low ambient temperatures.

The Research Section will therefore proceed with an investigation of equipment needs for field application of heated sand and estimates of the related costs. This investigation will allow a comparison of the expected costs and benefits of using heated sand on icy roads. This comparison will be used to determine if field trials are warranted.

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Alaska Department of
Transportation and
Public Facilities
Research Section

REFERENCES

1. Hegmon, R. R. and Meyer, W. E. The Effectiveness of Antiskid Materials as Measured on a Circular Track Apparatus. Automotive Safety Research Program Report S22. Department of Mechanical Engineering, The Pennsylvania State University, November 1966.

2. National Safety Council. Committee on Winter Driving Hazards. Annual Winter Test Reports. Stevens Point, Wis.

3. Hayhoe, G. F. and Hopac, P. A. Evaluation of Winter Driving Traction Aids. Final Report on Project 1-16 to National Cooperative Highway Research Program. Pennsylvania Transportation Institute, The Pennsylvania State University, June 1981.

APPENDIX. TEST RESULTS

Figures A.1 through A.7 are plots of the test results. Details of the test and data reduction procedures are given in Chapter 3. Notation for the figures is as follows.

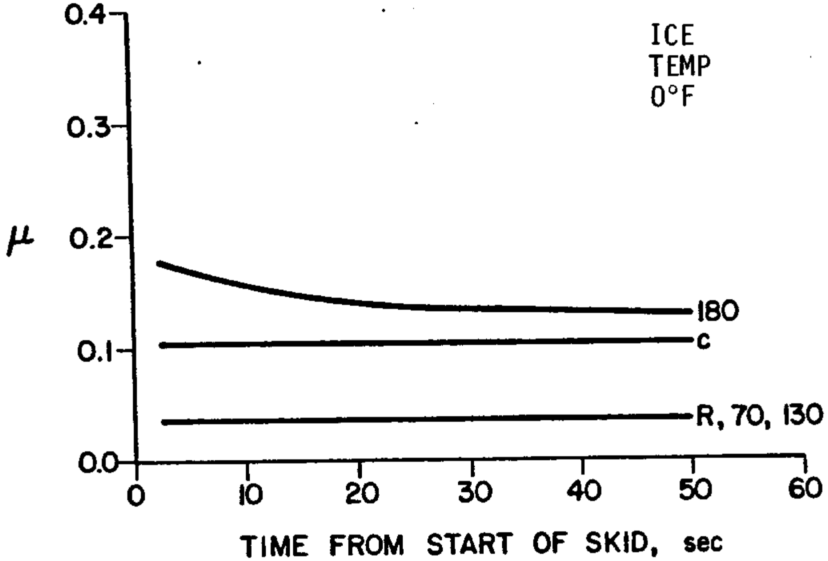
μ = coefficient of friction in locked wheel sliding.

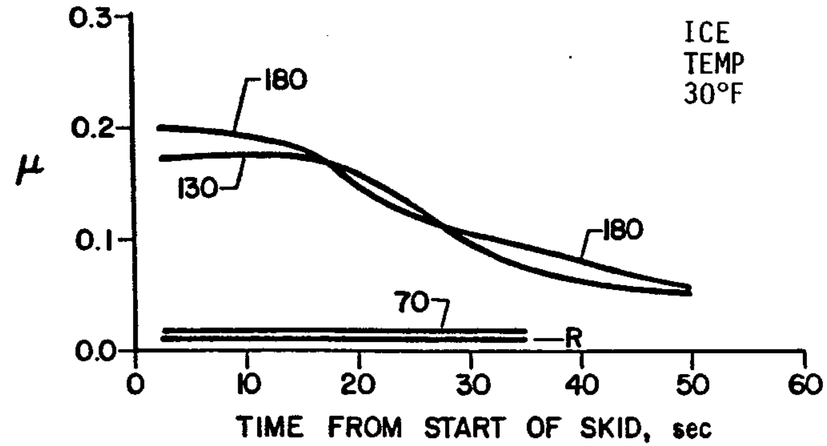
Graph labels refer to sand grade, sand type, and room temperature,

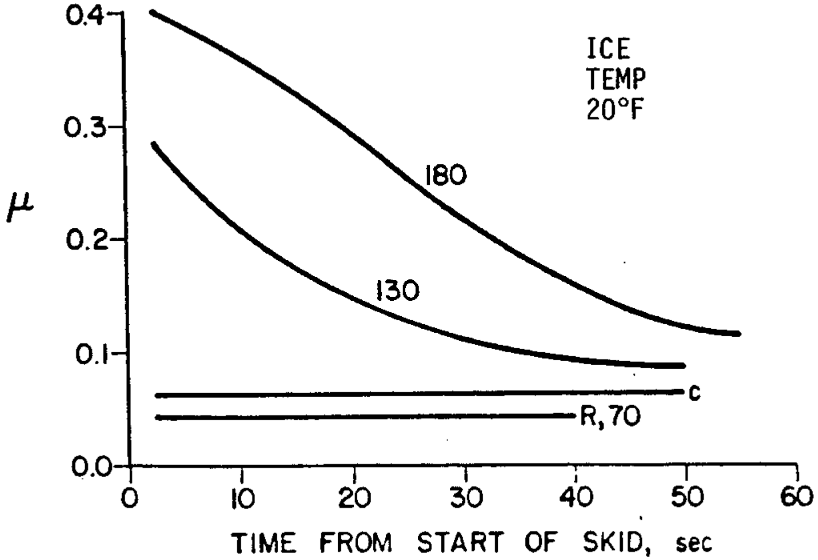
e.g. 200-16 UC 30°F — denotes uncrushed #16-#200 sand with tests run at a room (ice) temperature of 30°F.

