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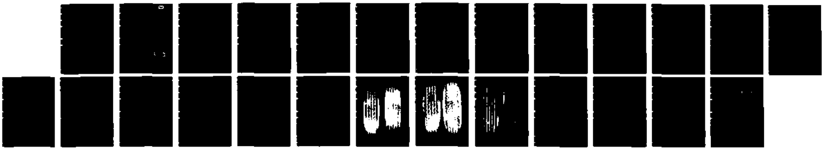

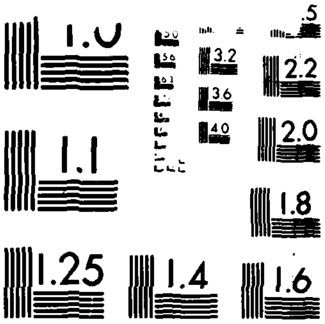

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April 1986

US Army Corps of Engineers
Cold Regions Research &
Engineering Laboratory

Performance of highway and all-season radial tires and traction aids on ice and in snow

Terry Rogers and Ronald Liston

Prepared for
OFFICE OF THE CHIEF OF ENGINEERS

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This study compares the traction performance of a group of all-season radial tires, highway radial tires, link and cable chains. The tests were conducted on ice and snow. The all-season radials perform slightly better on ice, presumably because of the adhesive compound used in manufacturing these tires. The chains significantly improved traction on ice over bare tires, the link chain being best. In snow, the bare tires performed approximately the same. The cable chains provided only a slight improvement, while the link chains again performed best.

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PREFACE

This report was prepared by Terry Rogers, Mathematician, and Dr. Ronald Liston, Supervisory Research General Engineer, of the Applied Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding was provided by DA Project 4A762730AT42, Design, Construction and Operations Technology for Cold Regions.

The authors express their appreciation to Gunars Abele and Gary Phetteplace for their valuable reviews and comments. They also thank William Greeley and Melissa Hutt for their able support and the National Safety Council for providing the tires, chains and testing area.

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 the use of such commercial products.

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PERFORMANCE OF HIGHWAY AND ALL-SEASON RADIAL TIRES AND TRACTION AIDS ON ICE AND IN SNOW

Terry Rogers and Ronald Liston

INTRODUCTION

Tests were conducted during the winter of 1985 to compare the tractive capabilities of a sample of all-season and highway radial tires, link chains and cable chains. The testing was done on ice in Stevens Point, Wisconsin, and in shallow snow in Newport, New Hampshire.

The shallow snow tests were conducted in virgin snow that ranged in age from a new snowfall to approximately 10 days old. Since the snow was not compacted and was allowed a period to age harden, the snow tests differed from the industry-wide practice, but did follow procedures developed by CRREL, the Tank-Automotive Command and the Waterways Experiment Station.

The CRREL Instrumented Vehicle (CIV) was used to test each tire and traction aid used in the study. The MUA (μ-area Average) method of analysis was used to determine performance values; temperature effects were also observed.

These tests were that portion of the 1985 National Safety Council program for which the CRREL mobility team was responsible.

TEST EQUIPMENT

All tests were conducted using the CRREL Instrumented Vehicle (CIV) (Blaisdell 1983a). The CIV is equipped with moment-compensated triaxial load cells to measure the vertical, longitudinal and side forces of the front wheels at the tire-surface contact area, while four locking hubs allow for front-, rear- or four-wheel drive. Vehicle speed and distance traveled are measured by a fifth wheel attached to the rear bumper. A system using a proximity detector and a series of steel nodes measures the velocity and distance traveled by the front wheels. Also, the vehicle is equipped with air adjustable shock absorbers to accommodate testing of oversize tires and to vary the vertical force on the front or rear tires by up to 89 N (20 lbf).

All data are collected with an on-board computer (Hewlett-Packard 9845B) equipped with two tape cartridge drives and an internal thermal printer. The test data are processed and stored for later analysis.

TEST DESCRIPTIONS

Resistance and traction tests were performed on ice and in snow for each tire type and traction aid listed in Table 1. All test tires were size P205/75R15, and inflation pressures were maintained at 206.8 kPa (30 lb/in.^{2}). Tire A served as the control tire and was used with the traction aids. The vertical load varied between 5800 and 6200 N (1300-1400 lbf).

Resistance tests were conducted with the front tires free-wheeling and the rear hubs locked for rear-wheel drive; the load cells measured the motion resistance acting on the front tires. The vehicle was driven in a straight line at 8 km/hr (5 mi/hr) for a distance of approximately 10.7 m (35 ft). Three resistance tests were conducted for each tire and chain, and resistance was taken as the average of the longitudinal force readings during each test.

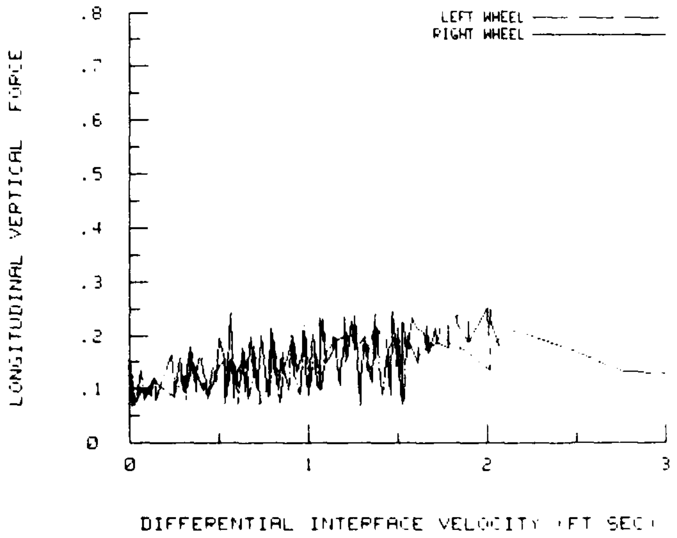
Table 1. Description of test tires and chains.

Code	
A (Control Tire)	Radial highway tire
B	Radial all-season tire
C	Radial highway tire
D	Radial all-season tire
E	Radial highway tire
F	Radial all-season tire
0	Cable chain
1	Class 's' link chain
2	Cable chain
3	Reinforced link chain
4	Cable chain

The conventional traction tests were conducted on ice with the front wheel hub locked and the rear wheel hubs unlocked for front-wheel drive. The vehicle speed was maintained as close as possible to 8 km/hr (5 mi/hr) using the rear brakes while the front tires were accelerated through Differential Interface Velocity (DIV) values between 0 and 16 km/hr (14.7 ft/s) (DIV is the difference between vehicle speed and tire speed). Six conventional traction tests were conducted for each tire and chain.

