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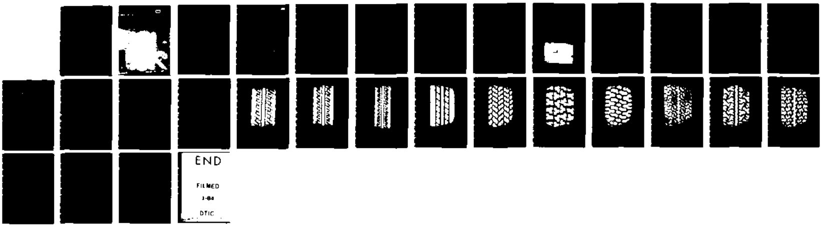

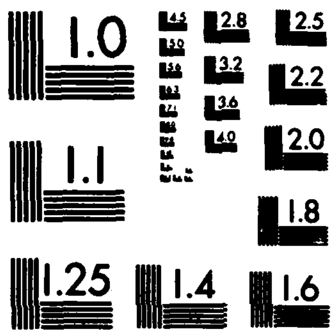

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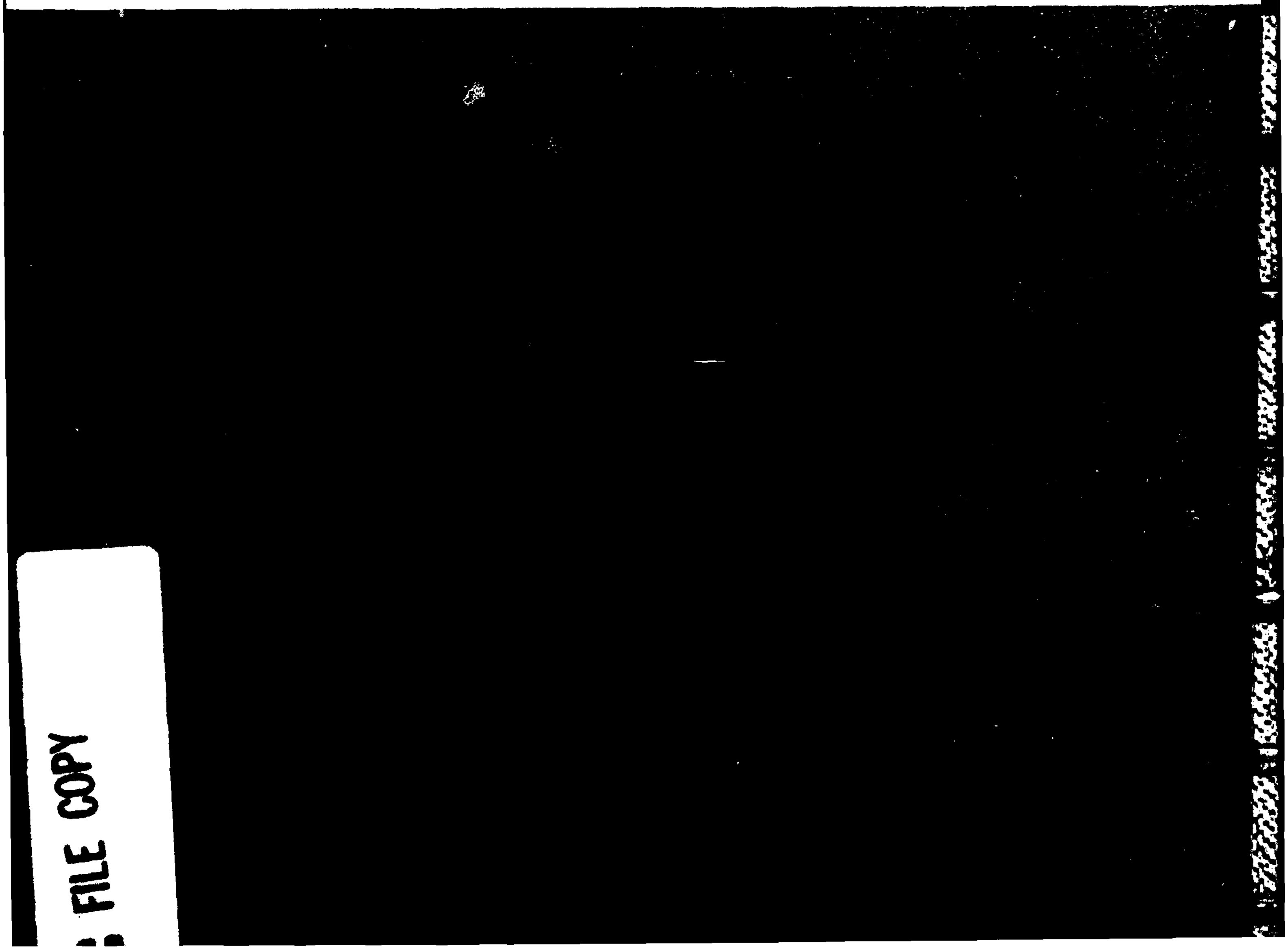
CRREL REPORT 83-27

US Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

AD-A136115

Driving traction on ice with all-season and mud-and-snow radial tires



For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380, Metric Practice Guide, *published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.*

Cover: Footprint of an all-season radial tire.

CRREL Report 83-27

November 1983

Driving traction on ice with all-season and mud-and-snow radial tires

George L. Blaisdell

Prepared for
OFFICE OF THE CHIEF OF ENGINEERS

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This study reports on a comparison of the driving traction performance on ice of a selected group of all-season radial tires with mud-and-snow radial tires. In addition to performance variation due to tread design, the effects of tire inflation pressure and ice temperature are explored.

The results indicate that no significant tractive advantage on ice can be attributed to tread design. The contribution of tire tread to traction on ice is completely overshadowed by adhesion between the ice and the compound which makes up the tire's contact surface. Based on adhesion, a slight favoring of all-season tires is found.

Increasing ice temperature generally decreased the tractive capability of a specific tire. For several tires, however, the opposite was true. Reduced inflation pressure also caused a slight decrease in the tractive performance parameters calculated.

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PREFACE

This report was prepared by George L. Blaisdell, Research Civil Engineer, of the Applied Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding was provided by Project 4A762730AT42, *Design, Construction, and Operations Technology for Cold Regions;* Technical Area A, *Combat Operations Support;* Work Unit 9, *Battlefield Mobility in Cold Regions.*

The author recognizes Dr. Ronald Liston and Gunars Abele for their technical reviews of this report. Particular thanks are also due to Melissa Hutt and William Greeley for their diligent efforts in collecting the field data and to the National Safety Council for providing the tires, test facility and field support for this work.

The contents of this report are not to be used for advertising or promotional purposes. Citation of brand names does not constitute an official endorsement or approval of such commercial products.

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DRIVING TRACTION ON ICE WITH ALL-SEASON AND MUD-AND-SNOW RADIAL TIRES

George L. Blaisdell

INTRODUCTION

One of the more recent developments in the tire industry has been the advent of the all-season radial tire. For many motorists, use of all-season radial tires has become a popular alternative to changing between two sets of seasonal tires. Many varieties of these tires currently exist; some appear similar, but many do not. While the tires appear to perform well under the majority of conditions during spring, summer and fall (compared to other tire types), their relative performance in winter environments has not been determined. This study was designed to determine the relative driving-traction performance of the all-season radial tire on ice.

Variability in tractive performance on cold regions materials within the all-season group of tires is related to differences in tread design, tread compound and other design features. Isolation of the effect of various design features on tractive performance will greatly enhance our understanding of traction on cold regions surface materials and allow improvements in design for and prediction of tractive capability in cold regions.

It is also of considerable interest to compare the overall tractive performance of the all-season tire design to that of the so-called mud-and-snow design. Does a compromise in performance on snow, ice and mud occur with the all-season design to gain the convenience of not having to change tires during the year? If performance is, in fact, reduced, it is of interest to determine the degree of reduced mobility and to assess when this trade-off is reasonable.

To do this, tractive performance for each tire type was determined using available performance evaluation techniques. Tire performance variation with tread type, ice temperature and tire inflation pressure was studied.

DATA COLLECTION

Three designs of each tire class were tested, along with a surface-properties measurement tire and an original-equipment highway tire. Utilizing an instrumented vehicle, traction and motion resistance tests were performed at various ice temperatures and at several tire inflation pressures.

Test tires

This study used three types of radial mud-and-snow tires and three radial all-season tires (plus a surface-properties measurement tire which is all-season in design). An original-equipment (OE) highway radial was also included in the tests as a baseline reference tire. The OE tire was approximately 1-2 years old and had about 25,000 miles of road usage. A description of the tires is contained in Table 1. The tires were all footprinted (Appendix A) at their test inflation pressure (165 kPa), and the contact area and void ratio (void area in the contact patch divided by the total contact area) were determined. Tire D was also footprinted (and tested) at two other tire pressures, 110 and 55 kPa. Tire D is used as a surface-properties measurement tire because of its "neutral" design; its tread represents a compromise in performance for all surface conditions.

Table 1. Description of test tires.

