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STUDY ON THE EFFECTS THAT THE DECREE ON TYRE STUDS HAS HAD ON CURRENTLY AVAILABLE STUDDED TYRES

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1. INTRODUCTION

1.1 Background and purpose of the study

In 2009, regulations concerning tyre studs for vehicles entered into force in Finland, the transition period for which ended on 1 January 2013 (LVM 2003/408; LVM 2009/466). The new decree changed the basis for determining the number of studs from rim diameters to tyre rolling circumferences. The maximum number of studs was limited to 50 studs per one metre of tyre rolling circumference. This meant an average reduction of around 15% in the number of studs used in the most common tyre sizes at the time. (Unhola 2008, 20)
In connection with this change in decrees, the long-term ban on placing studs in the middle third of a studded tyre was abandoned, meaning that studs could now be placed on the entire cross-sectional surface of the tyre.

Simultaneously, an amendment was added to the decree that provided the opportunity to apply for the type approval of a studded tyre on the basis of an alternative based on road wear instead of the option based on the number of studs (the over-run test). Tyres that were approved on the basis of the over-run test were allowed additional freedoms related to e.g. the number of studs, stud mass, stud protrusion and stud force.

In 2009, the over-run test was used to demonstrate that the tyre that was up for approval did not cause any more road wear than a generally available studded tyre that had been granted type approval. In 2011, the over-run test included fixed wear limits for stone samples for the first time. In 2013, the wear limits for stone samples were restricted further. These wear limits were still in use at the time that this study was written.

The over-run test has become the established type approval method for studded tyres, and the type approval based on the number of studs used has become the exception. This has resulted in a situation where, in a very short period of time, the number of studs used in tyres has increased significantly, with the largest figure reaching 250 studs / tyre (Michelin XIN4), i.e. 1000 studs / vehicle. As the number of studs has increased, the studs have also changed. To meet the limit values for road wear when using a greater number of studs, there has been a reduction in stud sizes. Even though other changes have also been made to studded tyres during this decade, for the purposes of this review the most significant changes are related to the studs and to the number of studs used.

The purpose of the study was to assess how the studded tyres that are on the market have changed after the latest amendment to the decree on tyre studs (2013). What changes have occurred with the tyres' ice grip features and over-run wear. The purpose of the study was also to ascertain how the ice grip features and over-run wear of a tyre change when there is a decrease in the number of studs used in a tyre. At the same time, the study will also provide researched information for the background work of the ongoing Trafi regulation drafting process on whether the grip features of the tyres that have been changed in this way remain at a usable and safe level for use in winter conditions.

1.2 Research material and method

After the amendment to the decree in 2013, the most important change to the tyres that are available on the market was in the number of studs used. On the one hand, some tyres were brought to market with a decreased number of studs. On the other, some tyres were also introduced that featured a significant increase in the number of studs used when compared to the products that were available before the amendment to the decree was made. The study included those tyres where the change in the number of studs used was most prevalent. The second selection criteria were that the same manufacturer had to be able to provide several different generations of studded tyres for testing.

In addition, the study material included four example tyre brands from three different manufactures, and 25% of the studs were removed from these tyres. These tyres were compared to a set of control tyres that featured the full number of tyre studs.

The study method utilised tyre ice grip measurements, i.e. ice acceleration, ice braking and ice circle as well as the over-run test. The grip measurements were done in Ylöjärvi ice arena and the over-run tests were conducted in Hanko Airfield. The tests were implemented by BD Testing Oy.
The tyre size was 205/55R16.

