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Optimal proportion of studded tyres in traffic flow to prevent polishing of an icy road

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ABSTRACT

Studded tyres can significantly wear the road surface and increase particle emissions from the road surface, which has a negative impact on air quality in urban areas. However, road wear might have a positive aspect by roughening the road surface and thus preventing polishing. As a consequence, other vehicles than the ones using studded tyres might also benefit from the usage of studded tyres. The impact of the proportion of studded tyres in the traffic flow on the tyre–ice friction coefficient was studied with a fleet of real cars in a closed environment under strict procedural control. The results show that a proportion of 25–50% studded tyres in the traffic flow is enough to prevent ice from developing in a manner that is critically slippery for non-studded winter tyres. It was also observed that the visual appearance of the ice surface does not indicate if the ice has become more slippery or not.

1. Introduction

Winter tyres are often required or recommended to be used, e.g. in Europe, Japan, Russia, China, and North America. The term ‘winter tyre’ is a general term without any exact connection to its snow or ice performance. For example, the M & S (Mud and Snow) marking indicates decent performance in poor road conditions, which does not necessarily guarantee a sufficient performance in real winter conditions. In this paper, a winter tyre means a tyre that is engineered for snowy and icy driving conditions even when the temperature is well below zero. Such winter tyres are widely used in Scandinavia, Russia, and Canada. Thus, here the term ‘winter tyre’ does not include the all-weather tyres that are used e.g. in Central Europe as winter tyres.

Nordic winter tyres can be divided into two categories (Fig. 1):

- a studded tyre (ST) has metal spikes in the tread, traditionally around 130 per tyre (stud protrusion about 1.2 mm). These studs are intended to offer extra grip when there is a smooth ice surface on the road. The number of studs and permitted usage season are often limited by legislation. Studded tyres are used in wintertime traffic e.g. in Scandinavia, the US, Russia, and Canada;
- a friction tyre (FT) has no studs, but the contact patch is divided into sipes and the rubber compound is softer, especially at low temperatures. Over the last decade studded and non-studded winter tyres have approached each other with respect to the design of the tread pattern and hardness of the tread rubber. One remark is that in this research an FT is the so-called Nordic type of tyre and it has been optimised for snow and icy roads, i.e. for real white winter conditions. There is a large market segment for “Central European winter tyres”, but wet asphalt grip and speed rating have a higher priority than snow and ice performance for this type of tyre.

The main advantage of studded tyres is clearly the ice grip close to a temperature of 0 °C (Rantonen et al., 2012; Svendenius et al., 2009). In addition, the roughening of the asphalt surface might have a positive indirect effect on the grip that the road can provide. Therefore it protects against polishing, which is a major problem on some road networks. A rough road surface may offer a better grip, especially in wet conditions. However, general guidelines are difficult to draw up, because the length scale of the roughness seems to be important. A macro rough asphalt surface can store water in the valleys between stones, thus providing more roughness for the viscoelastic dissipation of the rubber, which results in sliding friction (Persson et al., 2004). It is possible that the slipperiness of the ice is partly due to its smoothness and inability to store melt water. However, the ice does not actually melt to a significant extent under the tyre contact patch, but only very locally (Fülöp and Tuononen, 2013). The influence of the roughness and quality of the ice on the friction coefficient was studied as early as in the ‘90s (Shimizu and Nihei, 1992) with an indoor drum, but the tyre technology has changed significantly since those days. However, they observed that the ambient temperature has a greater effect

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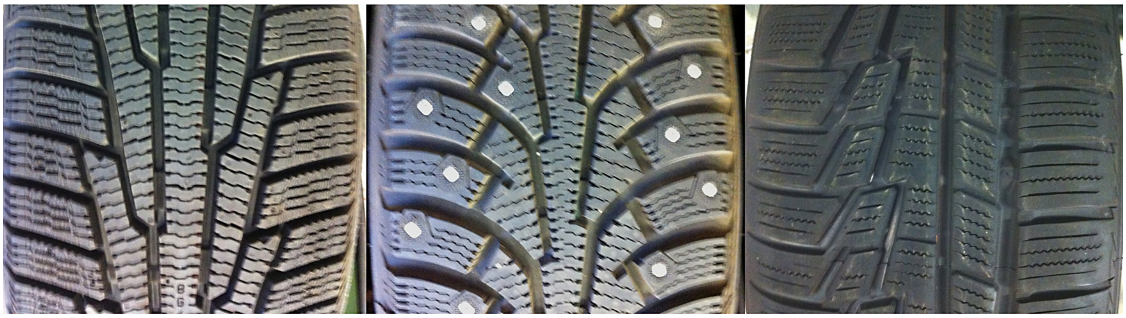

Fig. 1. Three types of winter tyres: Nordic winter tyre ("friction tyre") on the left, studded tyre, and Central European winter tyre on the right (not considered in this article).

on ice friction on smooth surfaces than on macro-rough surfaces (roughened by studded tyres).