Tire code	Type	Size	Plies: Tread	Plies: Sidewall
D	all season	P225/75R15	2 polyester cords 2 steel cords	2 polyester cords
R	highway	P195/75R14	2 polyester cords 2 fiberglass cords	2 polyester cords
S	mud and snow	P195/75R14	2 polyester cords 2 fiberglass cords	2 polyester cords
T	mud and snow	P195/75R14	2 polyester cords 2 steel belts	2 polyester cords
U	mud and snow	P195/75R14	2 polyester cords 2 aramid cords	2 polyester cords
V	all season	P195/75R14	2 polyester cords 2 steel belts	2 polyester cords
W	all season	P195/75R14	2 polyester cords 2 steel belts	2 polyester cords
X	all season	P195/75R14	2 polyester cords 2 steel cords	2 polyester cords

Measurement vehicle

Ice surface and tire performance parameters were measured with the CRREL Instrumented Vehicle shown in Figure 1. This vehicle, described in detail in Blaisdell (1983), is equipped with moment-compensated triaxial load cells, which are installed in the two front-wheel assemblies. The load cells measure three mutually perpendicular forces located at the tire/ice contact patch and are denoted by vertical, longitudinal and side directions (Fig. 2). Wheel speed and distance traveled are measured for each front wheel and a trailing fifth wheel.

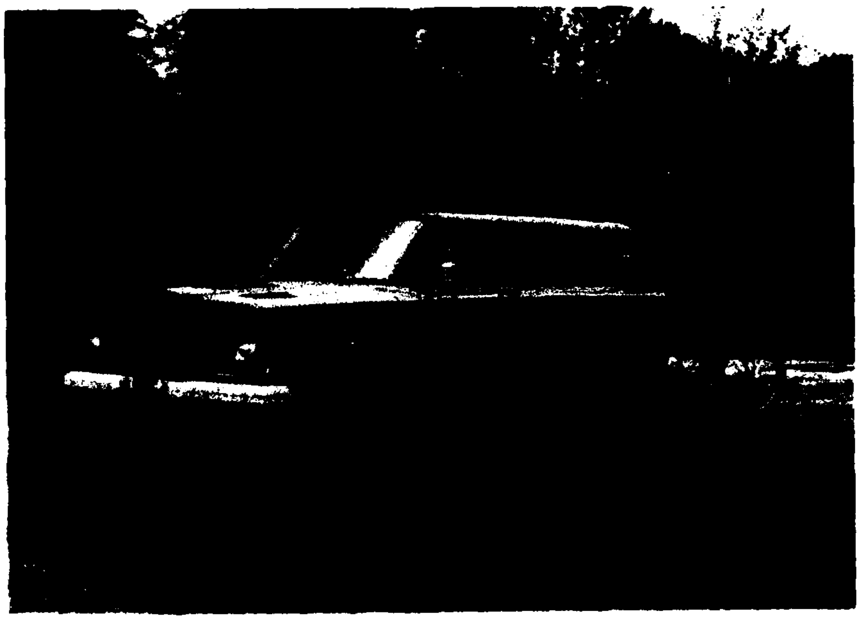


Figure 1. CRREL Instrumented Vehicle.

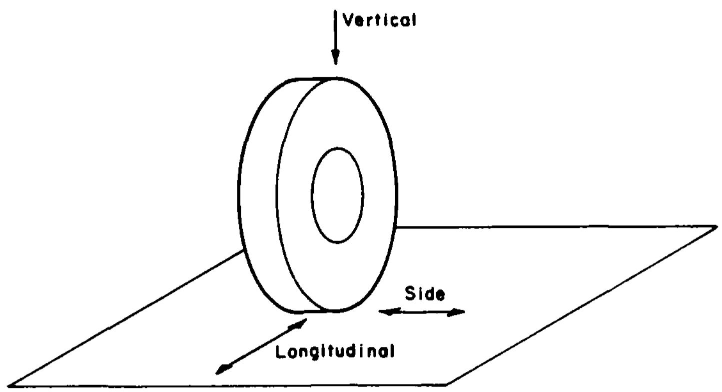


Figure 2. Axis conventions for triaxial load cells.

To enable driving and free-wheeling test modes, the vehicle is equipped with lock-out hubs on each of the four axles. This permits front-, rear-, or four-wheel drive. Additionally, individual brake valves provide for front-, rear-, or four-wheel braking.

An on-board, minicomputer-based data acquisition system is used to control data collection and to manipulate, analyze and store the incoming information. Sampling rates up to 60 samples per second (per channel) are maintained by the system during test performance.

Test area

A level, 90- x 300-m area of the Stevens Point, Wisconsin, airport was used as a test area. The area was initially flooded and subsequently maintained daily using a water truck with an attached sprinkler bar. An ice sheet approximately 15 cm thick resulted. A tractor-mounted broom was used to keep the ice surface clear of loose and blowing snow.

Ice temperature was measured with a thermocouple frozen into the upper centimeter of the ice sheet. A digital thermocouple reader was used to provide a continuous readout of ice temperatures. Air temperature (0.25 m above the ice surface) was also measured and recorded in a similar manner.

Test procedure

Resistance and traction tests were performed for each of the tires at 165 kPa, and at 110 and 55 kPa for tire D. Motion resistance values were generated by operating the instrumented vehicle with the rear tires driving and the front tires free-wheeling. This resulted in a measurement of the resistance to forward motion felt by the front tires. The magnitude of the resistance force represents energy losses caused by tire flexing.

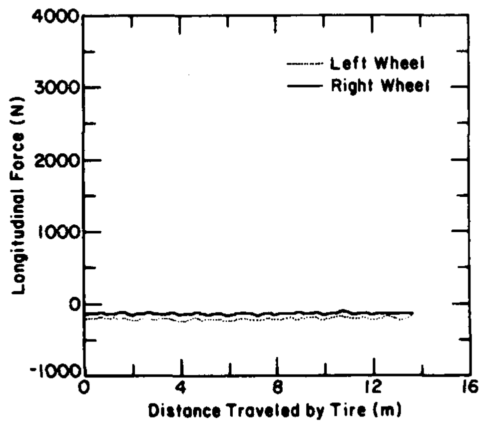


Figure 3. Typical data from a motion resistance test on ice.

Resistance tests were performed at a vehicle speed of 8 km/hr and over a straight 10-m section of the ice. A sampling rate of 10 samples per second per channel was maintained during resistance measurement. The resistance force values were computed as the average longitudinal force reading during the test run. Typical output for a resistance test is shown in Figure 3.

Traction tests were performed with the instrumented vehicle in a front-wheel-drive, rear-wheel-braking configuration. Vehicle speed was held constant at 8±1 km/hr (using the rear-wheel brakes) while the front tires were accelerated through a range of slip values between 0 and 16 km/hr. (Slip is defined here as differential interface velocity, or the difference between vehicle and tire speeds.)

A sampling rate of 10 samples per second per channel was also used for the traction tests. The data generated during these tests were analyzed using several methods. (Details of the analyses will be covered in the following section.) Individual traction test runs (spin-ups) were repeated seven times in succession for each tire type. At least three spin-ups were performed in each direction of the test course. Tire types were tested in random order. The test period was chosen so that an ice and air temperature fluctuation of ±2°C was the maximum possible between any of the tires.

DATA ANALYSIS

Review of analysis techniques

A number of methods for assigning a winter-surface tractive performance value to a tire exist in the literature. The most recent methods all use results obtained with an instrumented vehicle. Our attention will be limited to these schemes. Typical output from a traction test, plotted in several ways, is shown in Figure 4.

Domeck (1982) identified three traction performance methods which are based on the tire's measured coefficient (the coefficient of friction, or the longitudinal driving force divided by the vertical force) during a traction test. The Smithers Scientific Average (SSA) is defined as the area under the coefficient vs time curve (between the limits of 0.8 and 24 km/hr differential interface velocity) divided by the elapsed time between the integration limits. A more recent version of this nondimensional mean coefficient begins integration at 1.6 km/hr* to reduce the effect of the instability of data developed at low values of slip.

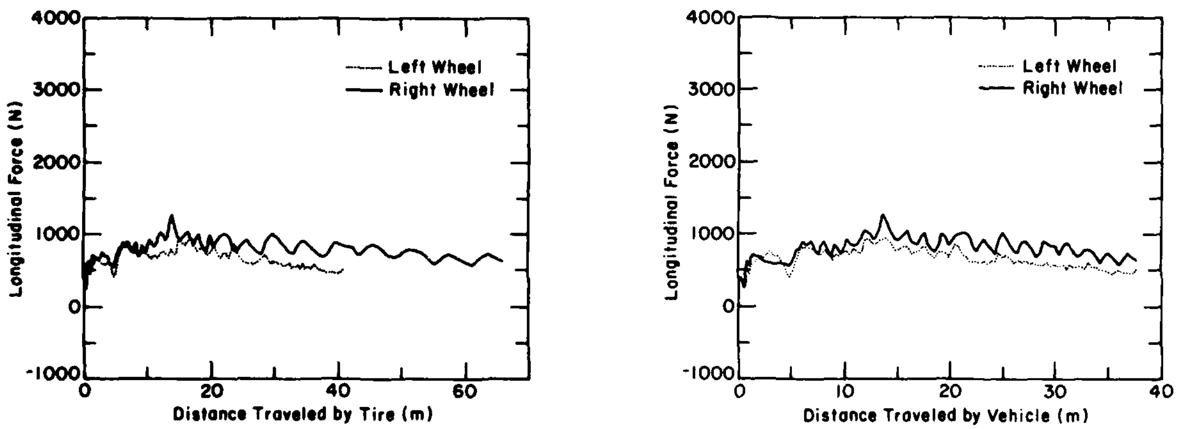
Similar in nature is the General Motors Average (GMA) method of data analysis. The GMA is calculated as the area under the coefficient vs time curve beginning at the time when 3.2-km/hr differential interface velocity is reached and continuing for 1.5 s, regardless of the final rate of slip. The area is then divided by the time elapsed between the integration limits (1.5 s) to yield a nondimensional mean coefficient. The GMA analysis method assumes that the traction test is performed using an automatic throttle-control device so that the final tire speeds are somewhat similar from test to test.