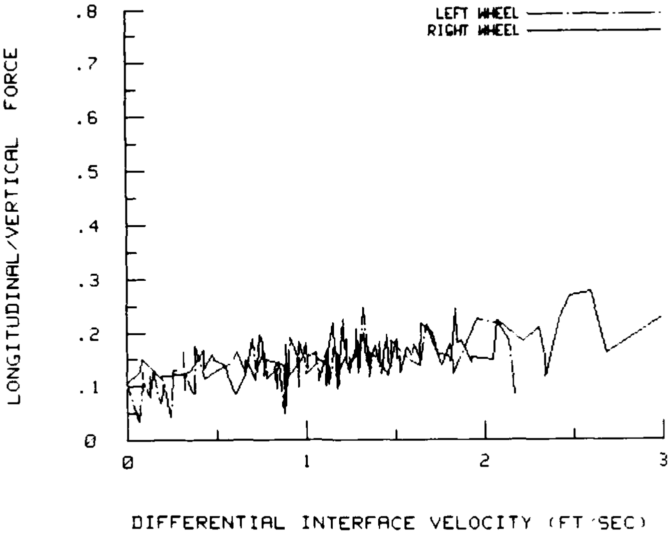
Steady-state traction tests were conducted in snow with the hub set for front-wheel drive. By use of the rear brakes, vehicle speed was maintained and held for several seconds at descending speeds of 8 (7.36), 6.4 (5.89), 4.8 (4.42), 3.2 (2.94), and 1.6 km/hr (1.47 ft/s). Steady-state traction tests have the advantage of eliminating the need to spin the front tires at high slip values, and this minimizes the damage to the grass and soil beneath the snow cover. Six steady-state traction tests were also conducted for each tire and chain.

A comparison of longitudinal/vertical force versus DIV plots for conventional and steady-state traction tests (Fig. 1 and 2) shows that very similar results, based on averaged values, are obtained from both methods at high slip rates. Future tests will be conducted to establish the relationship for DIV rates on the order of 15% of the vehicle speed.

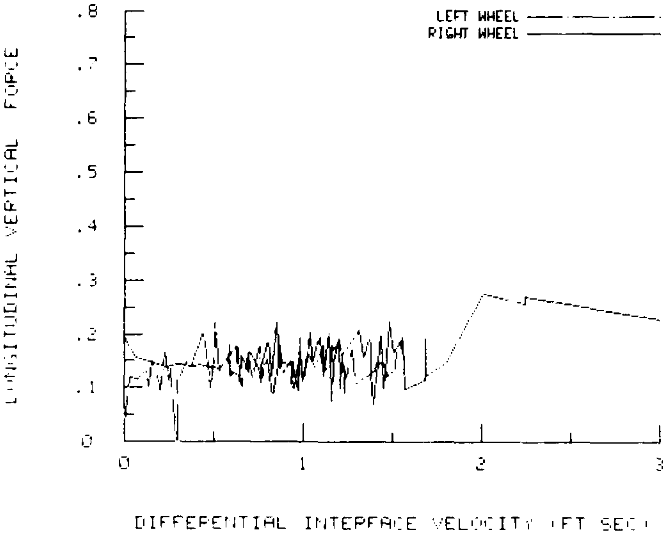


a. First test.

Figure 1. Steady-state traction tests.

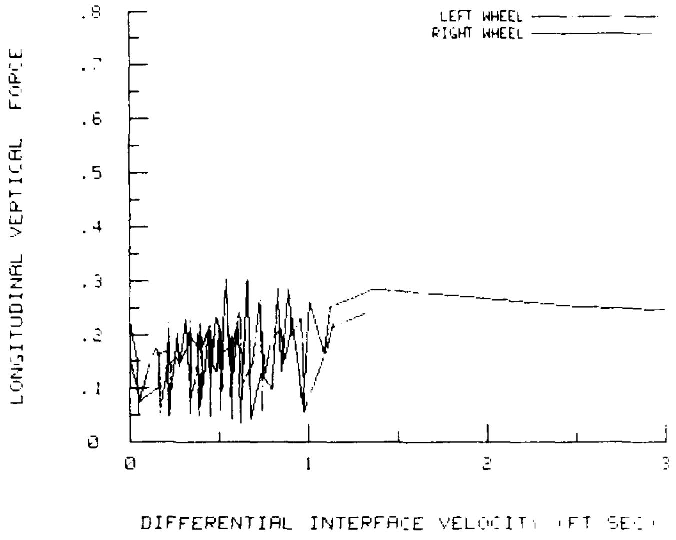


b. Second test.



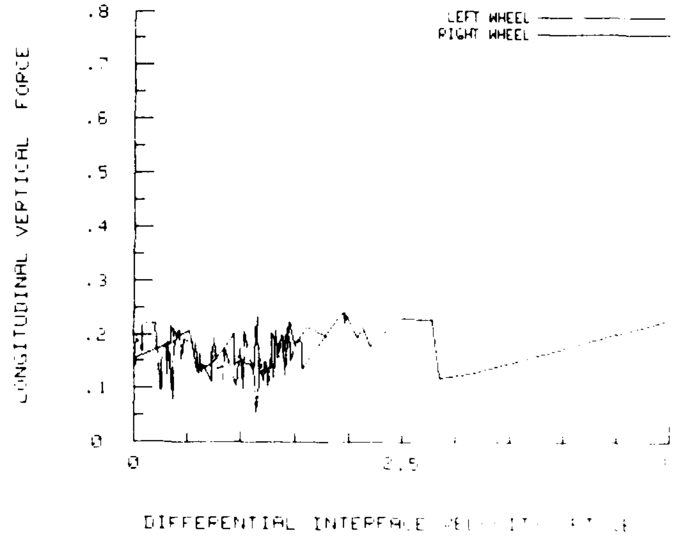
c. Third test.

Figure 1 (cont'd). Steady-state traction tests.