Curve labels refer to the sand application temperature in degrees Fahrenheit. (R = sand applied at the same temperature as the room ambient.)

Tables A.1 through A.7 contain the test results. Coefficient of friction in locked wheel sliding, measured as an average value over succeeding 5-sec measurement periods, is listed in columns for each of the application temperatures.







Legend:

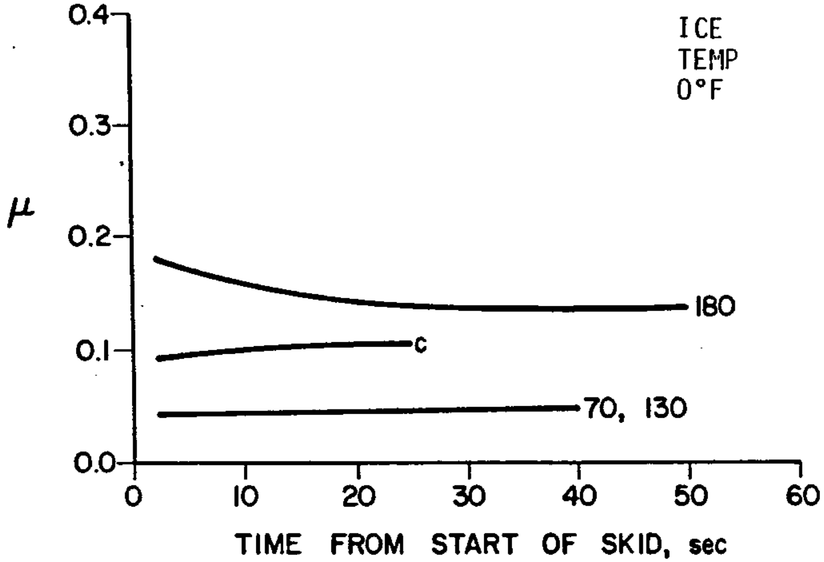
μ = coefficient of friction in locked wheel sliding.

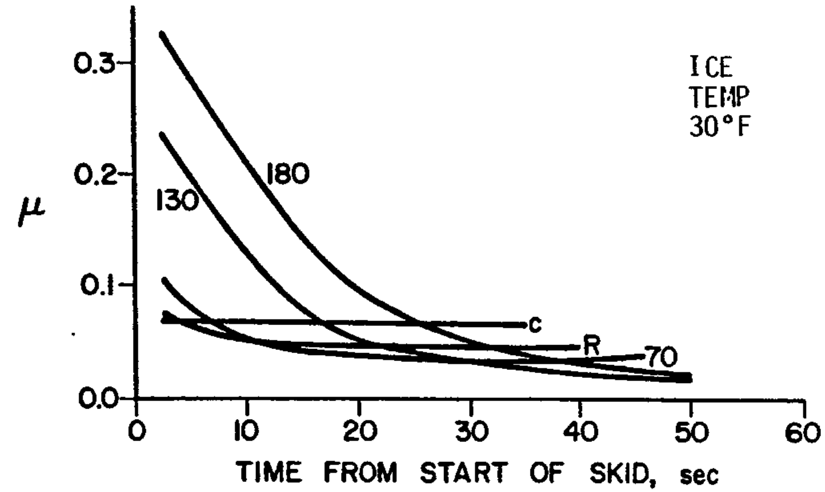
R = sand applied at the same temperature as the room ambient.

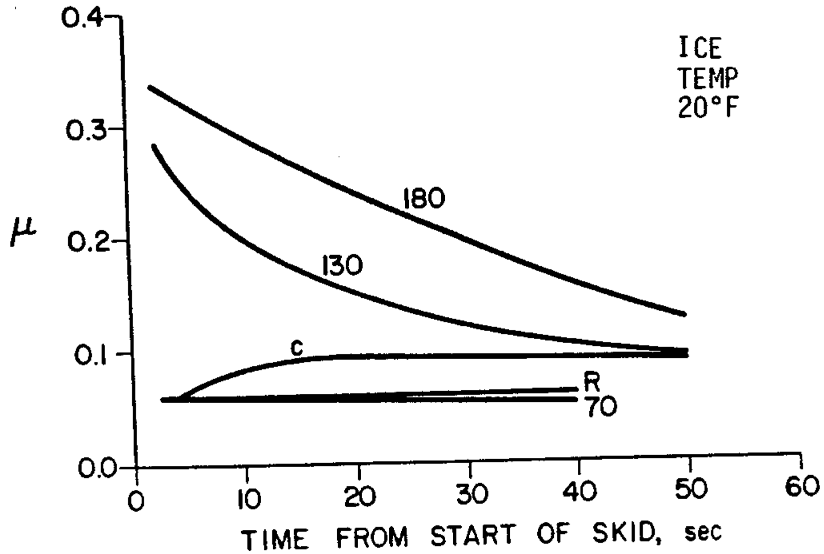
Curve labels = sand application temperature in degrees Fahrenheit.

c = clean ice

Figure A.1 Results for #16 - #200 uncrushed sand.