The third method of analysis outlined generates the μ-Area Average (MUA). The coefficient vs differential interface velocity curve is integrated between the limits of 0.8 and 24 km/hr. The area is then divided by the difference in differential interface velocity over the integration (23.2 km/hr) to obtain the MUA average coefficient. Like the SSA the MUA method has recently been redefined to begin integration at a 1.6-km/hr rate of slip.

Three additional tire traction parameters are introduced in Blaisdell and Harrison (1982). Like the previous approaches these evaluation methods involve an integration of the longitudinal force (or coefficient) plot and unitization by dividing by the difference between the limits of integration. However, rather than having a fixed upper and lower limit of integration, these methods all begin averaging at the beginning of the test (time, distance and differential interface velocity equal to zero) and continue until the test is completed at a differential interface velocity of approximately 16 km/hr.

The first of these parameters, the unit total energy dissipation ω_T, is determined by integration of the entire plot of the theoretical distance traveled by

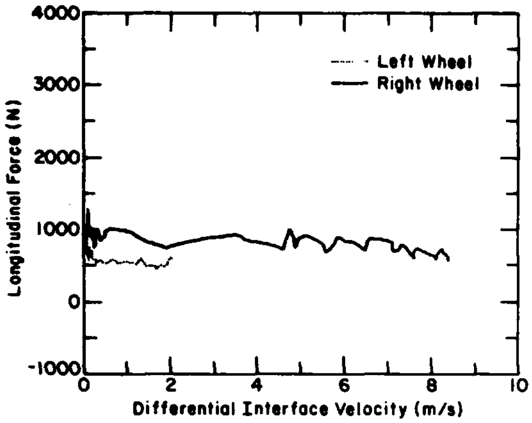
*D.C. Domeck, Smithers Scientific Services, Inc., personal communication, 1982.



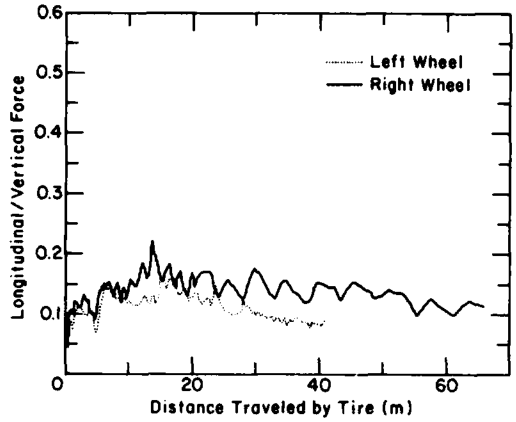
a. Longitudinal force vs distance traveled by tire.

b. Longitudinal force vs distance traveled by vehicle.

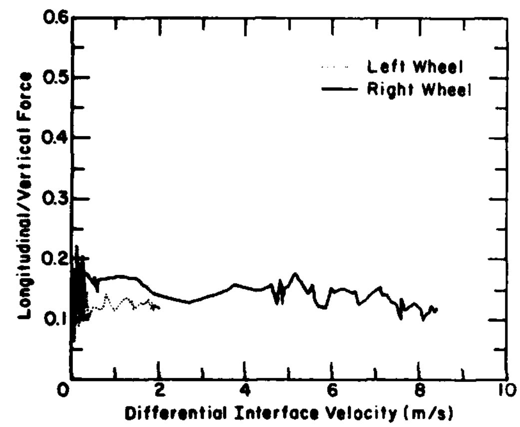
Figure 4. Typical data from a traction test on ice.



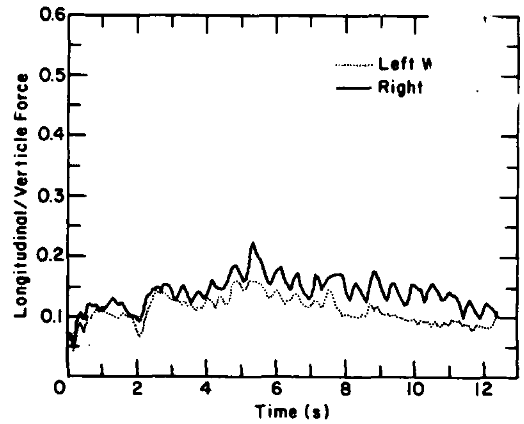
c. Longitudinal force vs differential interface velocity.



d. Longitudinal/vertical force vs distance traveled by tire.



e. Longitudinal/vertical force vs differential interface velocity.



f. Longitudinal/vertical force vs time.

Figure 4 (cont'd).

the spinning tire vs the tractive force. Dividing this area by the maximum theoretical distance traveled by the tire then yields ω_T. In a similar manner, ω_v, the unit energy dissipation factor, is determined from the plot of tractive force vs vehicle distance traveled. Again, the energy found by integration is divided by the maximum distance traveled, this time by the actual distance the vehicle moved. The third parameter, the unit slip-shear energy dissipation factor ω_D, is found by integrating the plot of tractive force vs differential interface velocity and then dividing by the maximum distance traveled by the vehicle.

Harrison (in press) proposed two additional performance parameters, again based on energy calculations. The first, termed unit slip energy ω_s, divides the difference between the maximum theoretical (tire distance traveled) and actual vehicle distance traveled. He also defined an energy efficiency parameter ϵ_t as the area under the coefficient vs wheel distance travel plot multiplied by the ratio of vehicle to wheel distances and then divided by the tire width. Harrison also mentions the usefulness of the parameter longitudinal force divided by vertical force (previously referred to as the coefficient of friction).

Analysis and results

The average force resisting forward motion was calculated for each tire (Table 2). For most tires an increase in resistance is shown with decreasing temperature; lower temperatures generally make rubber compounds less flexible. It is also apparent that decreased inflation pressure results in larger increases in resistance at lower pressures. This is the result of the large sidewall deflections associated with lower inflation pressures.

Table 2. Resistance data for test tires (all tires at 165 kPa except as noted).

Tire code	*Rolling resistance (N)* -5°C	-12°C
D	107	130
D (110 kPa)	130	125
D (55 kPa)	*	370
R	*	280
S	190	250
T	195	180
U	250	195
V	*	330
W	190	200
X	130	260

*Data missing.

Table 3. Ice traction performance values at -5° and -12°C using the MUA and SSA evaluation methods.

	-5°C		*-12°C*	
Tire code	*MUA*	*SSA*	*MUA*	*SSA*
D	0.100	0.095	0.144	0.129
R	*	*	0.089	0.086
S	0.097	0.093	0.087	0.086
T	0.112	0.115	0.144	0.149
U	0.100	0.100	0.121	0.120
V	0.124	0.125	0.130	0.120
W	0.110	0.114	0.123	0.138
X	0.102	0.101	0.086	0.090

*Data missing.

Because of the number of techniques available for evaluating tractive performance, it was necessary to determine the method best suited for the ice tests performed. In the literature addressing rubber/ice interfaces, ice temperature is consistently identified as a property critical to adhesion between the two substances (Roberts 1981). The relationship between the friction coefficient and temperature for slipping tires on ice has been established (Figure 5). Between the temperature limits of -5° and -30°C, an approximately linear relationship holds, with the coefficient of friction increasing with decreasing temperature.

Scatter diagrams were generated for ice temperature vs each of the identified performance parameters (Appendix B). (The GMA method was not used since it is very dependent on a throttle applicator and the instrumented vehicle used for these studies was not equipped with one.) Correlation coefficients, a measure of the strength of linear association (Miller and Freund 1977), were calculated for each set of data and are shown on the plots. The best correlations, 0.79 and 0.75, were found using the MUA and SSA methods, respectively.

Since these two methods appeared approximately equally well suited for analyzing the ice traction data, both methods were used. It was also of interest to see if the two methods would yield the same rank order for tractive performance of the tires. Test results are presented in Table 3 and Figure 6. Tire D was also tested at several tire pressures to determine the effect of inflation pressure on tractive performance (Fig. 7).

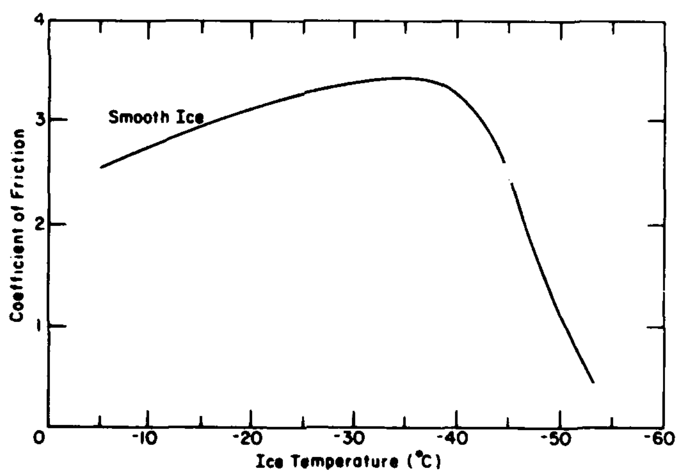


Figure 5. Friction coefficient variation with temperature. (After Schallamach and Grosch 1981.)