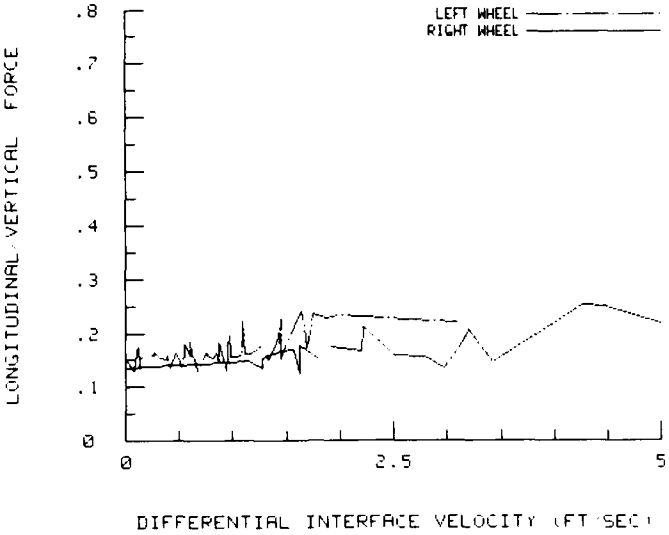
d. Fourth test.

Figure 1 (cont'd).

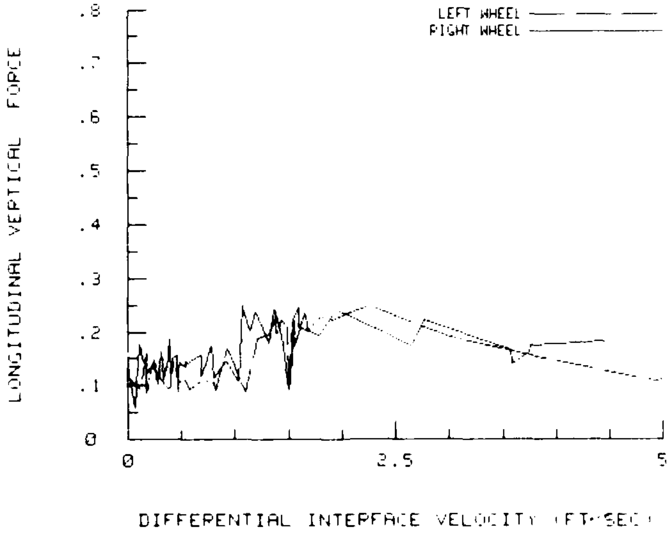


a. First test.

Figure 2. Conventional traction tests.

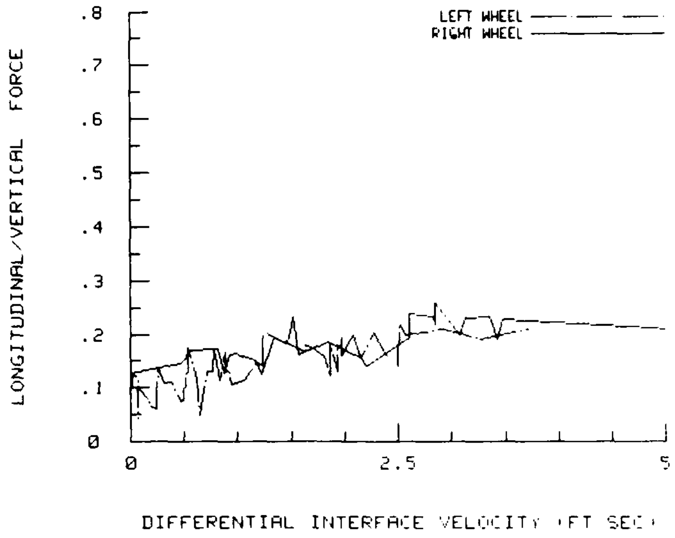


b. Second test.



c. Third test.

Figure 2 (cont'd). Conventional traction tests.



d. Fourth test.

Figure 2 (cont'd).

All resistance and traction tests on ice were conducted in Stevens Point, Wisconsin, during the week of 25 January - 2 February 1985. A 305 m (1000-ft) by 76-m (750-ft) by 13-cm (5-in.) ice sheet was maintained by the city of Stevens Point and kept clear of snow so that ice conditions remained relatively stable.

The tests in snow were conducted during March 1985 at the Parlin Airfield in Newport, New Hampshire. The long, snow-covered grass shoulders of the runway provided appropriate test areas.

DISCUSSION AND RESULTS

Ice tests

A traction performance value for each tire and traction aid was calculated using the μ-area Average (MUA) method of analysis. This is the area under the traction coefficient versus DIV curve between 0.8 km/hr (0.74 ft/s) and 24 km/hr (22.1 ft/s), divided by the difference between 0.8 and 24 km/hr. An average MUA value was obtained from the six traction tests performed for each test item.

Figure 3 shows the average performance of each tire and traction aid as a percent of the control tire's performance (tire A). It can be seen

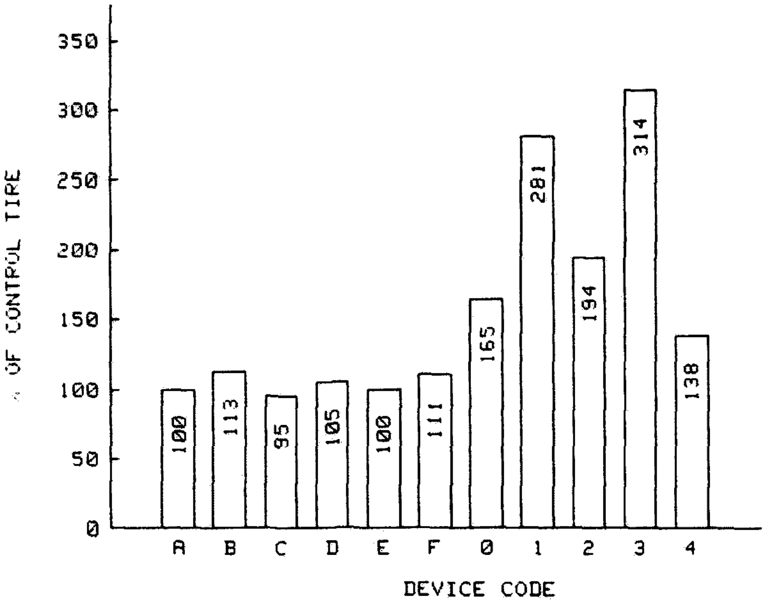
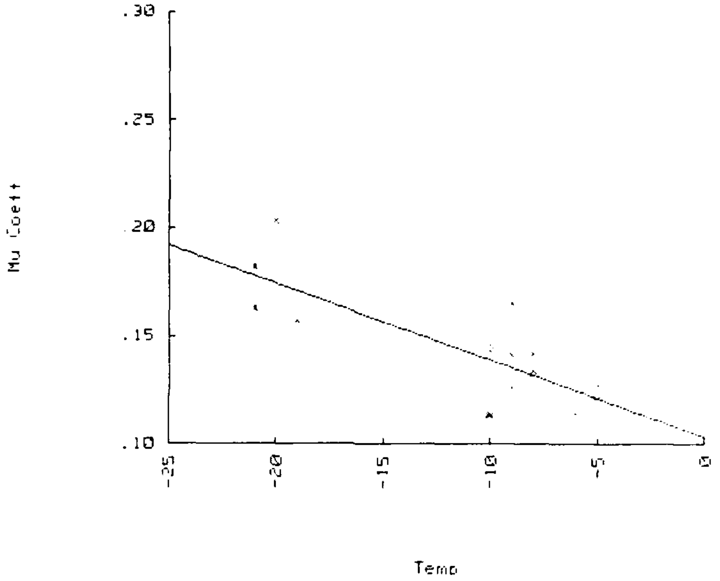