Legend:

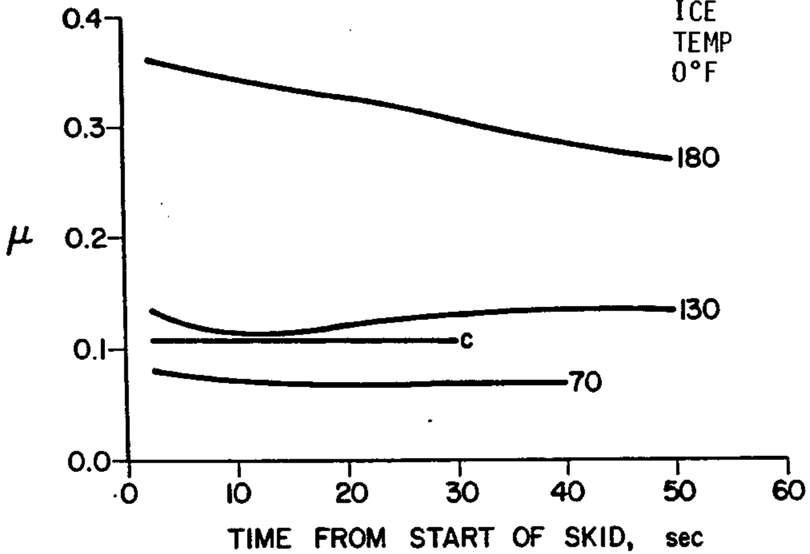
μ = coefficient of friction in locked wheel sliding.

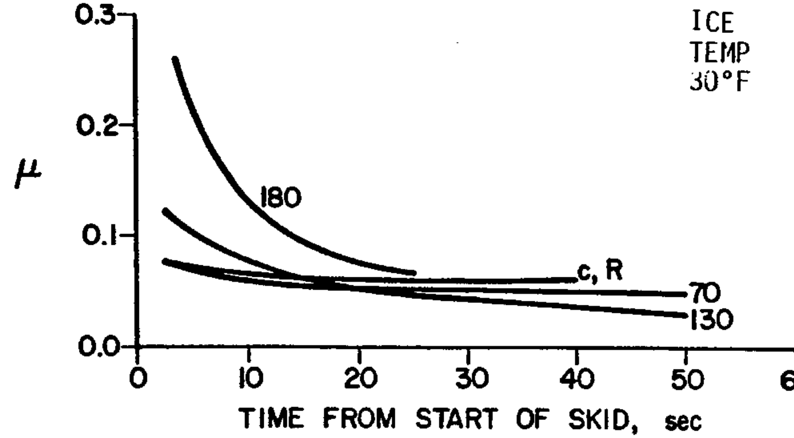
R = sand applied at the same temperature as the room ambient.

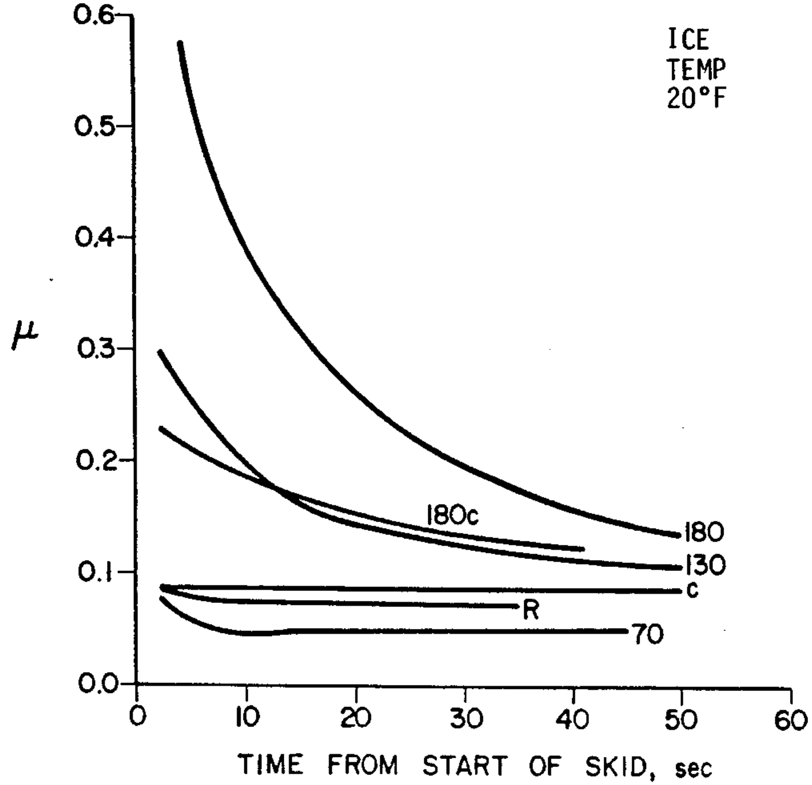
Curve labels = sand application temperature in degrees Fahrenheit.

c = clean ice

Figure A.2 Results for #16 to #200 crushed sand.