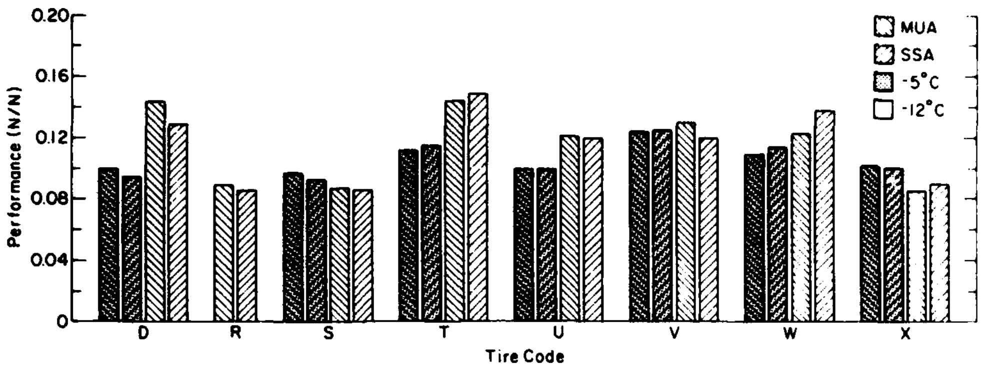


Figure 6. Tire performance at -5° and -12°C evaluated using the MUA and SSA methods.

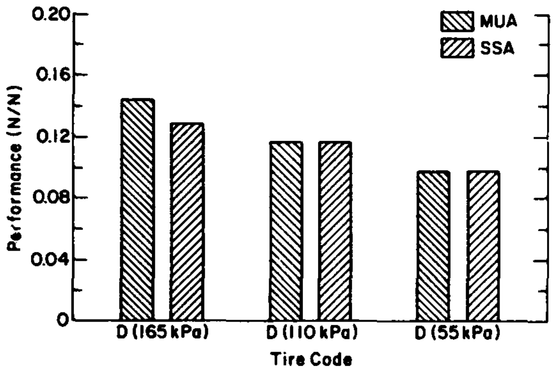


Figure 7. Performance of tire D at various pressures evaluated using the MUA and SSA methods.

DISCUSSION

The fact that the MUA and SSA methods provided the most nearly linear relationship of ice temperature vs performance parameter should not be surprising. Both of these methods determine an average interfacial coefficient of friction, which, with an unaided tire (no studs, chains, etc.) on an unyielding surface, would fully describe the mechanics of the tire-ice interaction. The majority of the other evaluation methods look at various calculated energies and distances and might be expected to show erratic results in the region of low forces (and thus low energy) encountered on ice. Additionally these methods were designed to be sensitive to more tire characteristics than just the tread compound. It follows that the evaluation methods designed to consider tire structure, tread angle, etc. provide less reliable results on ice.

Tire performance ranking (Table 4) using the MUA and SSA methods shows agreement at -5°C. At -12°C the tire ranking is identical for both methods except for the two-step increase in rank by tires W and X. The rank orders at the two temperatures show overall agreement. For the MUA method, differences in ranking between the two temperatures are no more than reversals of some adjacent pairs, except for tires D and X, which showed a significant increase and decrease in rank, respectively, with decreasing temperature. This may be a real feature of operation on different temperatures of ice but may also be caused by the combined effects of experimental error and the compacted range of performance parameters at -5°C.

Four methods of combining the tire rankings at both temperatures are used to give each tire (except tire R, the OE tire) an overall rating. The first method utilizes only the results of the MUA evaluation technique since it offers the best correlation with established ice adhesion-temperature relationships. The sums of the MUA values at each temperature (Table 3) for each tire type give the combined rankings shown in Table 5. The second method is similar to the first, except that both the MUA and SSA values are summed at both temperatures (Table 5). In the third and fourth methods, each tire is given a numerical ranking between 7 (best performance) and 1; the combined rankings of the two temperatures are again found by summation (Table 5). Sums for both the MUA technique by itself and the combined MUA and SSA techniques are generated. Tires which had the same tractive performance level were given the same rank.

With the exception of tires D and W, the four combined ranking methods correlate exactly. Tires D and W exchange rank throughout the various ranking methods. The combined ranking for all of the methods used indicates that the superior performers were a mud-and-snow tire (T) and an all-season tire (V). The MUA-only methods show that

Table 4. Ice traction tire performance rankings at -5° and -12°C.

	-5°C		-12°C	
	MUA	*SSA*	*MUA*	*SSA*
highest	V	V	T	T
	T	T	D	W
	W	W	V	D
	X	X	W	V
	U	U	U	U
	D	D	R	X
	S	S	S	R
lowest			X	S

Table 5. Ice traction tire performance.

Tire code	*Sum*
MUA combined method	
T	0.256
V	0.254
D	0.244
W	0.233
U	0.221
X	0.188
S	0.184
MUA-SSA combined method	
T	0.520
V	0.499
W	0.485
D	0.468
U	0.441
X	0.379
S	0.363
Numerical position method, MUA	
T	13
V	12
D	10
W	9
U	6
X	5
S	3
Numerical position method, MUA-SSA	
T	26
V	23
W	20
D	17
U	13
X	11
S	4

the two tires performed nearly equally well. A second or "runner-up" category of tires includes tires D and W, both all-season in design. The remaining tires, U, X, and S, show increasingly poorer performance.

From the combined rankings, it is apparent that neither the all-season nor the mud-and-snow tire design has superior traction on ice. This result seems reasonable since, intuitively, the effect of tire tread on ice traction is negligible. It may, however, be significant that three of the top four tires at both temperatures (and for the combined rankings) are all-season in design. This result is probably because the all-season tires are constructed from a different type of compound, which adheres more effectively to ice.

The tractive performance of the OE tire (tire R) proved to be poor (Table 3); however, its rank was not significantly different from tires X and S. The poor performance of tire R is probably due partially to deterioration of the tire's tread compound from age and use. Use of a similarly designed, new highway radial tire would not necessarily have ranked the OE tire the same.

Another interesting feature of these tests is the notable (up to 30%) decrease in tractive performance with increasing temperature (from -12° to -5°C) for most of the tires. This agrees with any predictions made from Figure 5; however, some tires (S and X with MUA and S, X and V with SSA) show a decrease in tractive capability for decreasing temperature. These tires undoubtedly contain compounds which show decreasing coefficients with decreasing temperature (Schallanmach and Grosch 1981).

The effect of tire inflation pressure on ice traction can be seen from Figure 7. Both the MUA and SSA methods show a decrease in tractive performance with decreasing tire pressure. This result is in contrast with results on snow, where significant increases in traction result from reduced inflation pressure. In snow, increased contact area allows more tread area to mobilize the shear strength of the snow; on ice, tire tread has little effect. The reduced tractive performance indicated by the MUA and the SSA methods may be caused by less uniformity in the contact area pressure distribution with decreased inflation pressure.

Another measure of the effectiveness of tread on a tire driving on ice can be found from the tire D data at several pressures. Values of tractive force, contact area and vertical load can be input for several tire pressures into the relationship (Harrison 1981)

$$H = Ac_a + W \tan \delta$$

where H = maximum tractive force
A = contact area of tire
c_a = interfacial adhesion
W = vertical load on the contact area
δ = interfacial angle of friction.

The interfacial properties of adhesion and angle of friction can be calculated by solving simultaneous equations. This approach assumes the interface to be Mohr-Coulomb in nature, with c_a and δ indicating the contribution of the adhesion and friction components, respectively. For the -12°C ice, the three equations become

$$1005 = 0.048\, c_a + 6116 \tan\delta$$

$$961 = 0.035\, c_a + 6005 \tan\delta$$

$$921 = 0.028\, c_a + 6094 \tan\delta\ .$$

Solving for c_a and δ yields values of 4.46 kPa for adhesion and 7.5° for the angle of friction. The tangent of 7.5° is only 0.13, indicating that the contribution of interfacial shearing (developed as a result of tire tread action) is quite small. This result substantiates the previous conclusion that tire tread plays a very minor role in traction on ice. Comparing these values with typical c_a and δ values for snow indicates their relative contributions to the total tractive output. Values of adhesion for snow are shown to range between 20° and 30° (Harrison 1975). Clearly the ice data show a much higher dependence on adhesion for generation of traction. Correspondingly the contribution of the angle of interface friction (tread effect) on ice is very low when compared to operation on snow.

CONCLUSIONS

With the advent of instrumented vehicles and their expanded use in mobility research, an increasing number of tire-traction performance evaluation techniques using instrumented vehicle output have been developed. Applying these evaluation methods to a common set of data shows a varied degree of agreement between them. For a large set of ice traction data generated with the CRREL instrumented vehicle, the μ-Area Average (MUA) and Smithers Scientific Average (SSA) methods showed the best correlation with documented ice temperature-elastomeric compound adhesion data.

Four combined ranking methods were used to generate an overall rating for each tire, combining its performance at two distinct temperatures. Except for two tires, the combined rankings were exactly the same for all four methods. This suggests that the combined ranking methods are equally well suited for determining overall (multi-temperature) tire performance.

The MUA and SSA performance evaluation methods did not show a significant distinction between all-season and mud-and-snow tires based on their tread design. The small or nonexistent contribution of tread to traction on ice is illustrated by the tire-ice interfacial properties of adhesion and angle of friction. The contribution of tire tread to traction on ice is significantly less than on snow. Adhesion on ice by comparison with snow, however, can represent an overwhelming increase in contribution to tractive effort.

The adhesion data suggest that the all-season tires perform slightly better. Although the highest performance was from a mud-and-snow tire, the next three highest performers were all-season tires. This result is probably due to a more ice-adhesive compound used in the construction of the all-season tires.

The effect of ice temperature on driving traction, in general, agreed with published results. Most of the tires used in this study showed improved levels of tractive performance at lower temperatures. Several tires, however, showed the opposite relationship, most likely due to the particular type of compound used in the manufacture of the tire's contact surface. The difference in tire performance between individual tire types was less pronounced at higher temperatures.