Figure 3. Relative performance values for traction tests on ice.

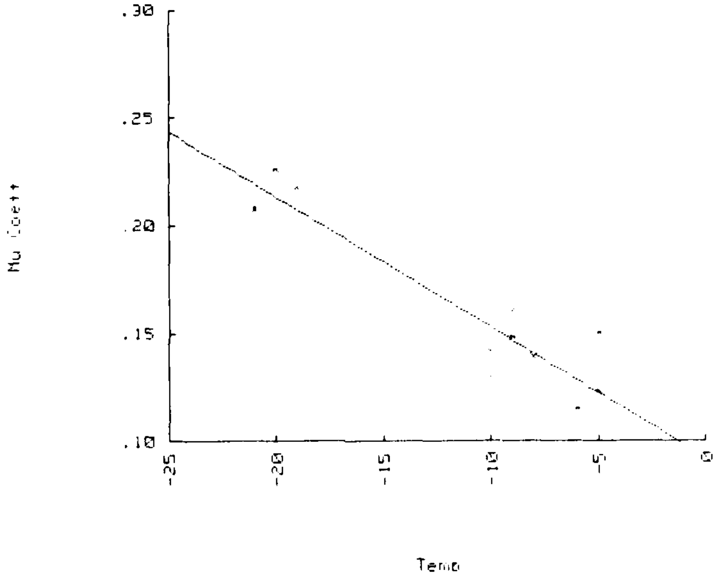
that, for bare tire traction, the all-season radials (tires B, D and F) performed slightly better (approximately 10%) than the highway radials (tires A, C and E). Since past data have shown that bare tire traction on ice depends only on the tire compound, which affects the tire-to-ice adhesion (Blaisdell 1983b), the higher performance of the all-season radials would suggest that their compounds are somewhat more effective than those used in the highway radial tires.

All traction aid devices tested showed a significant improvement over bare tire traction on ice (Fig. 3). The less aggressive cable chains (chains 0, 2 and 4) provided an average improvement of 66% over the bare tire while the two link chains (chains 1 and 3) showed an improvement of approximately 200%. The reinforced link chain, as might be expected, provided the best traction on ice because of its more aggressive design.

The ice temperature varied between -11°C (12.2°F) and -5°C (23°F) on the first three days of testing and between -22°C (-7.6°F) and -19°C (-2.2°F) on the last day. To take the temperature effect into consideration, linear regressions (MUA versus temperature) were run on all data: for each tire and chain separately, for the group of highway radial tires, for the all-season radial tires and for the group of chains. Figure 4 shows the linear relationship between the traction performance value (MUA) and temperature for the highway and all-season radial tires. It can be



a. Highway radial tires (A, C and E).



b. All-season radial tires (B, D and F).

Figure 4. Performance on ice (Mu Coeff = MUA) versus temperature (°C).

seen that the performance of the bare tires significantly depends on temperature. The data yield a stronger correlation for the all-season tires (r = -0.93) than for the highway radial tires (r = -0.78). In both cases, as ice temperature decreased, the tractive performance of the test tires improved. The regression analysis for the test chains showed virtually no apparent dependence on temperature because the chains obtain their traction by causing fractures of the ice rather than from friction. The strength of ice depends on temperature but this effect on chains is not as strong as that caused by the frictional characteristics between the tire and ice.

The traction performance values for the test tires at various temperatures were calculated from the regression equations and are presented in Table 2. At ice temperatures below -9°C (15.8°F) the tractive performance of the all-season radial tires is higher than that for the highway radials. However, at temperatures above -9°C (15.8°F) the opposite is true, with the exception of tire F. Since traction on ice depends on the adhesive quality of the tire compound, it would appear that the compound in these specific test tires does not react as effectively with ice at temperatures above -9°C (15.8°F). Traction performance values for the test

Table 2. Performance values for test tires on ice at various temperatures (calculated from regression analysis).

	Tire code					
Temperature	Control A	B	C	D	E	F
-3.9°C (25°F)	0.118	0.108	0.117	0.108	0.116	0.125
-5°C (23°F)	0.122	0.116	0.120	0.114	0.120	0.132
-7°C (19.4°F)	0.130	0.130	0.125	0.126	0.128	0.144
-9°C (15.8°F)	0.138	0.144	0.130	0.138	0.136	0.156
-10°C (14°F)	0.142	0.151	0.133	0.144	0.140	0.162
-12.2°C (10°F)	0.150	0.167	0.138	0.157	0.149	0.175
-15°C (5°F)	0.161	0.187	0.145	0.173	0.160	0.191
-17.8°C (0°F)	0.172	0.207	0.153	0.190	0.171	0.208
-20°C (-4°F)	0.181	0.223	0.158	0.203	0.180	0.221
-25°C (-13°F)	0.200	0.259	0.171	0.232	0.200	0.251

Table 3. Performance values for chains on ice (percent of control tire's).