Tyre model		DOT / Production week	Country of manufacture	Year introduced to market	Number of studs	Studs per metre of rolling circumfere	Stud weight [g]
205/55R16 94T XL	Nokian Nordman 7	DOT 60CP 2418	Russia	2009 (2017)*	128	64	0.98
	Nokian Hakkapeliitta 8	DOT 60CP 3418	Finland	2013	190	96	0.84
	Nokian Hakkapeliitta 9	DOT 60CP 2218	Russia	2017	190	96	0.80 / 0.87****
	Michelin X-Ice North XIN2	22WC 7W6X 1211	Russia	2009	118	59	0.95
	Michelin X-Ice North XIN3	22WC OUAX 2317-2417	Russia	2012	96	50	0.97
	Michelin X-Ice North XIN4	DOT OK1X 2018-2818	Russia	2018	250	126	1.23
	Yokohama Ice Guard IG55	TK8K YYY 2517-3117	Russia	2014	128	64	0.89
	Yokohama Ice Guard IG65	TK8K YYY 3018-3118	Russia	2017	172	87	0.82
	Continental Ice Contact	CPOF NVVD 3813-3913	Germany	2010	130	65	0.98
	Gislaved Nord Frost 100	VLOF CNV8 2315	Russia	2013	96	50	0.97
	Continental Ice Contact 2	CPOF CUJ6 3218	Germany	2015	190	96	0.77

* **2009** *Nokian Hakkapeliitta 7* , **2017** *Nokian Nordman 7* (Type approval extension > change in product name)
** **2013** Tyre stud model changed
*** Rolling circumference calculated using ETRTO's nominal diameter
**** Tyre features 2 stud models

Table 1. Tyres under inspection

1.3 Organisation of the research

This study was commissioned by the Finnish Transport Safety Agency (Trafi). The contact person of the commissioner of the research was Keijo Kuikka. The production of the research was implemented by Black Donuts Engineering inc. (BDE) and their responsible persons were the development managers Jouni Raatikainen and Henri Kossi. The tests in their entirety were conducted by BD Testing inc., a testing laboratory approved by Trafi.

The idea for the study was presented in the summer of 2018 in a joint meeting with BDE and Trafi. The implementation itself was initiated in October 2018.

2. TESTING PROCESS

2.1 Tyre acquisition

The tyres were acquired primarily from the RengasCenter in Pirkkala in October 2018. The objective was to acquire tyres that were as new as possible. However, it was clear from the start that few new production lots would be available for the oldest models that were to be tested. The limit was set at 5 years from the date of manufacture, which corresponds with the recommendations set by the tyre industry's European organisations (STRO, ETRMA) and the Automobile and Touring Club of Finland. However, this requirement could not be met for the Michelin XIN2 (manufacturing year 2011).

2.2 Delivery inspection

A delivery inspection was performed for every tyre. The tyres were inspected visually, their basic details were recorded, and the tyres' hardness, weight and every stud protrusion were measured. The tyres' delivery inspection records are presented in appendix 1.

Figure 1. Measurement of stud protrusions

2.3 Reducing the number of studs

The purpose was to study the effect that the decrease in the number of studs had on the studded tyre's over-run wear and ice grip. As stated previously, there has been a significant and rapid increase in the number of studs used in studded tyres. The studs themselves have also been changed. Different tyre manufacturers utilise very different studs when it comes to their shape, size, material and weight. In addition, the same tyre can feature two different types of studs (Nokian Hakkapeliitta 9, Continental Ice Contact 3). Of the tyres that were inspected, the lightest stud weighed 0.77 g (Continental Ice Contact 2) and the heaviest 1.23 g (Michelin X-Ice North 4). Of the types of studs used, 11 featured aluminium frames and 1 featured a steel frame.

Figure 2. Stud types used in the tyres that were inspected

When a large number of studs are used, it is fairly easy to remove them in a way that the end result is as optimal as possible for the product's features when it comes to the placement of the studs.
The stud number study included four different products from three different manufacturers: Nokian Tyres Hakkapeliitta 8 and 9 (190 studs in both), Michelin X-Ice North 4 (250 studs) and the Yokohama Ice Guard IG 65 (172 studs). These products represented the largest number of studs used on the market. The Continental Ice Contact 2 would also have been a good addition to this study due the number of studs that are included in it, but since the studs are glued to the tyre, their removal would have caused too much damage to the tyre.

It was decided that 25% of the studs used in the aforementioned tyres would be removed. The reasons for this were manifold: first, the goal was to reduce the number of studs in a way that, based on prior experience, the change would be evident in the ice grip measurements and the over-run test. Second, since this study material will be used later as background material during the drafting process for the new amendment to the decree on tyre studs, the implementers of the study wanted to ensure that the order of magnitude of this change in the number of studs would be realistic considering the estimated future need for change.
Third, after the reduction, the remaining number of studs should be such that, from the perspective of planning, the principles of good stud distribution in a tyre would still remain intact.
What should be kept in mind is that, for the purposes of this study, the studs could only be removed from the tyres. If the tyres had been designed to use fewer studs from the get-go, their placement would likely have been partially different.

