Studded and non-studded winter tyres

Olle Nordström

Reprint of three articles in Nordic Road & Transport Research, No. 2, 1991, pp. 30–37, based on

VTI report 354, Road grip of winter tyres on ice by Olle Nordström and Elisabeth Samuelsson,

VTI meddelande 605, Study of the present status of studded tyres by Elisabeth Samuelsson and

VTI meddelande 606, Field test of studded and non-studded winter tyres. Subjective rating by taxi drivers by Elisabeth Samuelsson
Studded and non-studded winter tyres

Olle Nordström

Reprint of three articles in Nordic Road & Transport Research, No. 2, 1991, pp. 30–37, based on

VTI report 354, Road grip of winter tyres on ice by Olle Nordström and Elisabeth Samuelsson,

VTI meddelande 605, Study of the present status of studded tyres by Elisabeth Samuelsson and

VTI meddelande 606, Field test of studded and non-studded winter tyres. Subjective rating by taxi drivers by Elisabeth Samuelsson
Studded and non-studded winter tyres

Three VTI reports are presented. They document the results of tests on behalf of the National Road Administration and the Traffic Safety Office as part of the 1988 investigation on studded tyres. The investigation included a commission from the Government to the National Road Administration and the Traffic Safety Office in August 1988 to determine how road wear can be reduced through changes in the regulations on the use of studded tyres.

The two authorities were also asked to study the consequences in terms of social economics of a prohibition on studded tyres and the possibility of applying economic constraints to limit their usage. The effects on traffic safety of various actions in this context were also to be studied.

As a result of the Government commission, the National Road Administration and the Traffic Safety Office asked the VTI to carry out a series of studies on the road grip of winter tyres. The VTI has published the results in three reports, summarised on pages 31–37.
Road grip of winter tyres on ice

Studded tyres increase the friction coefficient by 0.05-0.10, which in very slippery conditions can mean a 50% reduction in the braking distance. These earlier results are confirmed in the VTI's latest studies, which also deal with the effects of roughening of the ice by studs and the significance of the number and protrusion of the studs.

The Institute's recently commissioned stationary tyre testing facility.

The starting point for this project was the 1975 investigation of studded tyres, which used a model for calculating the accident reduction resulting from the use of studded tyres during the period 1974-75. New accident studies could not be carried out within the time limits of the 1988 project.

Aim of the investigation

The aim of the 1988 investigation was to elucidate

– changes since the 1975 study, if any, in stud friction and friction differences between modern studded and non-studded winter tyres and summer tyres,

– factors that should be considered when establishing new stud regulations such as number of studs, stud protrusion and wear,

– the indirect stud effect of increasing the friction level by roughening the ice surface,

– the influence of speed on the friction level on ice for studded and non-studded tyres,

– the comparability between friction data from different measuring equipments.

Results

Comparison between new studded and non-studded winter tyres

New winter tyres of modern steel radial design increase friction considerably in braking and cornering on ice when fitted with 105-123 studs protruding 1.1-1.8 mm. The greatest absolute gain in the friction coefficient from the
Friction coefficient