	Chain code				
Temperature	0	1	2	3	4
-3.9°C (25°F)	223	347	236	380	175
-5°C (23°F)	216	335	229	367	169
-7°C (19.4°F)	202	315	215	345	158
-9°C (15.8°F)	191	296	202	325	149
-10°C (14°F)	185	288	196	315	145
-12.2°C (10°F)	175	273	186	299	137
-15°C (5°F)	163	254	173	278	128
-17.8°C (0°F)	153	238	162	260	120
-20°C (-4°F)	145	226	154	248	114
-25°C (-13°F)	132	205	140	224	103

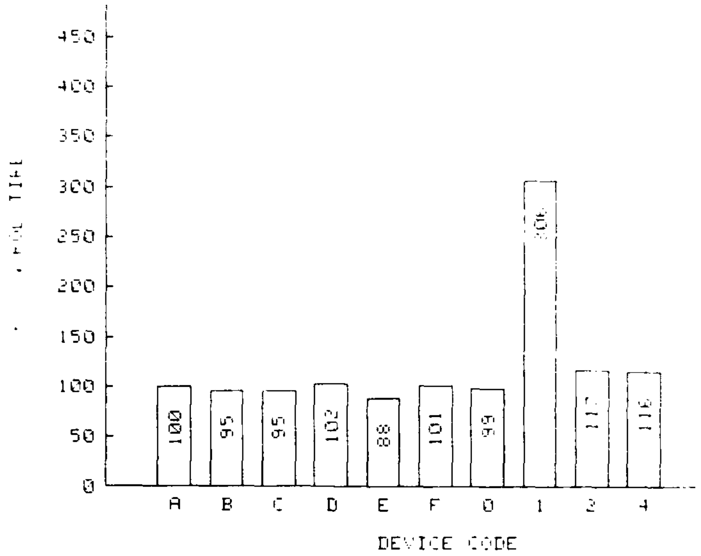
chains (Table 3) are expressed as a percent of the bare control tire's regression values.

In addition to measuring net traction, resistance tests were conducted for the tires and chains. The resistance value averaged nearly the same, 107 N (24 lbf), for each bare tire and increased slightly with the cable chains to 125 N (28 lbf). The link chains, however, showed a significant rise in resistance force to 173 N (39 lbf). These results are consistent with previous findings (NSC 1983).

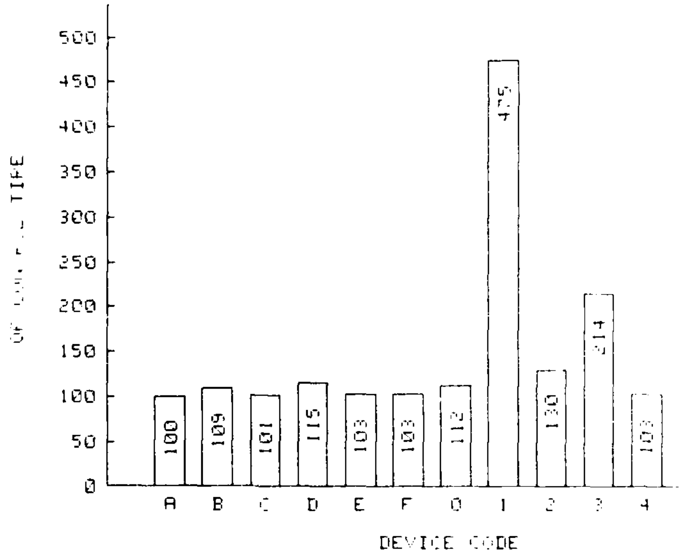
Snow tests

Steady-state traction tests were conducted in snow with the tires and traction aids listed in Table 1. The MUA method of analysis was again used to determine the traction performance values. However, because of the low slip values obtained in the steady-state traction tests, the upper integration limit of DIV used was 3.2 km/hr (2.94 ft/s) instead of 24 km/hr (22.1 ft/s).

During the first two days of testing, the snow conditions remained fairly stable and could be used in compatible data sets. The snow depth varied between 19 cm (7.5 in.) and 23 cm (9 in.), snow density between 0.164 and 0.170 g/cm^3 and snow temperature between -8°C (17.6°F) and 0°C (32°F).



a. First two days.



b. Last day.

Figure 5. Relative performance values for traction tests in snow.

The snow conditions for the last set of data were considerably different, though, and changed throughout the testing day. Initially, the snow was 13 cm (5 in.) deep with a density of 0.26 g/cm^3, a temperature of -1°C (30.2°F), and with a 3.8 cm (1.5 in.) top crusted layer. As the sun warmed the air and melted the snow to a thickness of 9 cm (3.5 in.), the layer of crust disappeared and the snow became wet with a density of 0.326 g/cm^3. Therefore, this last set of data will be discussed separately.

Figure 5a shows the average performance value from the first two days of testing for each tire and traction aid, expressed as a percent of the control tire's performance value. Of the bare tires tested, all performed approximately the same as the control with the exception of tire E, which showed a slightly lower performance. This may be attributable to tire E having a highway tread with sipes designed for efficient flow of water. This configuration likely degrades the performance of the tire in snow. It would appear that the link chain tested (acceptable tests were not obtained for link chain 3 during these two days) provided the only significant improvement in traction in snow, while the cable chains improved traction only slightly over the bare tires. It is possible that the cable chains would have performed better if the shallow snow tests had been conducted on a snow-covered road surface rather than on frozen ground. Because of the efficiency of New Hampshire snow removal crews, it was difficult to find snow covered roads that could be used for testing.

The performance values for the last day of testing in snow are presented in Figure 5b. With the significant change in snow conditions (discussed previously), the performance of link chain 1 improved by as much as 55% over the previous days. However, there were only slight increases in the performance of the other tires and chains tested (except chain 4), most likely because of their reaction to the higher cohesiveness of the snow caused by the increase in temperature.

CONCLUSIONS

The tests in this study compared the tractive capabilities of all-season and highway radial tires and of cable and link chains on ice and in snow. As might be expected, the chains significantly improved traction on ice over the bare tires; the link chains had the highest performance values. Bare tire traction tests on ice, as in the past, showed that the all-season radial tires performed slightly better on ice at the temperatures tested because of the manufacturing compound that makes them more adhesive to ice. In addition, ice temperature affected bare tire driving traction by decreasing performance with increasing temperature.