Legend:

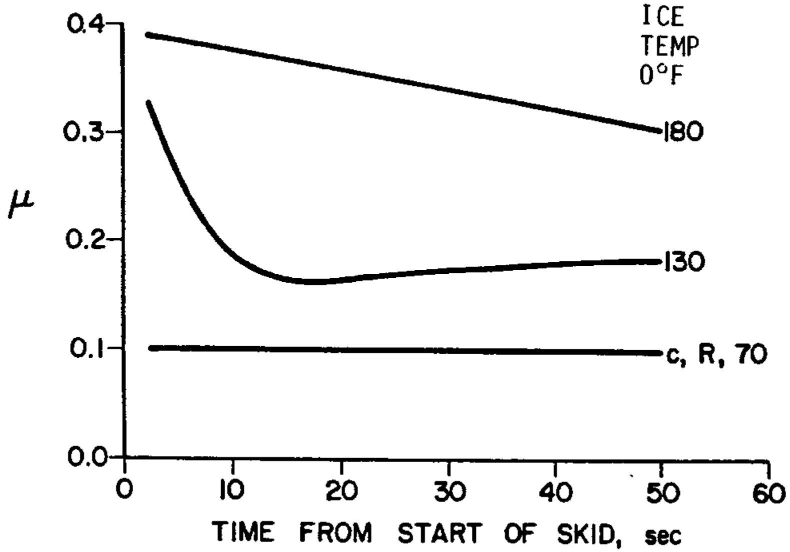
μ = coefficient of friction in locked wheel sliding.

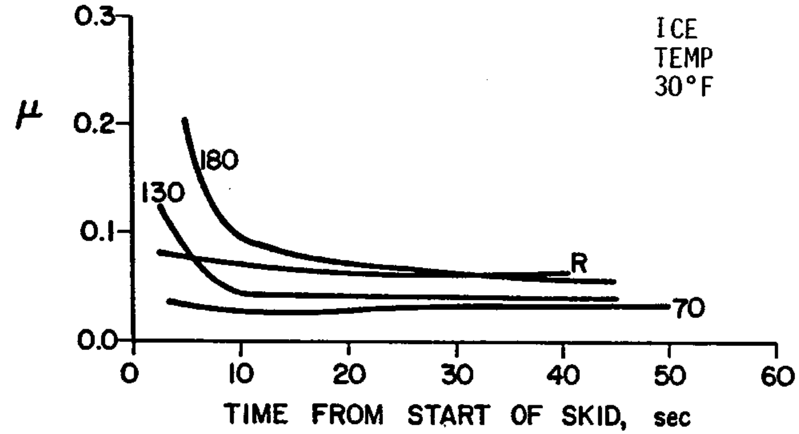
R = sand applied at the same temperature as the room ambient.

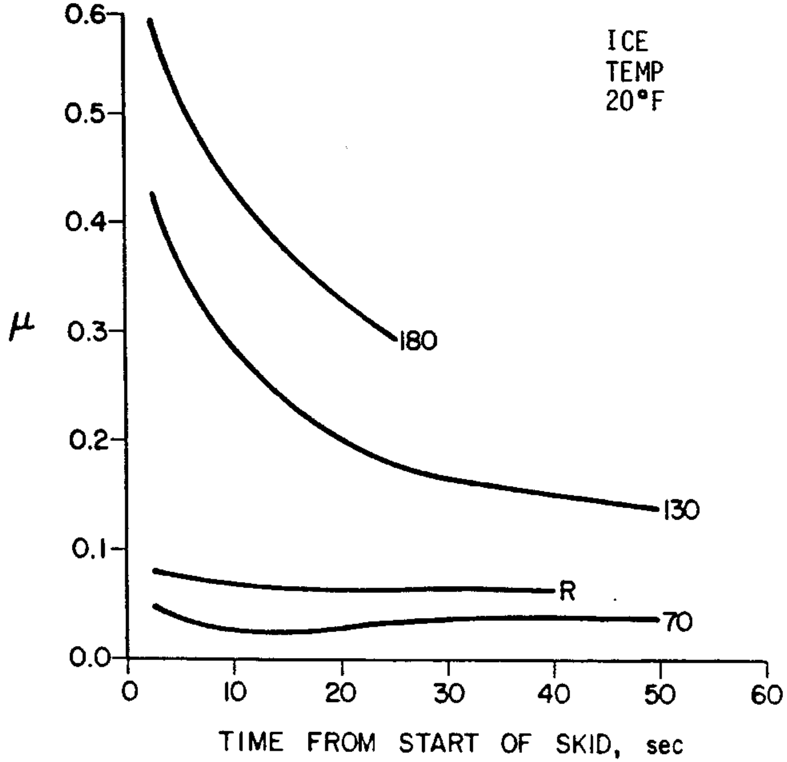
Curve labels = sand application temperature in degrees Fahrenheit.

c = clean ice

Figure A.3 Results for #4 - #16 uncrushed sand.