From a layman's perspective, the way that studs are placed on a tyre can seem random. This, however, is not the case. Good stud run planning, i.e. stud placement in proportion to other studs and the tread pattern used, can have a significant effect on a tyre's grip and noise features.

The detailed original locations of the studs in the tyres that were inspected were determined using laser measurements. These measurements were used in the planning of the stud reduction process. The objective was to ensure that the original placement principle of the studs remained intact. The studs were removed in a way that the number of studs featured on the road contact surface would remain proportional to the original design. If the number of studs on the road contact surface varied in the original stud run, this natural variation was preserved using a smaller number of studs.

The studs were removed evenly from different stud rows in a proportional manner to the original emphasis model. If the original stud placement did not feature any identifiable stud rows, the tyre was divided transversely into several sectors, from which the studs were removed on a sectoral basis while following the original stud run. The goal was to remove the studs evenly from the differently sized sectors if the aforementioned requirements were first met.

Figure 3. The studs were removed using a device designed for this purpose

2.4 Ice grip measurements

The ice grip measurements, i.e. ice acceleration, ice braking and ice circle, were done in Ylöjärvi ice arena. A front-wheel drive VW Golf 2.0 TDi was used for the ice grip measurements.

When testing any ice-related features of a tyre, the identification and management of testing conditions represent key factors. The features of the ice and the surrounding environment have a significant effect on the types of grip features that a tyre can achieve. To be able to generate a reliable result, the conditions must remain unchanged during the entire testing series.
The tyre industry has begun to emphases indoor testing for any ice-related tests. This way, temperature and air moisture can be kept very stable during testing. Indoor testing also helps

prevent the effects of snow, wind and the sun on the measured results. In addition, the preparations for the testing platform can be done in a replicable manner.

The conditions present in Ylöjärvi ice arena are favourable for studded tyre tests. When the temperature is near the melting point of ice, there is very little surface friction. These conditions correspond to a situation where the need for studs is at its greatest. The weakness of the ice arena is its size. Due to the small space available, the speeds used in the tests are low.

In addition, even an ice arena cannot completely eliminate every change in condition. The established method in tyre testing is to measure any changes in condition using a control tyre. During the testing series, the control tyre is subjected to several measurements, and at least one at the beginning and end of the testing series. This study utilised either 3 or 4 tyre versions, including the control tyre, as the size of the testing series. The control measurements were conducted at the beginning and end of the testing series.

The effect that stud protrusion has on ice grip is significant. When driving on ice, the stud transmits a significant share of the forces between the vehicle and surface. Braking and accelerating repeatedly and forcefully during the test increase stud protrusion. The control tyre is subjected to more test runs than other tyres, so the assumed change in stud protrusion will also be greater. For this study, the Continental Ice Contact 2 was selected as the control tyre. The tyre in question features studs that have been glued to the tyre, which helps prevent changes in protrusion and thus variance in the grip level of the tyre between different test measurement runs. The stud protrusions of every test tyre were measured before and after the test.

Each tyre was subjected to 5 consecutive measurements during the acceleration and braking tests, and each of these was conducted on an undriven icy surface. The results include the average of the measured results, which was then corrected on the basis of the change in conditions measured using the control tyre. The acceleration test measured the time spent on acceleration for speeds between 5−20 km/h, and the braking test measured braking distances for speeds between 20−5 km/h.

The circle test measured lap times. Along with the tyre's side grip, lap times are also affected by how predictably the tyre will perform when it is at the limit of its grip. The lap time is thus the joint result of both grip and handleability. Before the measurements were made, the ice was coarsened by driving a few laps on it with studded tyres. The test driver drove enough laps with each test tyre so that the tyre's driving behaviour could be ascertained and the lap time stabilised. During the circle test, the control measurements were conducted at the beginning and end of the testing series. Figures 4−8 present the test series of the ice grip tests.