Reduced inflation pressures decreased the tractive performance of a tire on ice, evaluated with the MUA and SSA methods. The peak force developed, however, showed a very slight increase with decreasing inflation pressure. A tire operating on deformable snow, by comparison, shows marked increases in driving traction with decreased pressure. This result illustrates the relative ineffectiveness of the tread on ice.

LITERATURE CITED

Blaisdell, G.L. (1983) The CRREL Instrumented Vehicle: Hardware and software. CRREL Special Report 83-3.

Blaisdell, G.L. and W.L. Harrison (1982) Measurement of snow surfaces and tire performance evaluation. Society of Automative Engineers Technical Paper 820346, 7 pp.

Domeck, D.C. (1982) Winter tire testing as seen by the independent tester. Society of Automotive Engineers Technical Paper 820344, 12 pp.

Harrison, W.L. (1975) Vehicle performance over snow, math-model validation study. CRREL Technical Report 268, 84 pp.
Harrison, W.L. (1981) Prediction methods. In *Proceedings of the International Society for Terrain-Vehicle Systems, Workshop on Snow Traction Mechanics.* CRREL Special Report 81-16, pp. 39–46.
Harrison, W.L. (in press) Tire performance evaluation for shallow snow and ice. CRREL Report.
Miller, I. and J.E. Freund (1977) *Probability and Statistics for Engineers.* 2nd edition. Englewood Cliffs, New Jersey: Prentice-Hall, Inc.
Roberts, A.D. (1981) Rubber-ice adhesion and friction. *Journal of Adhesion,* 13: 77–86.
Schallanmach, A. and K. Grosch (1981) Tire traction and wear. In *Mechanics of Pneumatic Tires* (S.K. Clark, Ed.). U.S. Department of Transportation, HS 805 952, pp. 365–474.

APPENDIX A. TIRE FOOTPRINTS.

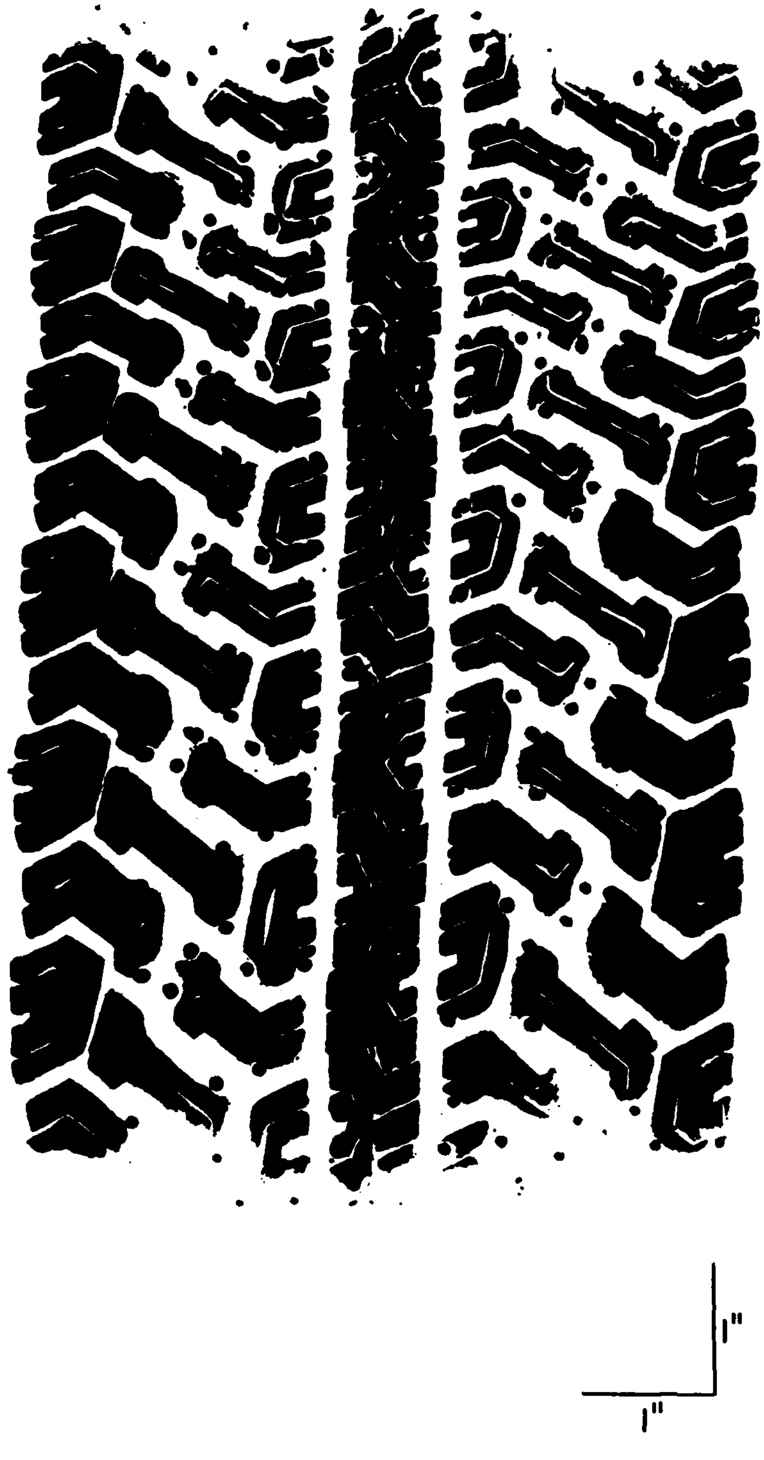


Figure A1. Footprint of tire D at 165 kPa (contact area: 307 cm^2; void ratio: 0.45).

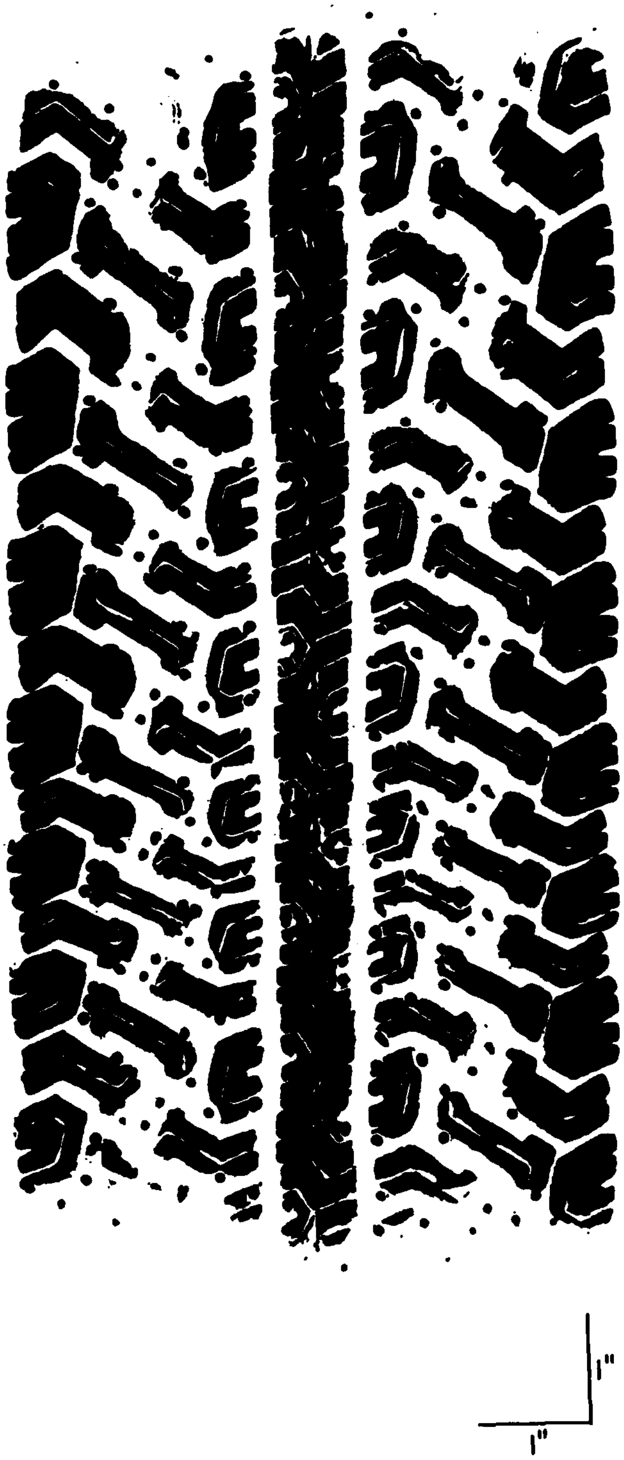


Figure A2. Footprint of tire D at 110 kPa (contact area: 380 cm^2; void ratio: 0.45).