The steady-state traction tests conducted in snow showed that all of the bare tires performed approximately the same, while the link chains again had the highest performance values. The cable chains performed only slightly better than the bare tires in snow. With an increase in cohesion in the snow, the performance of each tire and chain (except chain 4) increased slightly.

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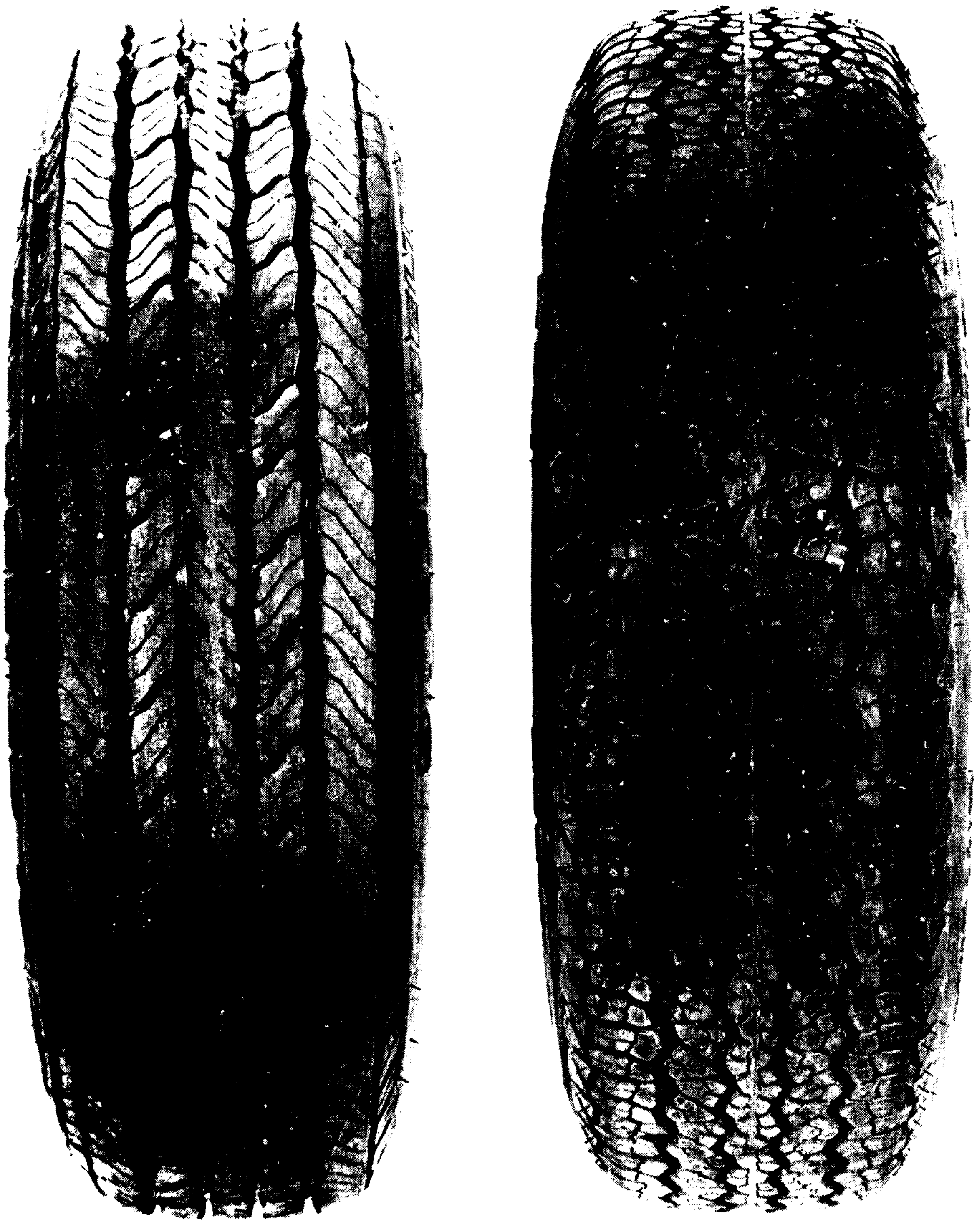
NSC (1983) 1982-83 Winter test report. Chicago, Illinois: National Safety Council.