Figure 4. Test series 1

Figure 5. Test series 2

Figure 6. Test series 3

Figure 7. Test series 4

Figure 8. Test series 5

Figure 9. Test series 6

Figure 10. Test series 7

Figure 11. Test series 8

2.5 Over-run tests

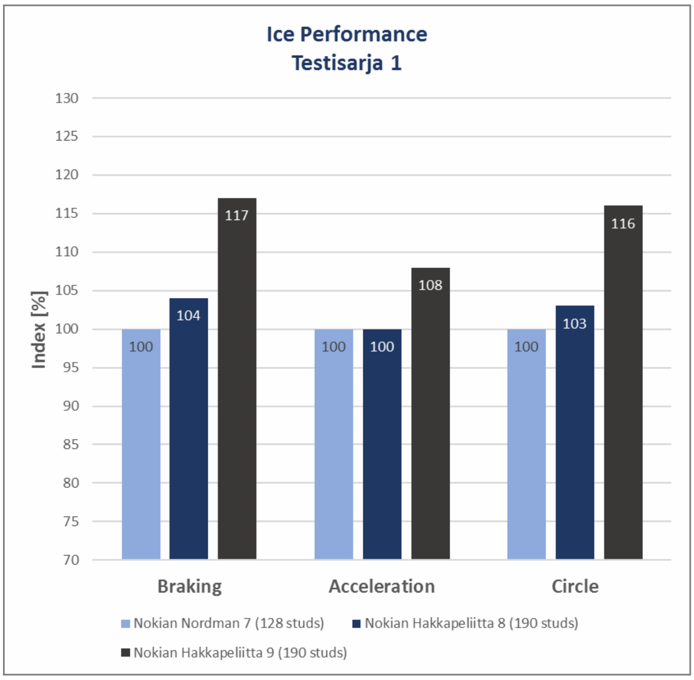
The over-run tests, i.e. the road wear measurements, were conducted at Hanko Airfield between 19 November and 10 December 2018. The tests were conducted in accordance with standard regulations (SFS 7503:2018). The test car was a four-wheel drive BMW X1. Due to the timing of the tests, the temperature was fairly low (2.2 … 6.6 °C). During most test runs, the surface of the test course was either damp or wet.
The processing and weighing of the test stones were conducted at BD Testing’s laboratory in Pirkkala. All test stones that were used in these tests came from the same production lot. The test tyres were the same tyre specimens that were used in the ice grip tests.

3. RESULTS

3.1 Ice grip and over-run wear

3.1.1 The ice grip and over-run wear of different product generations

The results present the change in ice grip features and over-run wear in the products made by the same manufacturer across different product generations. The ice grip results use the measurement result of the oldest product as the reference figure. This has been issued with a ratio of 100. The ice grip of newer products has been compared in relation to the oldest. The over-run wear has been recorded according to the average wear of the sample rows, in accordance with the standard for the over-run method (SFS 7503:2018). The descriptors include the type approval limit for the inspected tyre size.



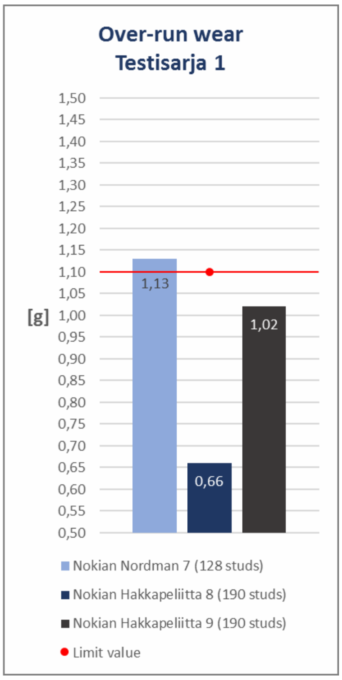


Figure 12. The ice grip and over-run wear of different product generations, Nokian

The first test series compared three studded tyres manufactured by Nokian Tyres: Nokian Nordman 7 (128 studs), Nokian Hakkapeliitta 8 (190 studs) and Nokian Hakkapeliitta 9 (190 studs). The Nokian Nordman 7 was brought to market in 2009, but with a different name (Hakkapeliitta 7). This is why the Nordman 7 has been used as the reference point, i.e. the oldest product, for this test series.
The results of the ice grip tests (Figure 12) demonstrate that the ice grip of products with a larger number of studs is better. The Hakkapeliitta 8 has, on average, 2% more grip than the Nordman 7.
The Hakkapeliitta 9 clearly has the most grip. On average, it has 12% more grip than the Hakkapeliitta 8 and 14% more grip than the Nordman 7.