Legend:

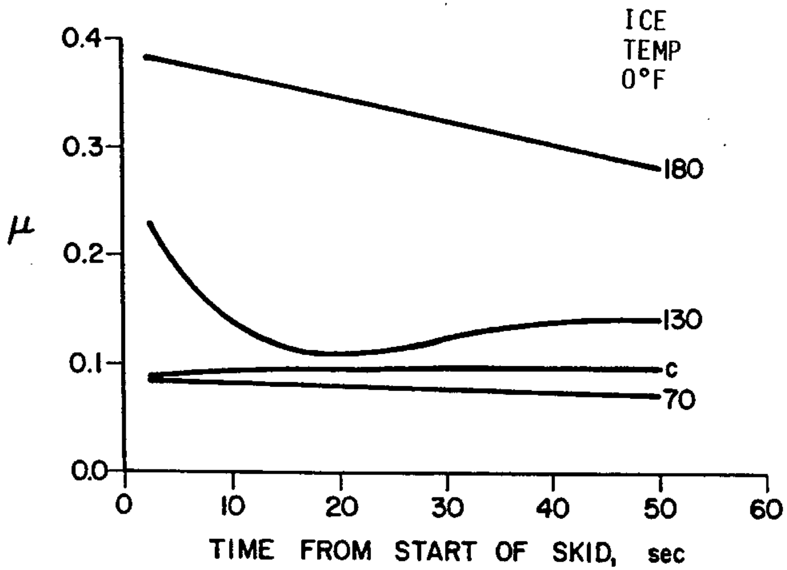
μ = coefficient of friction in locked wheel sliding.

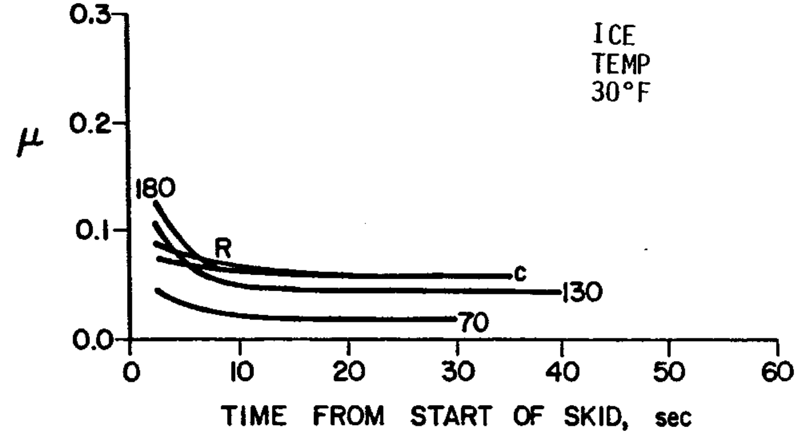
R = sand applied at the same temperature as the room ambient.

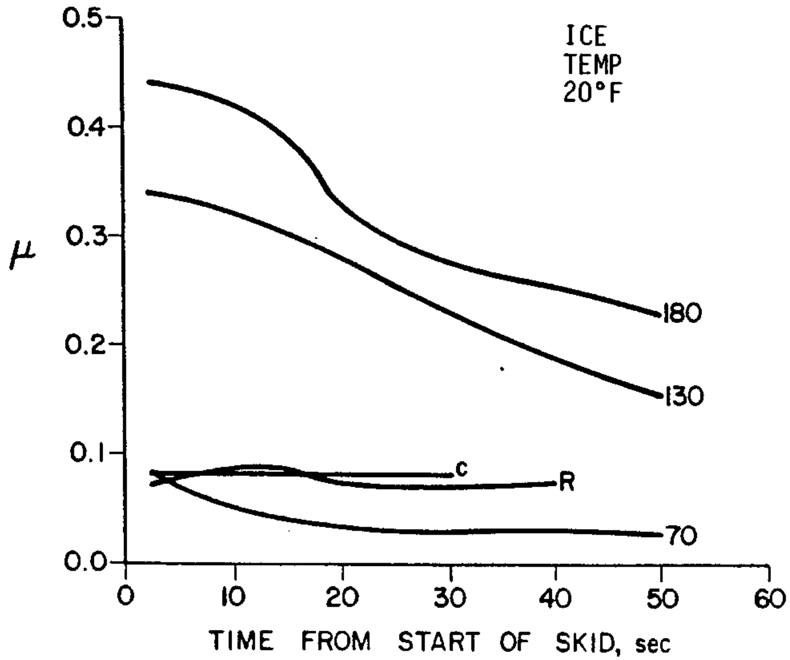
Curve labels = sand application temperature in degrees Fahrenheit.

c = clean ice

Figure A.4 Results for #4 - #16 crushed sand.