<table>
<thead>
<tr>
<th></th>
<th>Temp. 0°C</th>
<th>Smooth ice</th>
<th>Stud-roughened ice</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Non-studded tyre</td>
<td>Studded tyre</td>
</tr>
<tr>
<td>optimum slip</td>
<td>0.09 - 0.11</td>
<td>0.14 - 0.21</td>
<td>0.05 - 0.10</td>
</tr>
<tr>
<td>locked wheel</td>
<td>0.10 - 0.12</td>
<td>0.12 - 0.19</td>
<td>0.02 - 0.07</td>
</tr>
<tr>
<td>maximum cornering</td>
<td>0.12 - 0.12</td>
<td>0.16 - 0.17</td>
<td>0.04 - 0.05</td>
</tr>
<tr>
<td>optimum slip</td>
<td>0.36 - 0.38</td>
<td>0.36 - 0.44</td>
<td>0.00 - 0.07</td>
</tr>
<tr>
<td>locked wheel</td>
<td>0.20 - 0.23</td>
<td>0.24 - 0.33</td>
<td>0.02 - 0.13</td>
</tr>
<tr>
<td></td>
<td>Temp. -1 to -14°C</td>
<td>Smooth ice</td>
<td>Stud-roughened ice</td>
</tr>
<tr>
<td></td>
<td>Studded tyre</td>
<td>Non-studded tyre</td>
<td></td>
</tr>
<tr>
<td>optimum slip</td>
<td>0.14 - 0.27</td>
<td>0.18 - 0.27</td>
<td>-0.02 - 0.04</td>
</tr>
<tr>
<td>locked wheel</td>
<td>0.10 - 0.13</td>
<td>0.15 - 0.20</td>
<td>0.05 - 0.08</td>
</tr>
</tbody>
</table>

Table 1.
Friction levels for new winter tyres with and without studs.

<table>
<thead>
<tr>
<th>Smooth ice</th>
<th>Summer tyre</th>
<th>Stud</th>
<th>Non-studded</th>
</tr>
</thead>
<tbody>
<tr>
<td>optimum slip</td>
<td>65%</td>
<td>100%</td>
<td>65%</td>
</tr>
<tr>
<td>locked wheel</td>
<td>70%</td>
<td>100%</td>
<td>75%</td>
</tr>
<tr>
<td>Stud-roughened ice</td>
<td>85%</td>
<td>100%</td>
<td>90%</td>
</tr>
<tr>
<td>locked wheel</td>
<td>70%</td>
<td>100%</td>
<td>75%</td>
</tr>
</tbody>
</table>

Table 2.
Comparison between new studded tyres designed for studs (100%), and the same without studs ("non-studded") as well as so-called friction tyres.

<table>
<thead>
<tr>
<th>Smooth ice</th>
<th>Summer tyre V</th>
<th>Stud</th>
<th>Non-studded</th>
</tr>
</thead>
<tbody>
<tr>
<td>optimum slip</td>
<td>40%</td>
<td>100%</td>
<td>65%</td>
</tr>
<tr>
<td>locked wheel</td>
<td>65%</td>
<td>100%</td>
<td>75%</td>
</tr>
<tr>
<td>Stud-roughened ice</td>
<td>85%</td>
<td>100%</td>
<td>90%</td>
</tr>
<tr>
<td>locked wheel</td>
<td>65%</td>
<td>100%</td>
<td>75%</td>
</tr>
</tbody>
</table>

Table 3.
Comparison between new winter tyres with and without studs and a summer tyre in speed class V.

32
Nordic Road & Transport Research No. 2 1991
The corresponding non-studded winter tyres designed for studs were in some cases better and in some cases worse than the friction tyres. The comparison does not include measurements on smooth ice at 0°C, where ordinary non-studded winter tyres had 50-65% of the friction of a good studded tyre in both optimum slip and locked wheel. Similar figures can be expected from friction tyres and other non-studded tyres.

Comparison between winter tyres with and without studs and summer tyres

Tables 3 and 4 show comparisons between new winter tyres with and without studs and summer tyres in speed classes S and V. The comparisons relate to conditions below freezing where the values for non-studded winter tyres and friction tyres respectively are compared with studded winter tyres (100%). The results are not valid for smooth ice at 0°C. There, the studded tyres are even more advantageous.

Stud protrusion, number of studs and wear

No simple correlation between stud protrusion, number of studs and friction on ice was found when new studded winter tyres from different manufacturers were compared. The mean stud protrusion varied from 1.1 to 1.8 mm, and the number of studs between 105 and 123. The largest difference in friction between different studded tyres was due to differences in the friction properties of the tyre itself. The stud effect was probably influenced also by stud positioning and the tyre tread pattern.