Despite the significant increase in the number of studs used in relation to the Nokian Nordman 7, the products that feature a greater number of studs exhibit less over-run wear. The result of the Nordman 7's over-run test did not go below the type approval limit (1.1 g). The over-run wear of the Hakkapeliitta 8 was clearly the lowest among the tyres that were included in the study.

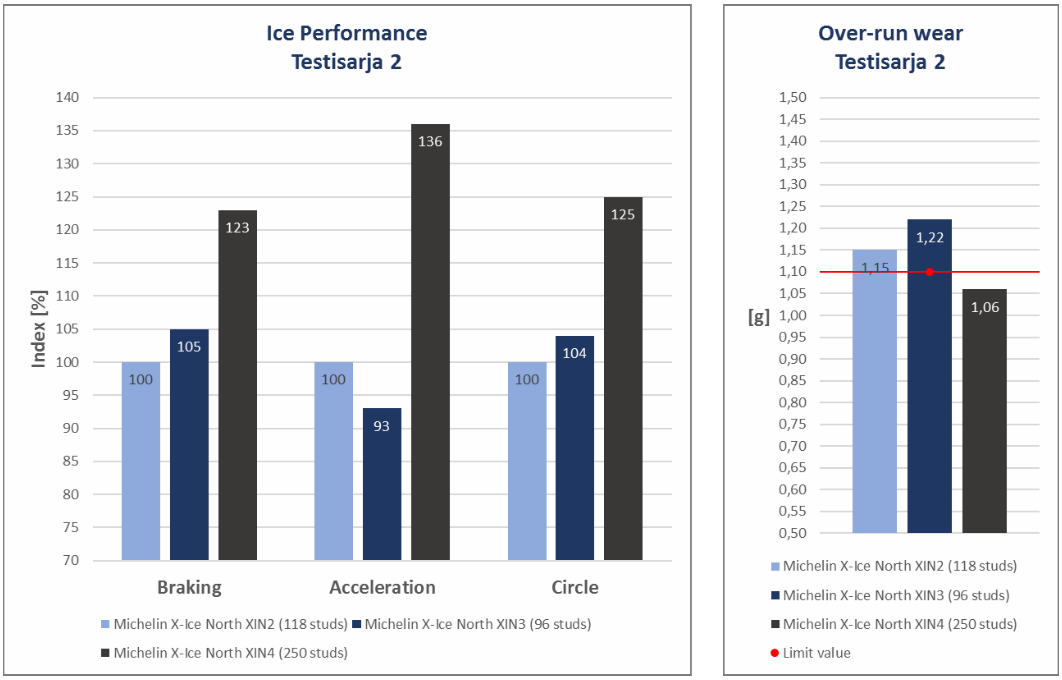


Figure 13. The ice grip and over-run wear of different product generations, Michelin

Test series 2 featured three studded tyres manufactured by Michelin: Michelin X-Ice North XIN2 (118 studs), Michelin X-Ice North XIN3 (96 studs) and Michelin X-Ice North XIN4 (250 studs). When assessing the results, keep in mind that the XIN2 was the only product in the study that did not meet the production time requirement that was set by us (max. 5 years). The rubber mixture used in the tyre begins to lose its features over time, and this can be assumed to have an effect on the results of the test.

The results of the ice grip tests (Figure 13) demonstrate that the XIN4 is superior when it comes to its ice-related features. On average, it has 27% more grip than the XIN3 8 and 28% more grip than the XIN2. The results of the over-run test demonstrate that the XIN4, which is the only tyre that falls below its type approval limit, had the lowest wear result, and the XIN3 had the highest wear result. The XIN4 features 2.6 times more studs than the XIN3, and one stud weighs 27% more as well.