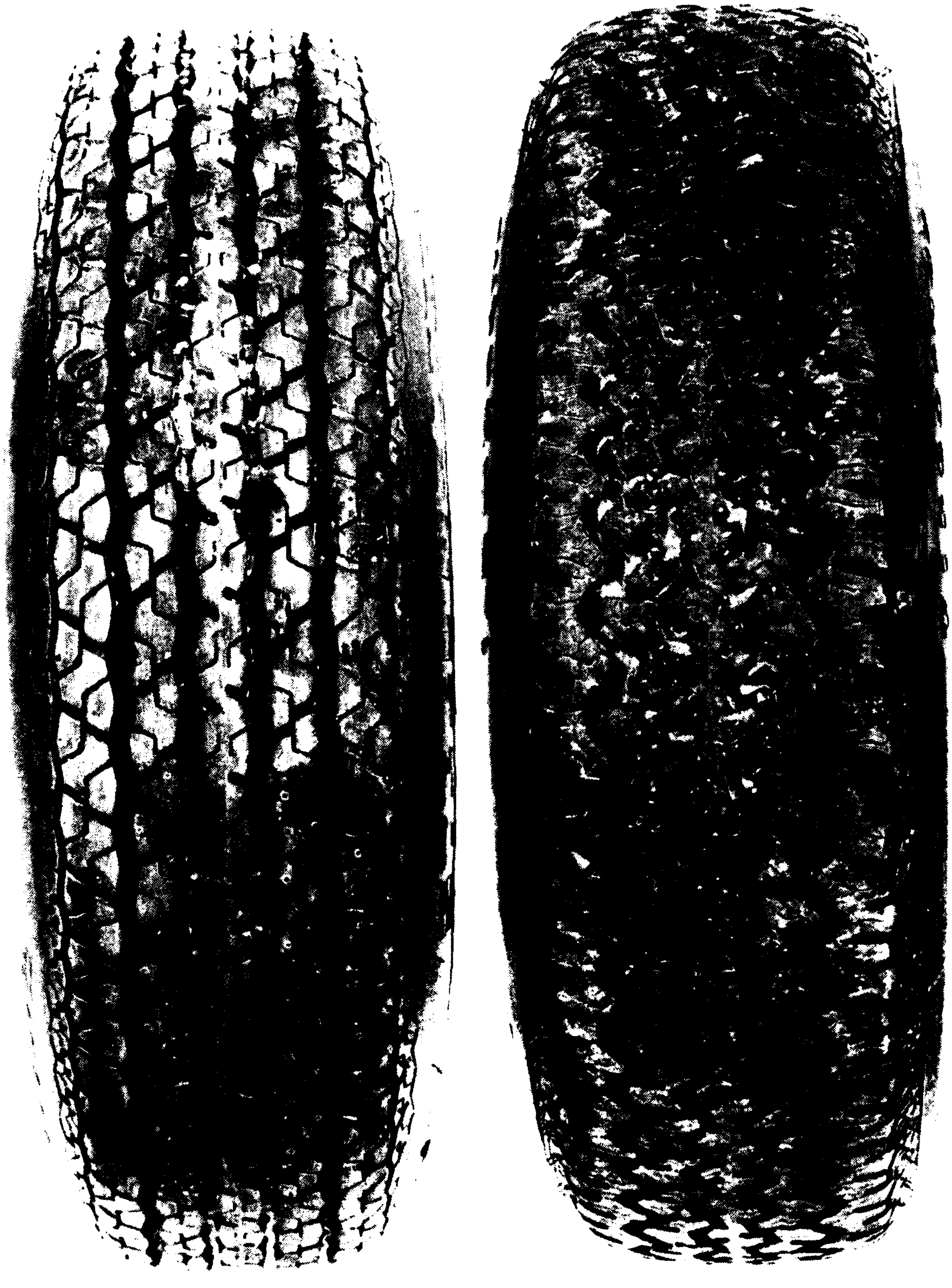
APPENDIX A: TEST TIRES AND CHAINS



a. Tire A.

b. Tire B.

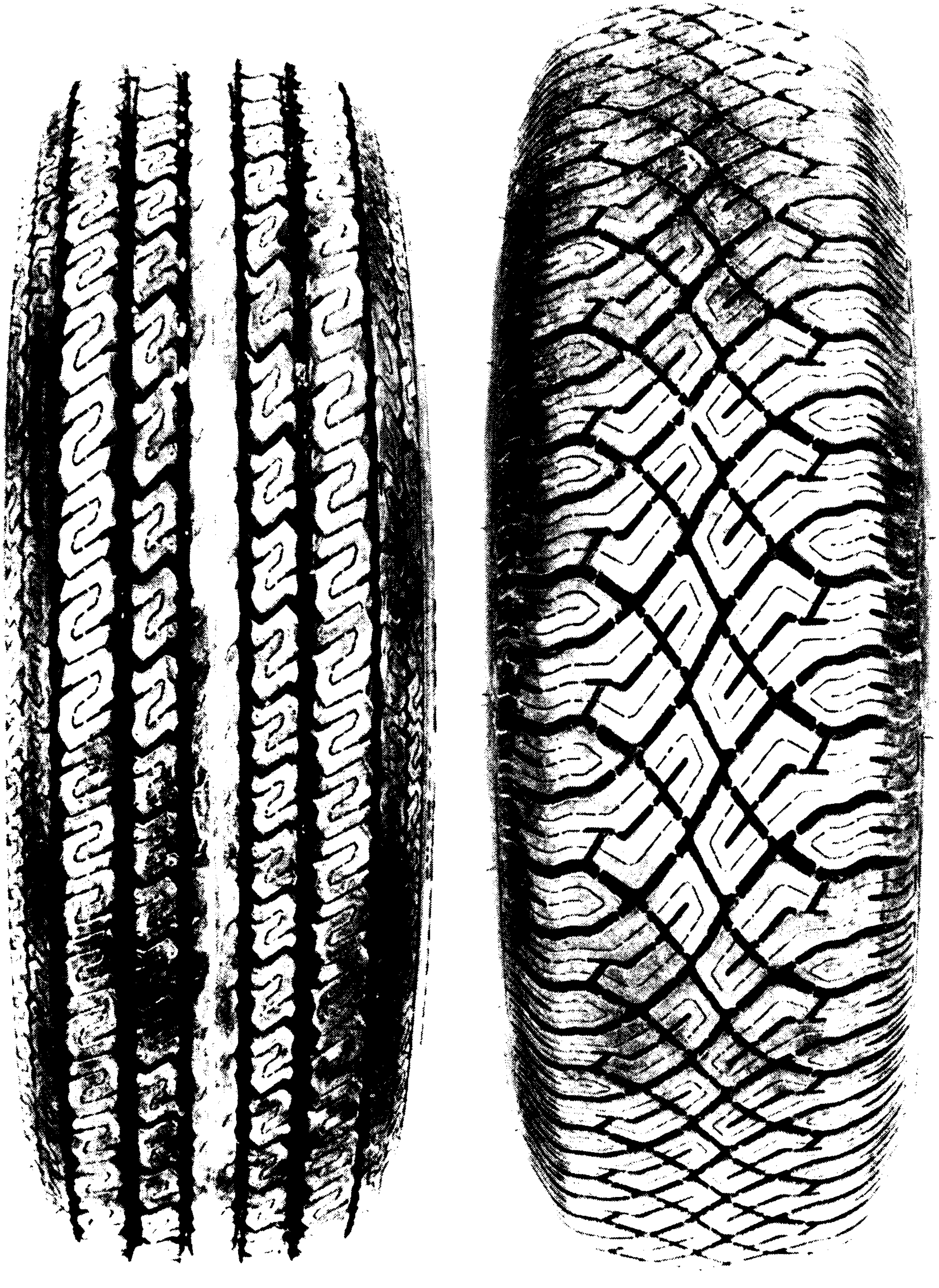
Figure A1. Test tires.



c. Tire C.

d. Tire D.