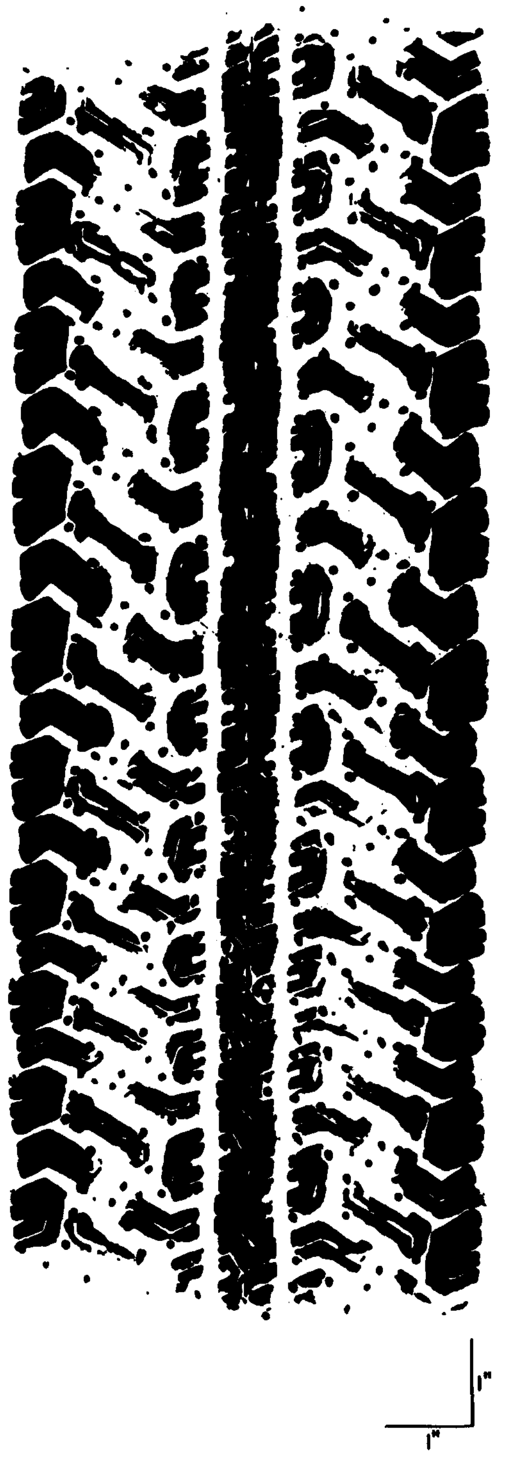


Figure A3. Footprint of tire D at 55 kPa (contact area: 516 cm^2; void ratio: 0.45).

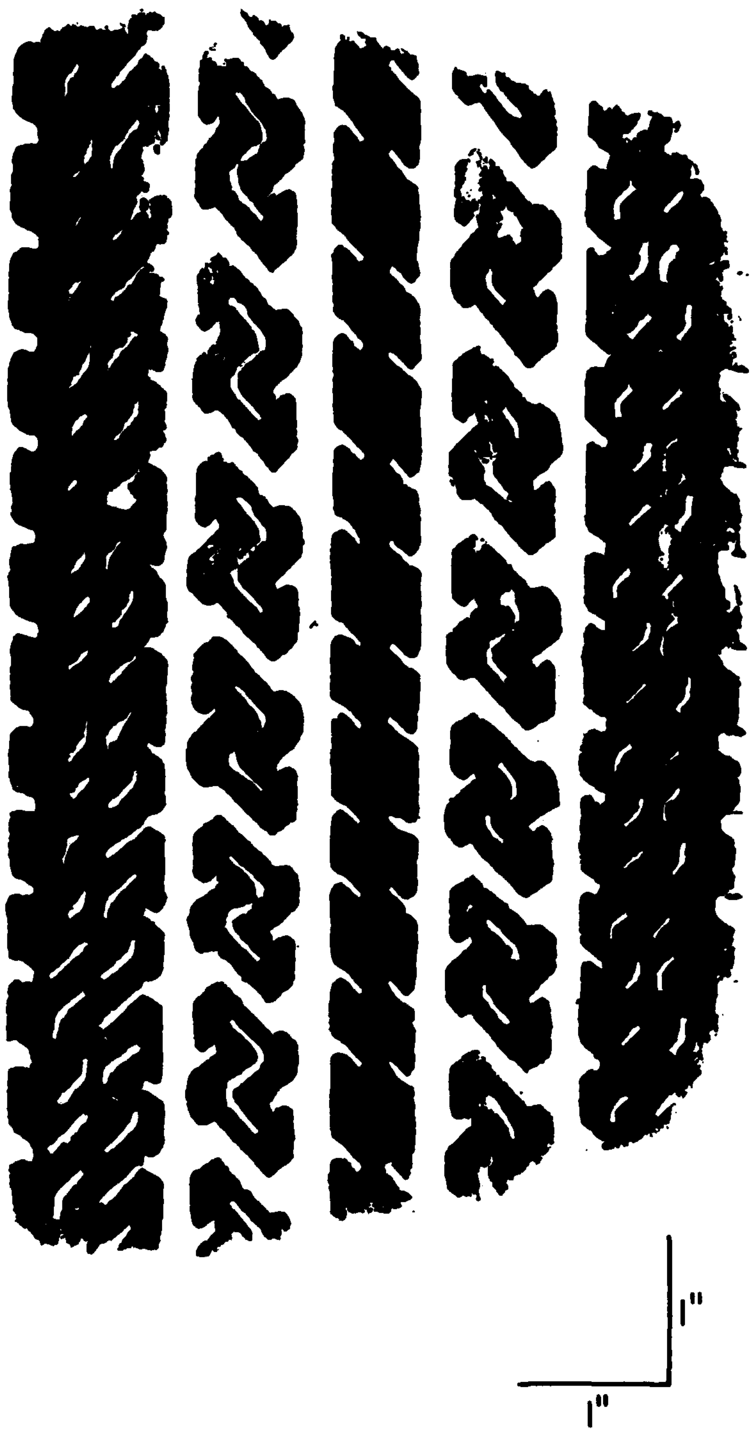


Figure A4. Footprint of tire R at 165 kPa (contact area: 260 cm^2; void ratio: 0.30).

Figure A5. Footprint of tire S at 165 kPa (contact area: 286 cm^2; void ratio: 0.47).

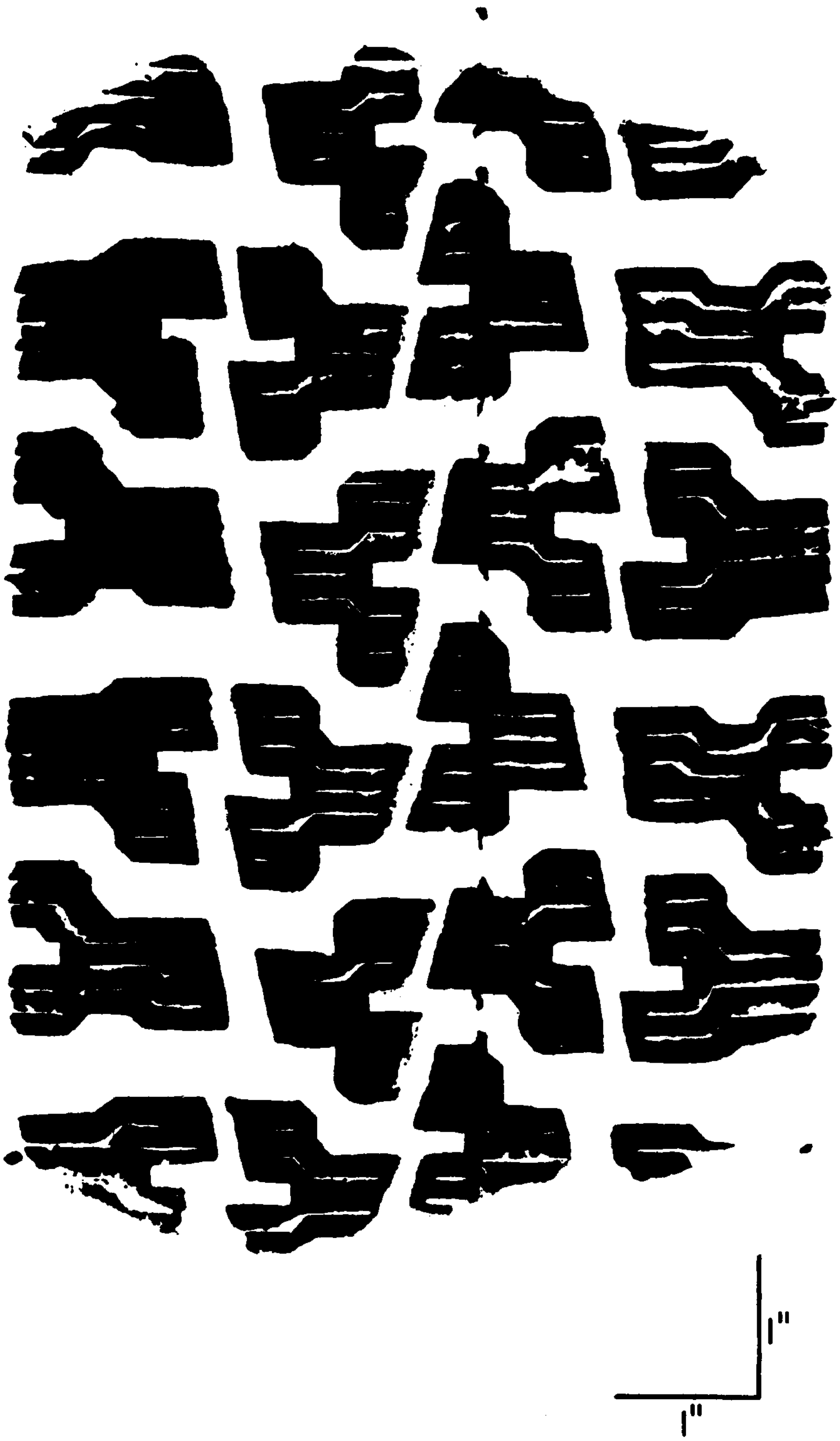


Figure A6. Footprint of tire T at 165 kPa (contact area: 305 cm^2; void ratio: 0.50).