Thus, it is possible that the ice being roughened by studded tyres is a prerequisite for friction tyres being able to be operated safely on icy roads. This statement is challenged in this paper.

Another essential aspect is whether studded tyres cause excessive wear of the road surface and road markings. This is both an economic and safety issue, because it can lead to rutting, which is a problem for lateral stability. Rutting can increase the potential for hydroplaning (Tuononen and Matilainen, 2009) and cause excessive road spray to reduce the vision of nearby motorists (Scheibe and Kirkland, 2002). In addition, studded tyres have a significant impact on noise (Becker, 2008) and on particle emissions because of road wear debris (Elvik, 1999; Karlsson et al., 2011; Kupiainen and Pirjola, 2011; Wik and Dave, 2009). A very plausible parameter study of the road wear caused by studded tyres was given by Gültlinger et al. (2012). A recent study shows that further reductions in particulate matter air pollution can be expected to reduce the number of lung cancer cases in Europe (Raaschou-Nielsen et al., 2013).

In order to reduce these negative effects, the usage of studded tyres is limited and their properties are regulated (Finnish Legislation, 2009). The number and properties of the studs have been revised every now and then. Recently, in Finland, the limitation on the number of studs has been able to be overruled if the road wear performance is proven separately. However, the road wear performance test is typically performed in summer conditions and the tyre is not braked or driven, i.e. the tyre is nearly rolling freely. Hence, the test probably does not give a proper indication about the road wear in winter conditions. It is worth noting that the Finnish stud regulations have previously been more or less adapted to the Swedish, Norwegian, and Russian markets.

There have been several total bans on studded tyres, e.g. in Germany and Japan, because of their negative environmental effects. There have also been many attempts to evaluate the safety benefits of studded tyres in winter traffic over the decades (Elvik, 1999; Fridstom, 2000; Roine, 1999; Strandroth et al., 2012; Zubeck et al., 2004). The importance of controlling confounding variables is extremely significant when evaluating the safety mechanism of studded tyres. For example, many studies indicate reduced accident rates for studded tyres, but in studies that control the driver-related variables better, the effect of studded tyres on accident rates almost disappears (Elvik, 1999). Studded tyres seem to have a slight positive effect on traffic safety, but this should be judged against the negative effects and costs to society and its members (Elvik, 1999; Elvik et al., 2013).

It was concluded in a recent article (Strandroth et al., 2012) that "studded tyres were found to have a statistically significant effect of 42% in terms of fatal crash reduction on roads covered with ice or snow, compared to non-studded winter tyres". It should have been emphasised more clearly that this result is based on cars without ESC (electronic stability control), which is not a likely scenario in a modern traffic environment. Moreover, the researchers stated that loss-of-control accidents are avoided with ESC, and studded tyres are not crucial to avoid these accidents. In a recent experimental study (Hjort et al., 2013), new and worn friction tyres achieved the same lateral stability rating as new studded tyres on a smooth ice surface.

Thus, in our opinion, it is shown by scientific research that friction tyres provide an adequate grip in most winter conditions and are a safe choice for modern cars with ESC. However, a crucial question remains unexplored: do studded tyres prevent icy roads from polishing and thus provide a decent level of irregularities in the road surface so as to maintain the grip of friction tyres? This could be termed an indirect safety effect of studded tyres. It is expected that a hard metal pin of the studs can scratch the ice surface and thus increase ice roughness (preventing polishing).

It has been proposed earlier that a reduced studded tyre flow may or may not reduce friction, depending on the ambient temperature and other effects of the weather (Vaa and Giaever, 2004). These tests were performed on rough ice and with a special friction meter or a measurement trailer (none of the tyres used were specified) and using a 30% slip ratio, which is unrealistically high for modern cars. In this study the effect is studied starting from the worst-case scenario for friction tyres, which is a smooth ice surface (e.g. black ice). It is also very important to measure the friction with a real tyre in the car instead of a friction meter, which is not certainly optimised for winter conditions and cannot control the tyre in the same way as a modern Anti-Block System (ABS). The authors propose that the main results of the study by Vaa and Giaever (2004), e.g. in their Fig. 3.2, are not plausible. As an example, their data shows that the friction coefficient hardly changed at all when the ambient temperature decreased from −1 °C to −14 °C, even if a 100% increase could be expected. Besides that, the authors suggested further studies because of the weather conditions during their field test.

Another earlier attempt to identify the indirect effect of studded tyres was made by VTI in 1990 (Nordström and Samuelsson, 1990). Friction measurements were performed using a special measurement vehicle, the BV12, and the ice surface was roughened by a special trailer with two sets of studded tyres at a steering angle of 10 degrees. The friction increased until there had been 20 roughening runs, but stabilised to a constant value after that. The roughening effect was more pronounced on wet ice and less when the ice temperature went down to below −5 °C.

In a recent analysis (Elvik et al., 2013), there are indications that the number of accidents increases when the use of studded tyres goes below 20–25% of the cars.

In this paper, the effect of the proportion of studded tyres and traffic flow on the ice grip of friction tyres in a controlled