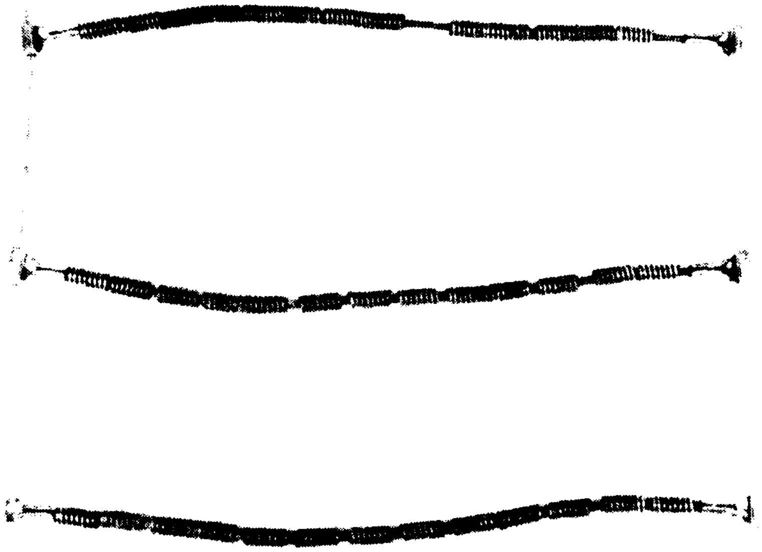
Figure A1 (cont'd). Test tires.



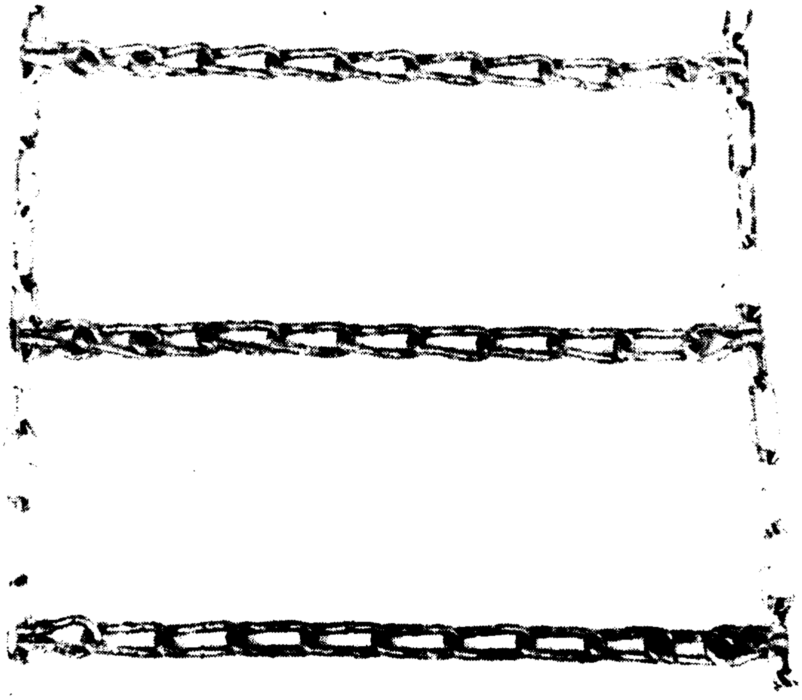
e. Tire E.

f. Tire F.

Figure A1 (cont'd).

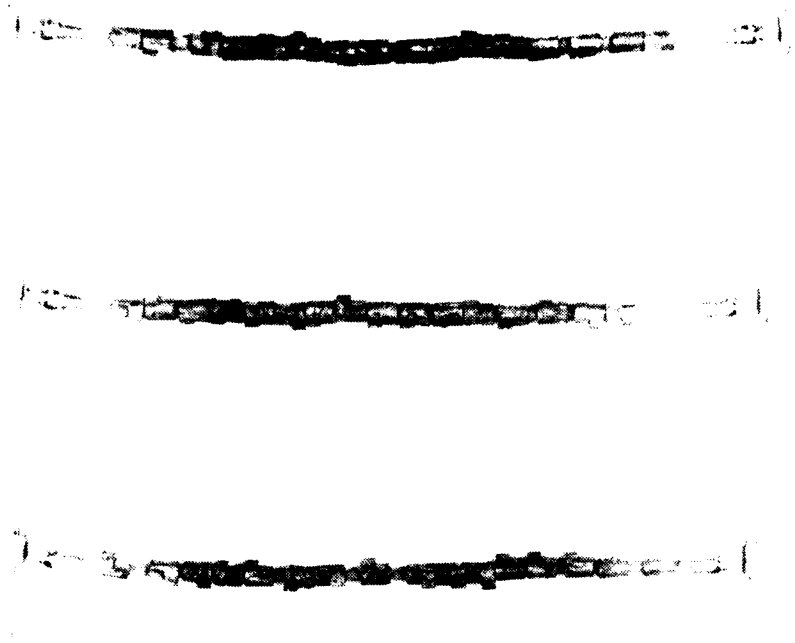


a. Chain 0.



b. Chain 1.

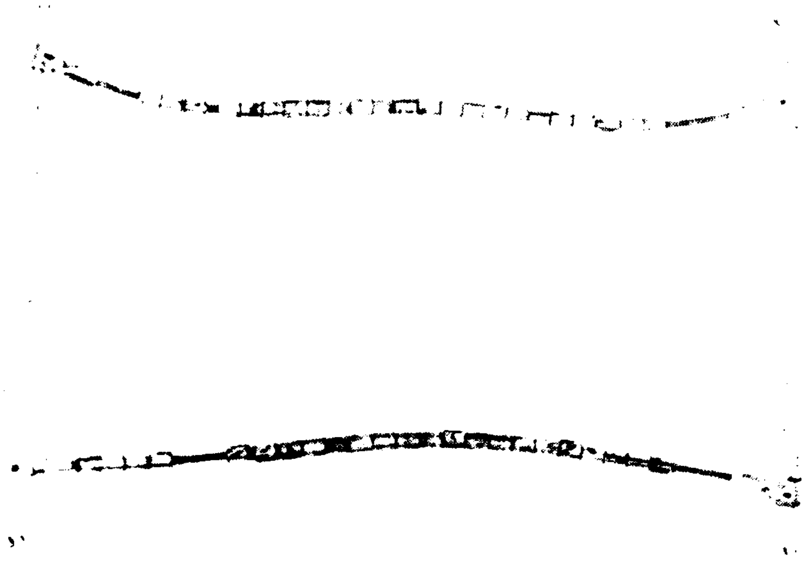
Figure A2. Test chains.



c. Chain 2.

d. Chain 3.

Figure A2 (cont'd).



e. Chain 4.

Figure A2 (cont'd). Test chains.

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