Legend:

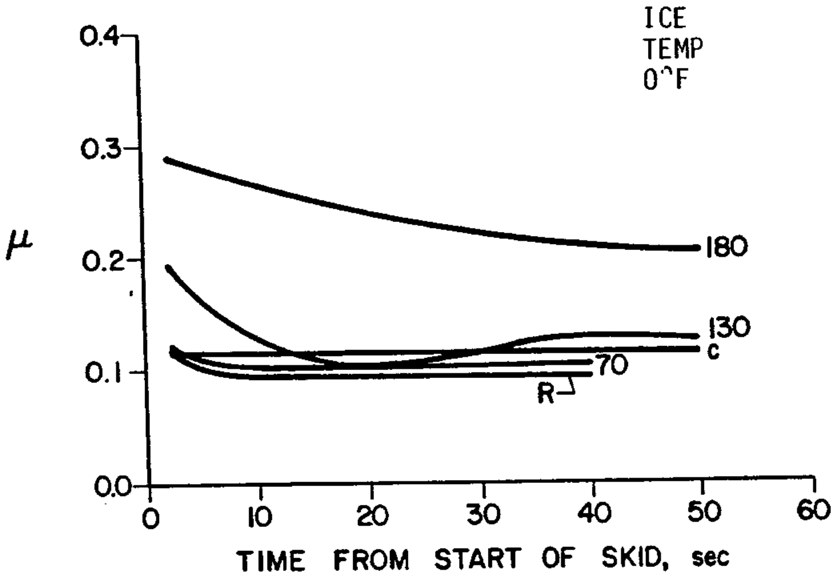
μ = coefficient of friction in locked wheel sliding.

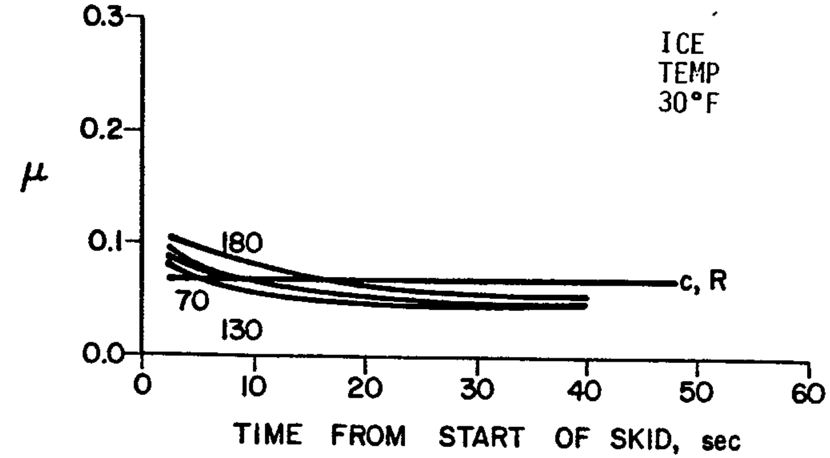
R = sand applied at the same temperature as the room ambient.

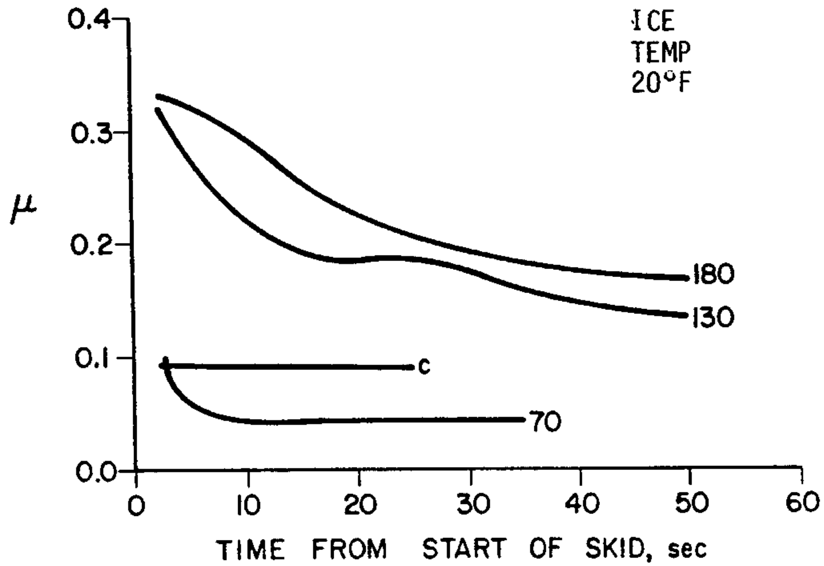
Curve labels = sand application temperature in degrees Fahrenheit.

c = clean ice

Figure A.5 Results for #4 - 3/8 in. uncrushed sand.







Legend:

μ = coefficient of friction in locked wheel sliding.

R = sand applied at the same temperature as the room ambient.

Curve labels = sand application temperature in degrees Fahrenheit.

c = clean ice

Figure A.6 Results for #4 - 3/8 in. crushed sand.