The worn studded tyres (5 mm tread depth) with a stud protrusion of 0.6 mm had about 20% lower friction on smooth ice than the corresponding new tyres without studs. On the other hand, a worn studded winter tyre with 5 mm tread depth and 1.0-1.1 mm stud protrusion had friction values of the same order as the best new studded tyres on the same smooth ice surface at optimum slip, as well as with locked wheel.

The results indicate that stud protrusion has much more influence than tyre wear and that the stud effect can be neglected when the stud protrusion is smaller than about 0.5 mm.

The static stud force is probably also important. This was as a mean 55 N, and 80 N for the tested worn tyres with 0.6 mm stud protrusion, compared with about 180 N for the new tyres.

Influence of stud-roughening

The influence on the friction level on ice at various degrees of stud-roughening was tested separately at temperatures between -1 and -10°C for a studded and a non-studded winter tyre of the same type, a friction tyre and two summer tyres. Except at very low levels of roughening, the friction increased with increasing roughness. From smooth ice to slight roughness, no change or decrease was obtained in most cases.

The increase was largest at optimum slip. This was especially the case for the friction tyre and the other non-studded winter tyre. From a certain degree of ice roughness, the same friction was obtained for these tyres as for the studded tyre. At further increase in roughness, the friction improved very little. On the roughest surface, the friction at optimum slip for the non-studded winter tyres was...
The BV12 friction measuring vehicle, designed and built by the VTI. The system measures braking friction ("road grip") between the vehicle’s tyre and the road surface. The measuring wheel, located beneath the chassis of the vehicle, is linked to the driven wheel by a gearbox with continuously variable ratio. This allows measurement at different slip values from 0 to about 50%. Measurement can also be performed with one wheel locked.

about twice as high as on smooth ice (a mean of 0.27 compared with 0.12), while the studded tyre friction increased about 30%, from 0.20 to 0.27. The effect for the summer tyres was about 70%, from a mean of 0.10 to 0.17, i.e. the absolute increase was equal to that of the studded tyre.

Comparative studies on smooth and stud-roughened ice at about 0°C gave additional information. For a summer tyre, the friction at optimum slip improved from 0.11 to 0.24-0.34 and at locked wheel from 0.09 to 0.17-0.21. Results to the same effect were produced from studded as well as non-studded winter tyres. Thus in all cases, the improvement was at least a doubling of the friction at 0°C.

Influence of speed

The influence of speed on friction on ice was in general found to be small for the summer tyres, the non-studded and the studded winter tyres. The largest influence was found for the studded tyres in the locked wheel condition on smooth ice and at optimum slip on stud-roughened ice. In both cases, the friction increased with speed by about 0.01 per 10 km/h. As a conclusion, test speeds between 15 and 65 km/h can in most cases be expected to give similar results. For the studded tyres, the friction level at higher speeds will be underestimated, but the test speed of 30 km/h is regarded as a good compromise.

Comparison between BV12 and passenger car

In general, the friction values obtained with the friction measuring vehicle BV12 were higher than those obtained with a passenger car. This was expected for two reasons, the first being the polishing effect from the front wheels of the car, lowering the friction for the rear wheels, and the second that the ABS on the car is not operating at optimum slip all the time and thus cannot utilize 100% of the peak friction.

However, the two types of measuring equipment produced similar results when testing the dependence of friction on speed, both on smooth ice and stud-roughened ice.

Comparison between BV12 and the stationary tyre testing facility

Comparable results from the BV12 and the VTI tyre testing facility show that the variation in friction is larger for BV12. An explanation for the larger range for BV12 is that the variation in the ice condition was larger on the outdoor track. The explanation is believed to be that the ice of the testing facility was cleaner and smoother, thus giving better contact between the ice and the rubber.

In addition to the above comparisons of different types of measuring equipment, the report contains comparisons between measurements with BV11, BV12 and passenger car.