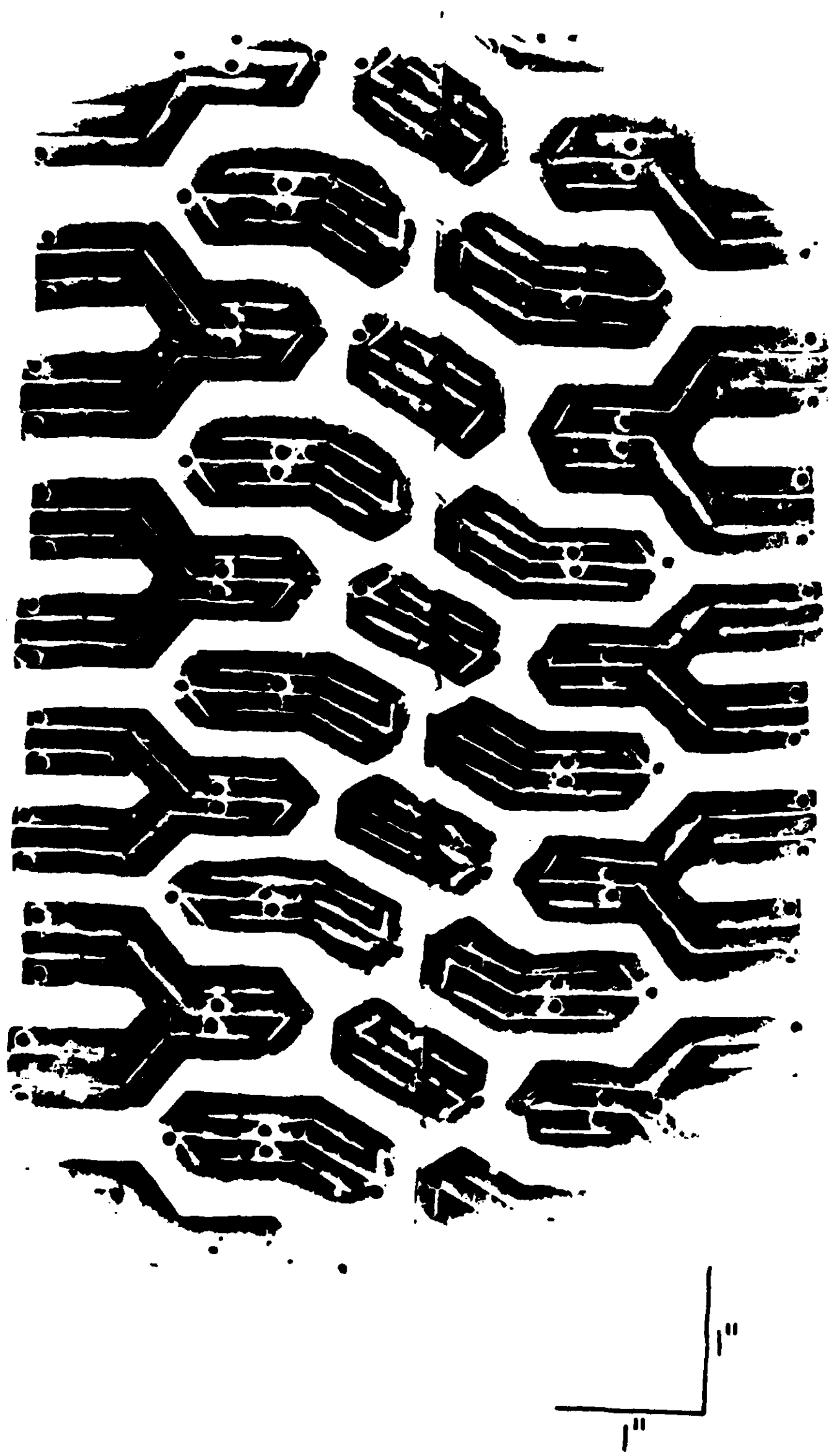


Figure A7. Footprint of tire U at 165 kPa (contact area: 286 cm^2; void ratio: 0.40).

Figure A8. Footprint of tire V at 165 kPa (contact area: 280 cm²).

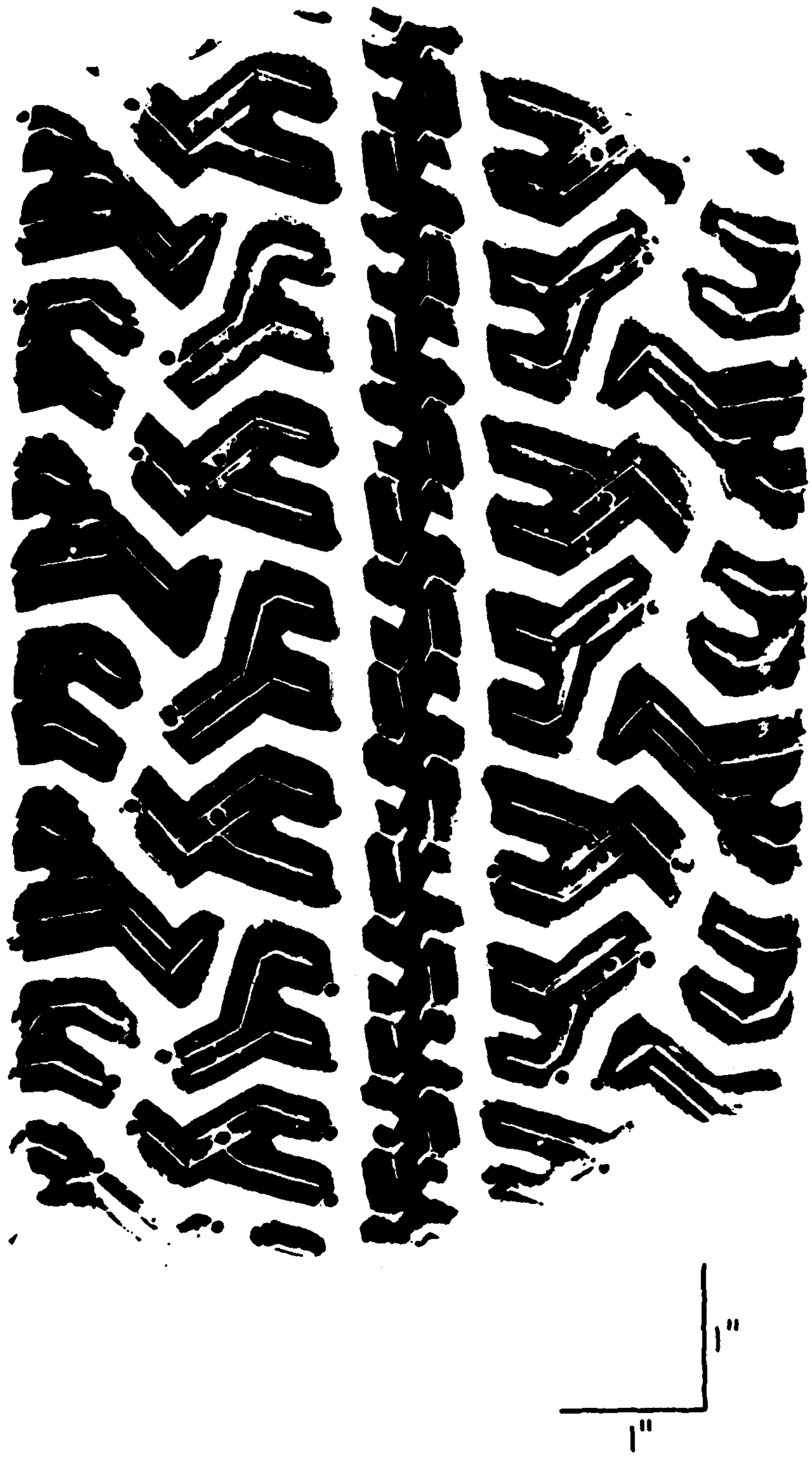


Figure A9. Footprint of tire W at 165 kPa (contact area: 289 cm^2; void ratio: 0.40).