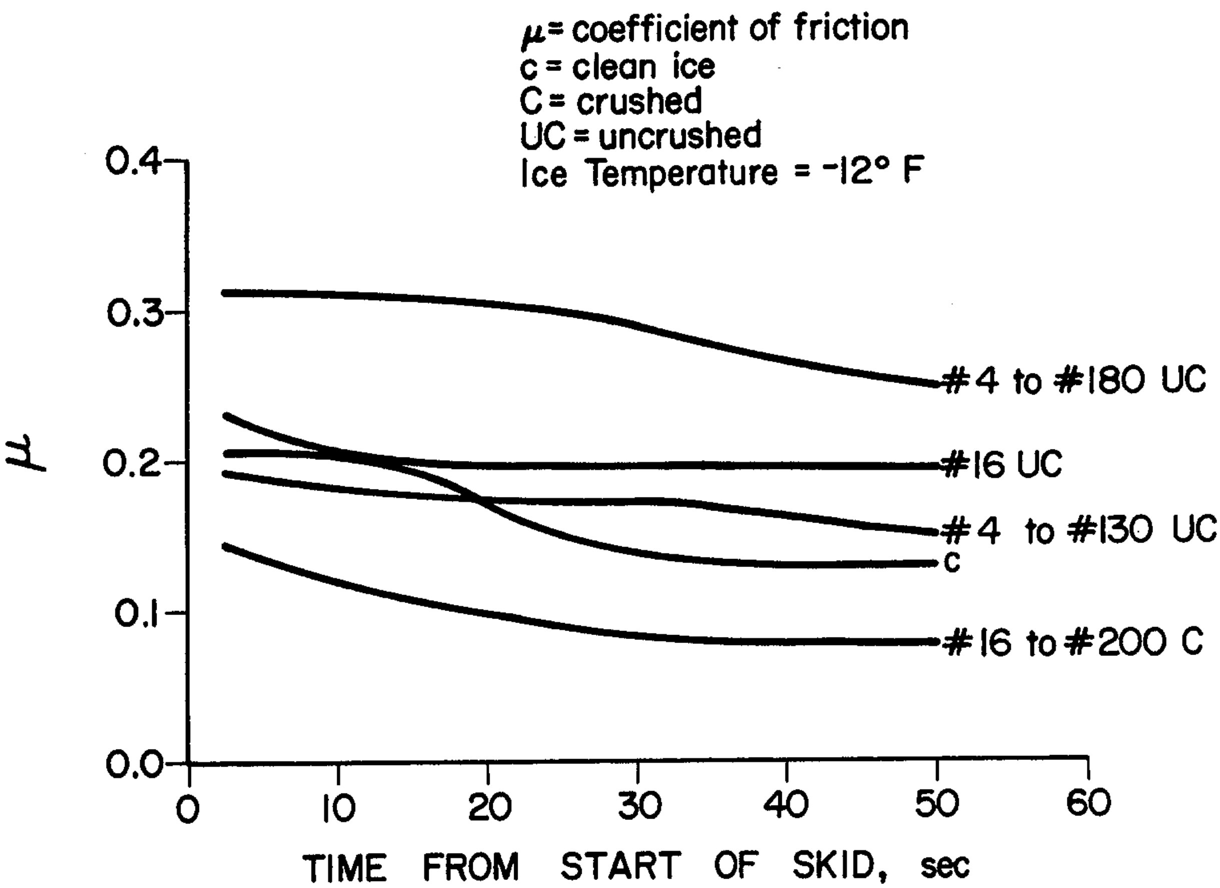


Figure A.7 Results for ice temperature of -12°F.

Table A.1 Coefficient of friction with #16 to #200 uncrushed sand.*

Room Temperature	Ice	Room	70°	130°	180°
30°F		.011	.006	.173	.196
		.011	.017	.173	.178
		.011	.016	.129	.125
		.010	.016	.075	.095
			.016	.062	.068
			.016	.046	.057
			.015	.038	.039
				.024	.030
				.023	.023
				.018	.022
				.018	.021
20°F	.067	.041	.040	.254	.388
	.065	.043	.041	.174	.334
	.064	.044	.041	.030	.255
	.064	.044	.042	.107	.185
	.063	.044	.042	.093	.139
	.063		.042	.083	.114
0°F	.107	.033	.028	.029	.158
	.104	.035	.031	.030	.147
	.103	.036	.031	.030	.138
	.102	.037	.031	.030	.134
	.103	.037	.032	.031	.132
	.103	.037	.032	.031	.129

* 10-sec gate time

Table A.2 Coefficient of friction with #16 to #200 crushed sand.

Room Temperature	Ice	Room	70°	130°	180°
30°F					
	.037	.044	.070	.115	.153
	.070	.064	.082	.193	.287
	.068	.055	.055	.133	.215
	.069	.052	.047	.076	.139
	.064	.050	.042	.062	.096
	.067	.048	.042	.045	.070
	.064	.048	.039	.036	.052
	.066	.045	.040	.029	.042
		.045	.037	.021	.032
			.038	.020	.023
				.016	.019
20°F					
	.021	.051	.060	.185	.272
	.064	.059	.064	.247	.319
	.083	.058	.059	.195	.287
	.091	.058	.057	.171	.263
	.093	.060	.056	.165	.244
	.092	.060	.054	.132	.220
	.091	.061	.054	.130	.202
	.089	.061	.054	.105	.174
	.089	.061	.053	.109	.159
	.088			.089	.137
	.087			.098	.126
0°F					
	.094		.041	.035	.110
	.099		.042	.043	.178
	.099		.042	.042	.149
	.104		.044	.043	.157
	.106		.044	.043	.139
			.045	.044	.142
			.046	.044	.149
			.047	.045	.132
			.048	.045	.141
				.045	.142
					.133

Table A.3 Coefficient of friction with #4 to #16 uncrushed sand.