Conclusions

The results support the assumption that the same accident-reducing effect from studded tyres that was used in 1975 can also be used in 1989.

When producing regulations concerning studded tyres, it should be observed that the friction on ice is reduced by a reduced number of studs, reduced stud protrusion and reduced radial stud force for a given tyre design. If the safety level is to be maintained, these variables must not be reduced without improving the tyre design. The possibilities of doing this are probably rather limited. The results indicate that no stud effect remains
at a stud protrusion of about 0.6 mm.

The investigation supports earlier results showing that the studs are most useful on wet clear ice and cold ice with surface contamination in the form of snow or ice powder. Doubling the friction is possible on these surfaces with studded tyres commonly used in Sweden. Performance testing of winter tyres should thus be carried out on such a surface.

The friction improvement from roughening the ice with studs can be important, especially on wet ice, where a doubling of the friction compared to smooth ice can be expected. On cold ice (below -5°C) the effect was much smaller for summer tyres. With locked wheels, this applied for all the tested tyre types.

The influence of speed is small. For studded tyres, friction increases somewhat with speed. The test speed 30 km/h is regarded as a good compromise for achieving suitable reference values.

Studded tyres give an increase in peak braking friction with rolling wheels (at optimum slip). This reduces the risk of wheel locking and subsequent loss of stability and steerability. This increase is primarily obtained under the most difficult slipperiness conditions, such as wet clear ice.

Studded tyres reduce the difference in braking friction between optimum friction and locked wheels on ice surfaces where this difference is large without studs. This could reduce the risk of misjudgement of necessary braking distance and give better operating conditions for antilock brakes.

Studded tyres give an increase in peak lateral friction, which reduces the risk of skidding during cornering.

Studded tyres give less loss in lateral friction at large sideslip angles (skidding). The skidding motion will as a result be slower and consequently easier to stop. Also, cornering performance will not be reduced so much, which further diminishes the risk of leaving the road.

References:


Title: Road grip of winter tyres on ice

Authors: Olle Nordström & Elisabeth Samuelsson

Series: VTI Rapport 354

Language: Swedish, with English summary
Laboratory measurements on a selection of tyres generally gave the expected result that the effect of the studs decreases when their protrusion decreases. In a separate study of vehicles in traffic, it was found that the average stud protrusion was rather small and that front-wheel drive cars had greater protrusion of the studs on the front tyres than on the rear tyres.

This study was divided into two parts. One part was a laboratory investigation of stud parameters measured on new and worn studded tyres. The second part consisted of a field survey of tyre properties among randomly selected vehicles in traffic. During December 1988 - January 1989, 400 vehicles were examined at each of two locations in Sweden. In northern Sweden, 92% of the examined tyres had studs, as opposed to only 69% in southern Sweden.

Results
In the laboratory tests, static stud force and stud protrusion were measured on 690 studs. They were mounted on different types of winter tyres. When analysing the linear correlation between static stud force and stud protrusion of the 690 measured values, the correlation coefficient was 0.7. Thus, there may be a connection, even if it is not complete. The results indicate that the stud force decreases when stud protrusion becomes smaller.

The field survey of all 800 tyres at the two sites provided the following mean values for the studded tyres:
- mean value of the tread rubber hardness = 59 SHORE
- mean number of studs on the tyres = 115 studs
- mean value for tread pattern depth = 7.5 mm
- mean protrusion of the studs = 0.87 mm

The mean protrusion of the studs is relatively small, which may give a longer braking distance on a slippery surface than the driver expects when the car has studded tyres. 19% of the non-studded tyres (155) were winter tyres and the rest summer tyres.

Front-wheel driven cars had as a mean 0.2 mm larger stud protrusion on the front wheels than on the rear wheels. This is rather alarming as better road grip on the front wheels increases the risk of rear end skidding.

There is a proposal for a sharpening of the regulations for studded tyres. The greatest change compared to the present situation would be achieved by the proposed new limitation of the maximum number of studs to about 110 studs per tyre.