Even though the products featured other differences that affect wear, such as the number of studs used and stud weight, the result of the over-run test is surprising and contradicts several other research results. The effects of stud weight on surface wear has been studies by e.g. Unhola (1989) and Gültlinger et al. (2014). The effect of the number of studs used on over-run wear is studied in this study as well.
The results of the stud number tests are presented later in this report in chapter 3.1.2.

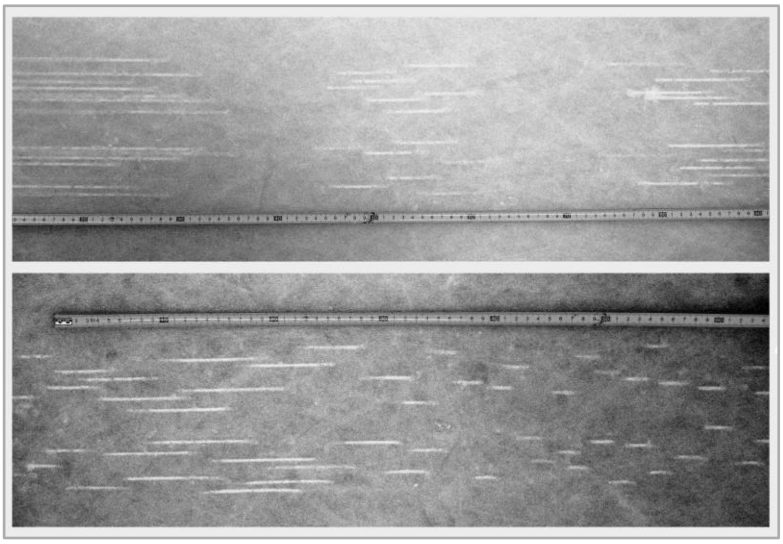


Figure 14. Stud scrape marks from the ice grip test

At the beginning of the 2000s, new types of studded tyres were introduced to the market where the shape of the studs was no longer round. At the same time, manufacturers began placing studs in an aligned manner, meaning that the studs were placed on the tyre in specific positions. Today, many studded tyres feature “rotation directions” for the studs as well, meaning that the stud is different on its entry and exit sides. The length of ice contact for a single stud can vary greatly in acceleration and braking situations (Figure 14).

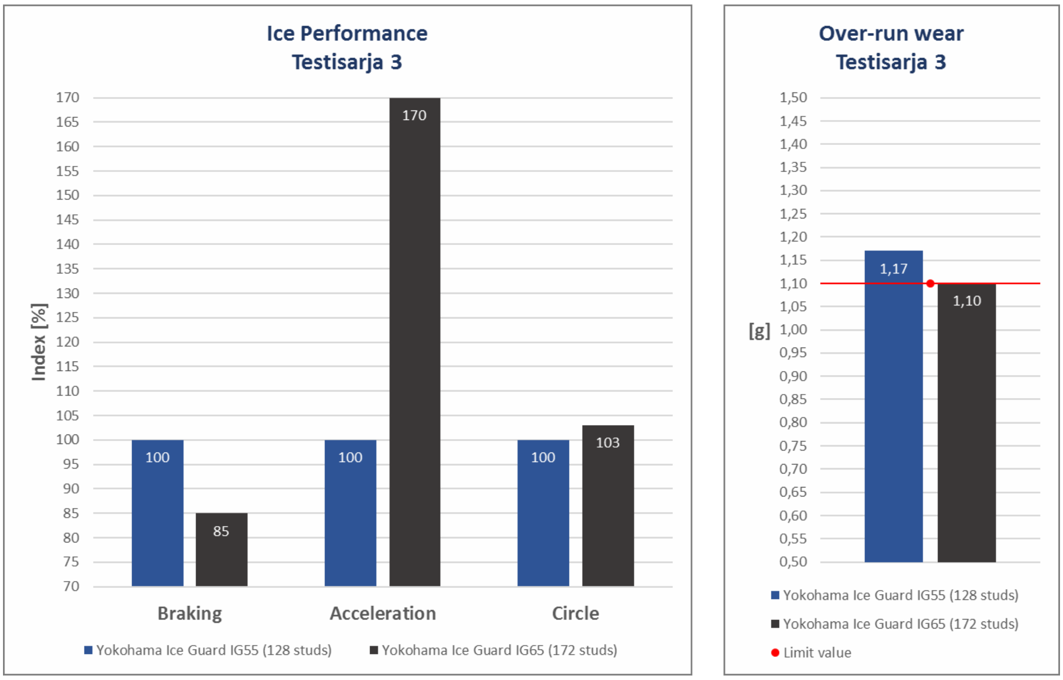


Figure 15. The ice grip and over-run wear of different product generations, Yokohama