Room Temperature	Ice	Room	70°	130°	180°
30°F	.038	.048	.048	.107	.182
	.070	.075	.068	.101	.218
	.068	.067	.060	.078	.132
	.064	.063	.059	.062	.093
	.062	.062	.055	.056	.081
	.061	.059	.055	.049	.065
	.061	.059	.052	.045	.060
		.056	.052	.040	.052
		.057	.050	.036	.051
			.049	.033	.045
			.048	.032	.045
20°F	.091	.078	.054	.209	.287
	.089	.081	.058	.253	.546
	.087	.077	.046	.194	.386
	.088	.076	.048	.164	.321
	.086	.074	.048	.145	.258
	.086	.074	.050	.137	.227
		.073	.050	.127	.195
		.073	.050	.124	.176
			.050	.112	.158
			.052	.116	.146
			.052	.106	.137
0°F	.106		.056	.134	.335
	.108		.077	.123	.345
	.108		.072	.116	.346
	.109		.069	.114	.336
	.109		.070	.122	.326
			.067	.124	.319
			.069	.131	.307
			.068	.133	.296
			.068	.135	.284
				.136	.274
				.134	.271

Table A.4 Coefficient of friction with #4 to #16 crushed sand.

Room Temperature	Ice	Room	70°	130°	180°
30°F					
		.040	.046	.126	.164
		.077	.032	.084	.200
		.070	.027	.044	.095
		.068	.029	.041	.096
		.066	.030	.040	.071
		.064	.031	.039	.064
		.063	.032	.041	.060
		.062	.032	.040	.058
		.063	.033	.041	.057
			.035	.040	.056
			.034		.055
20°F					
		.041	.058	.263	.305
		.075	.039	.365	.527
		.069	.028	.290	.447
		.067	.030	.220	.365
		.067	.034	.213	.334
		.066	.034	.183	.296
		.066	.037	.184	
		.065	.036	.156	
		.065	.038	.154	
			.037	.145	
			.038	.142	
0°F					
	.097	.097	.104	--	.205
	.095	.099	.104	.262	.366
	.101	.100	.104	.188	.383
	.097	.101	.104	.159	.344
	.101	.101	.103	.169	.376
	.098	.101	.103	.167	.348
	.101		.103	.184	.335
	.099		.103	.169	.345
	.101		.102	.183	.308
	.101		.102	.180	.330
	.101			.188	.300

Table A.5 Coefficient of friction with 3/8 in. to #4 uncrushed sand.

Room Temperature	Ice	Room	70°	130°	180°
30°F					
	.036	.044	.043	.069	.061
	.069	.077	.031	.074	.086
	.063	.069	.021	.050	.067
	.062	.066	.020	.047	.062
	.060	.062	.019	.044	.060
	.060	.060	.020	.045	.057
	.059	.058	.019	.043	.056
	.059	.057		.043	.056
		.056		.042	.054
		.056			.055
20°F					
	.042	.005	.005	.016	.125
	.082	.079	.068	.325	.434
	.085	.088	.057	.325	.420
	.084	.083	.033	.307	.391
	.082	.075	.038	.269	.328
	.082	.075	.034	.263	.295
		.073	.036	.221	.281
		.073	.031	.202	.271
		.072	.036	.203	.254
		.072	.027	.164	.240
		.072	.027	.162	.233
0°F					
	.091		.060	.137	.259
	.090		.084	.189	.365
	.094		.082	.135	.354
	.094		.081	.122	.369
	.096		.080	.111	.333
	.095		.077	.114	.349
	.097		.078	.129	.318
	.096		.073	.130	.307
	.097		.074	.146	.309
	.098		.074	.134	.287
	.098		.073	.145	.294

Table A.6 Coefficient of friction with 3/8 in. to #4 crushed sand.

Room Temperature	Ice	Room	70°	130°	180°
30°F	.037	.046	.051	.053	.052
	.068	.079	.067	.080	.092
	.067	.071	.054	.064	.083
	.066	.069	.052	.058	.069
	.065	.067	.047	.054	.063
	.065	.066	.048	.051	.059
	.065	.066	.045	.050	.058
		.064	.046	.048	.056
		.065	.046	.046	.055
				.047	.055
					.054
20°F	.052		.090	.181	.218
	.093		.059	.278	.319
	.092		.044	.221	.299
	.091		.044	.198	.255
	.090		.042	.186	.229
	.090		.041	.187	.206
			.045	.179	.193
			.040	.159	.184
				.147	.178
				.145	.174
				.135	.167
0°F	.114	.051	.023	.132	.147
	.117	.111	.102	.161	.282
	.115	.103	.095	.129	.227
	.117	.104	.096	.113	.237
	.115	.101	.092	.109	.257
		.105	.096	.109	.215
		.102	.092	.116	.244
		.106	.097	.124	.220
		.104	.094	.129	.203
			.099	.125	.219
			.096	.122	.175

Table A.7 Coefficient of friction with three sands at -12°F room temperature.

Ice	200-16 C @ 180°F	16-4 UC @ 180°F	4-3/8 UC @ 130°F	4-3/8 UC @ 180°F
.050	.145	.177	.129	.195
.178	.134	.228	.190	.300
.200	.118	.195	.176	.315
.196	.109	.200	.177	.300
.172	.094	.189	.173	.307
.150	.093	.198	.172	.300
.140	.084	.191	.172	.289
.130	.075	.195	.168	.267
.130	.079	.195	.160	.271
.131	.076	.188	.153	.252
.137	.078	.195	.152	.249

C = crushed
UC = uncrushed