Title: Study of the present status of studded tyres
Author: Elisabeth Samuelsson
Series: VTI Meddelande 605
Language: Swedish with English summary

Stud protrusion as a function of tread depth. Mean values for studded tyres. The number of tyres with each tread depth is indicated by the figures along the curve.
Studded and non-studded winter tyres: Opinions of taxi drivers

Stockholm taxi drivers consider that from time to time they need to use studded tyres for driving on icy roads, although it is also possible to adapt speed and driving technique so that friction tyres can be used instead. However, when using friction tyres, trafficability is reduced in certain situations.

During five winter months in 1988/89, a number of taxi drivers in Stockholm filled in a form after each driving period describing the conditions encountered during that period. The drivers used Volvo 740 and Mercedes 190 taxis fitted alternately with 110 studs and 56 studs and with non-studded winter tyres of the friction type.

In addition to the questionnaire, objective laboratory measurements were made on the tyres in the survey. Stud protrusion and static stud effect were measured, as well as the friction coefficient on a new and a worn tyre of each type used in the survey.

As well as the above studies, the frequency of accidents involving the vehicles in the survey was also observed.

Results

The answers to the questionnaire show that:

- Snow and ice were found on the roadway for a comparatively long time after a snowfall; not on highly trafficked roads and in the centre of Stockholm, but in suburbs and on minor roads. During 26% of the driving periods, the taxi drivers thought that studded tyres were needed.
- The studded tyres were preferable on icy roads. On other road surfaces, the friction tyres had equivalent driving qualities. Vehicles that are used in all weather conditions may have difficulties in certain situations if studded tyres are prohibited.
- The taxi drivers thought that studded tyres were sometimes useful. They are, however, of the opinion that they can adjust speed and driving technique so that friction tyres can be used in most circumstances, although in certain situations the traction on grades is insufficient.
- The friction tyres were less noisy than the studded tyres. That is an advantage from the working environment point of view.
- Both friction tyres and studded tyres were rated to be better than summer tyres for driving during the winter period.

The friction measurements showed that in new condition the fully studded tyre had a peak friction coefficient on smooth ice that was about twice as high as that of the non-studded friction tyre. The tyre with half the number of studs was about 1.7 times as good as the friction tyre. The locked wheel friction showed a smaller difference, 1.5 and 1.3 times respectively.

On ice roughened by studs, the differences in peak friction were small. With locked wheel, the fully studded tyre had 50% higher friction, but the tyre with fewer studs only 10% higher friction than the friction tyre. The differences in friction between the worn tyres were small. Wear reduced friction also on the friction tyre.

The largest number of accidents occurred on icy roads at the beginning of the test period. The accident rate was lowest for the vehicles with fully studded tyres and highest for vehicles with friction tyres. This result is, however, statistically of low significance.

Title: Field test of studded and non-studded winter tyres. Subjective rating by taxi drivers
Author: Elisabeth Samuelsson
Series: VTI Meddelande 606
Language: Swedish, with English summary
Swedish Road and Transport Research Institute

Forskar för ett liv i rörelse.
Research for an active community.

Statens väg- och transportforskningsinstitut har kompetens och laboratorier för kvalificerade forsknings- uppdrag inom transporter och samhällsekonomi, trafiksäkerhet, fordon, miljö samt för byggande, drift och underhåll av vägar och järnvägar.

The Swedish Road and Transport Research Institute has laboratories and know-how for advanced research commissions in transport and welfare economics, road safety, vehicles and the environment. It also has research capabilities for the construction, operation and maintenance of roads and railways.

Adress
581 95 Linköping
Address
S-581 95 Linköping Sweden

Telefon
013 - 20 40 00
Telephone
+ 46 13 20 40 00

Fax
013 - 14 14 36
Fax
+ 46 13 14 14 36

Telex
50 125 VTISGI S