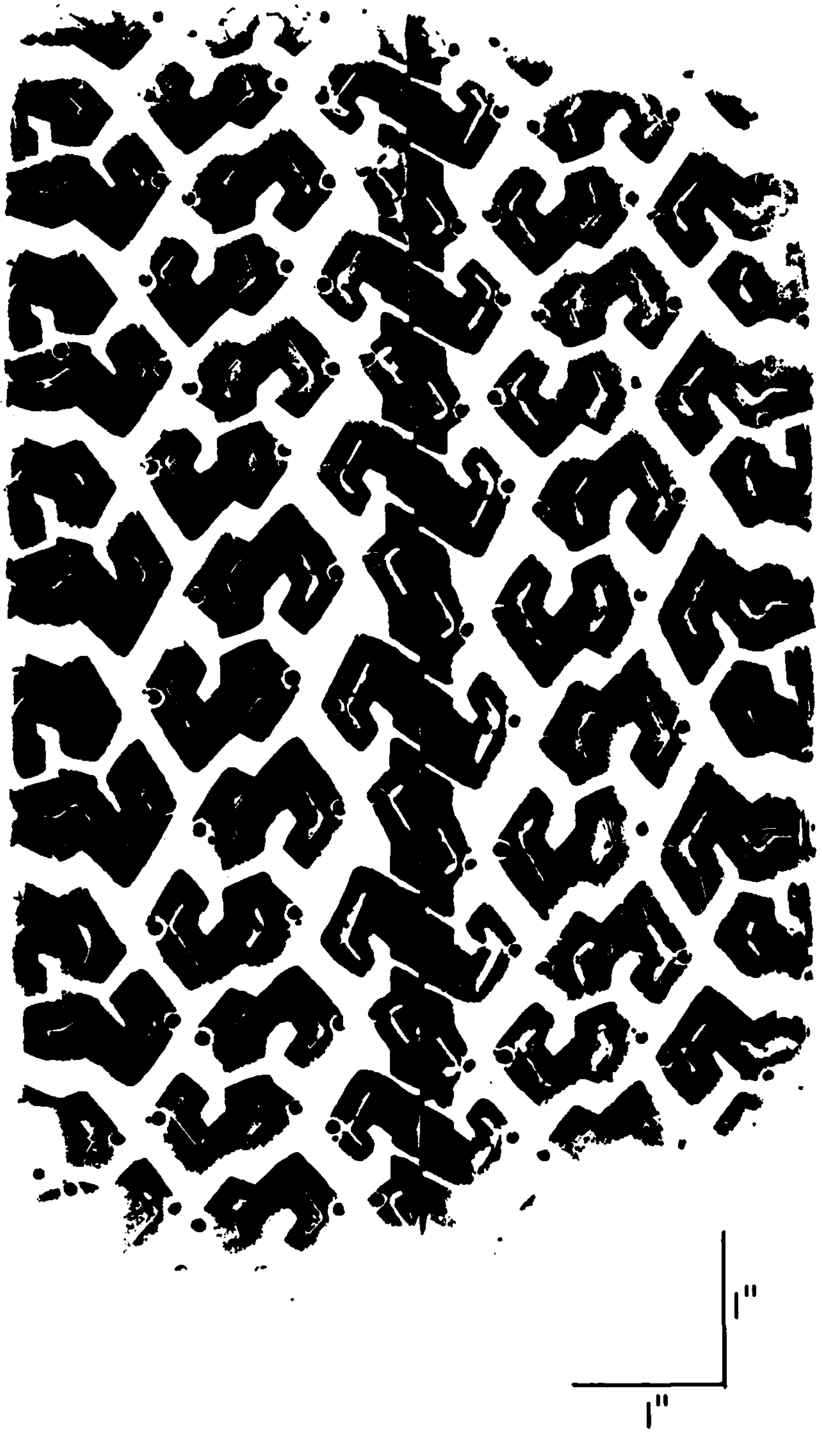


Figure A10. Footprint of tire X at 165 kPa (contact area: 277 cm^2; void ratio: 0.48).

APPENDIX B. SCATTER PLOTS OF PERFORMANCE PARAMETERS VS ICE TEMPERATURE.

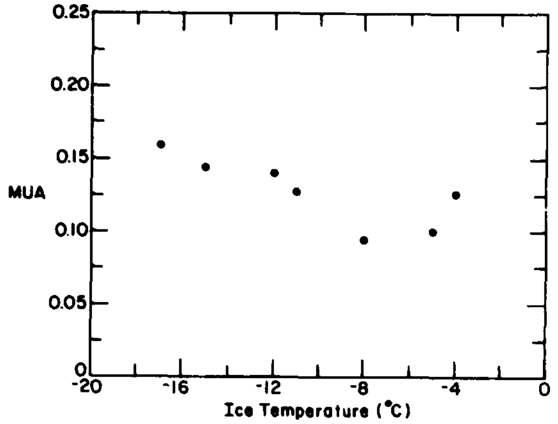


Figure B1. MUA vs ice temperature (correlation coefficient: 0.79).

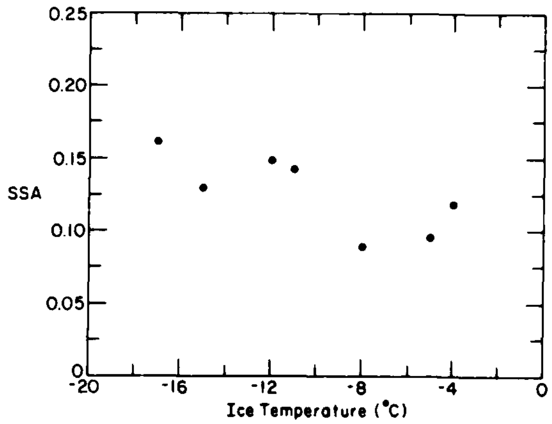


Figure B2. SSA vs ice temperature (correlation coefficient: 0.75).

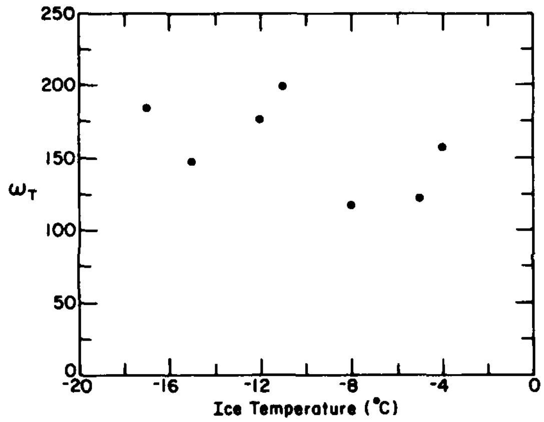


Figure B3. Unit total energy dissipation vs ice temperature (correlation coefficient: 0.52).

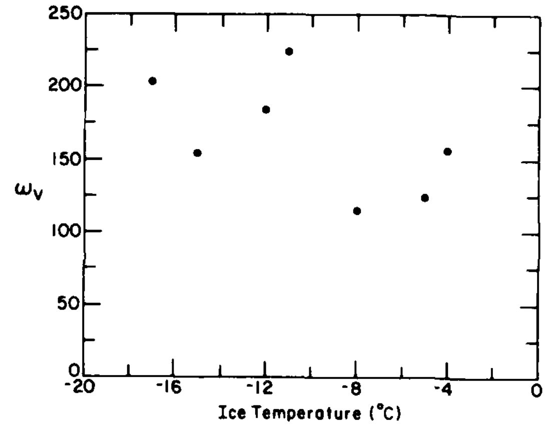


Figure B4. Unit energy dissipation factor vs ice temperature (correlation coefficient: 0.57).

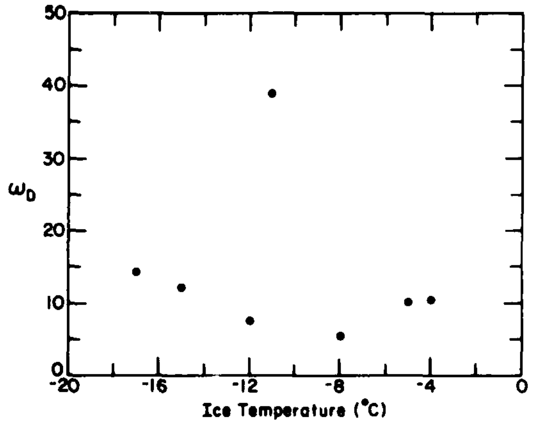


Figure B5. Unit slip-shear energy dissipation factor vs ice temperature (correlation coefficient: 0.19).

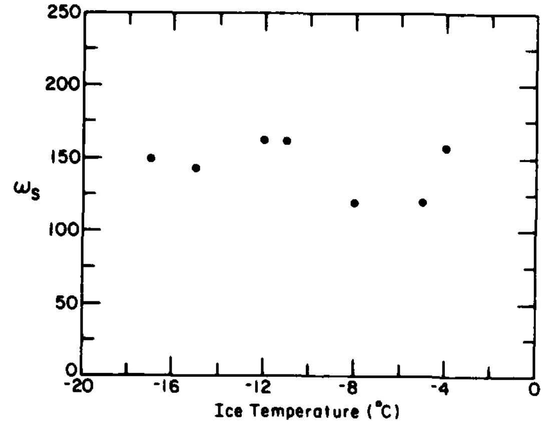


Figure B6. Unit slip energy vs ice temperature (correlation coefficient: 0.32).

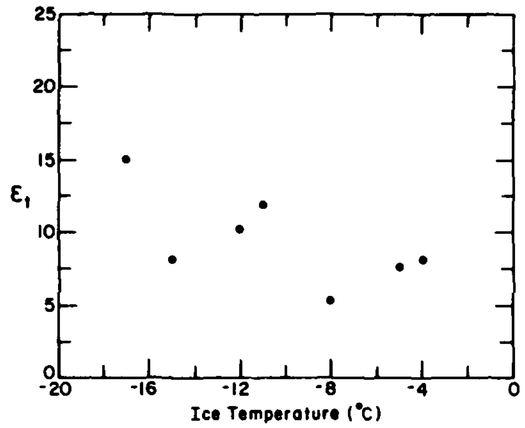


Figure B7. Energy efficiency parameter vs ice temperature (correlation coefficient: 0.66).

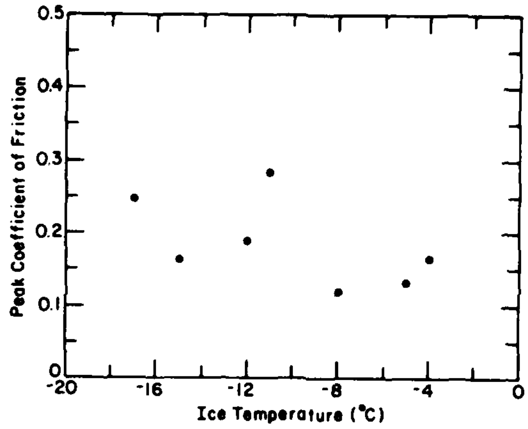


Figure B8. Peak coefficient of friction vs ice temperature (correlation coefficient: 0.54).

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Blaisdell, G.L.

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iii, 28 p., illus.; 28 cm. (CRREL Report 83-27.)

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Bibliography: p. 9.

1. Ice. 2. Radial tires. 3. Tires. 4. Traction. I. United States. Army. Corps of Engineers. II. Cold Regions Research and Engineering Laboratory, Hanover, N.H. III. Series: CRREL Report 83-27.

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