Test series 3 featured two studded tyres manufactured by Yokohama: Yokohama Ice Guard IG55 (128 studs) and Yokohama Ice Guard IG65 (172 studs). The ice grip results (Figure 15) demonstrate that the IG65, which contains the largest number of studs, does not function especially well during braking situations. However, its results during acceleration were excellent when compared to its predecessor, the IG55.

The IG65 features around 19% more grip when on ice than its predecessor. The over-run wear of the IG65 is also smaller. The result of the IG55's over-run test did not go below the type approval limit (1.1 g).

Figure 16. The ice grip and over-run wear of different product generations,

Test series 4 featured three studded tyres manufactured by Continental: Continental Ice Contact (130 studs), Gislaved Nord Frost 100 (96 studs) and Continental Ice Contact 2 (190 studs). In the ice grip tests (Figure 16), the results followed the number of studs used. The tyre with the most studs also had the most grip. The Ice Contact 2 featured, on average, 28% more grip than the Nord Frost 100 and 14% more grip than the Ice Contact.

The results of the over-run test demonstrate the Continental Ice Contact's large over-run wear figure (1.54 g). This wear result was clearly the largest that was observed out of all the tyres in the study. The stud force of the studs used in the Ice Contact was also the largest out of all the tyres in the study (225 N). Stud force figures are discussed in more detail in chapter 3.2. What is particularly notable is that none of the tyres in this test series fell below the over-run test's type approval limit (1.1 g). The stud used in the Gislaved Nord Frost 100 is an approved type, so the tyre/stud combo in question did not require an over-run test in connection with its type approval process.

3.1.2 The effect of the reduction in the number of studs on ice grip and over-run wear

The results demonstrate the effect that the change in the number of studs has on ice grip features and over-run wear. The ice grip results use the measurement result of the tyre with a full number of studs present as the reference figure. This has been issued with a ratio of 100. The over-run wear has been recorded according to the average wear of the sample rows, in accordance with the standard for the over-run method (SFS 7503:2018). The descriptors include the type approval limit for the inspected tyre size. The descriptor titled *The effect of studs reduced by 25%* presents the ice grip result as the average for the results of the braking, acceleration and circle tests (hereinafter ice grip (avg.)).

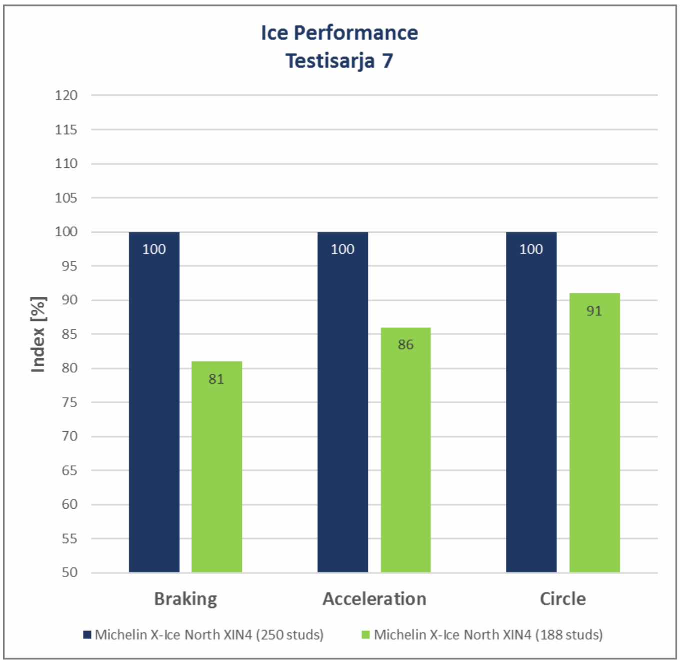
Figure 17. Number of studs reduced by 25%, Nokian Hakkapeliitta 8

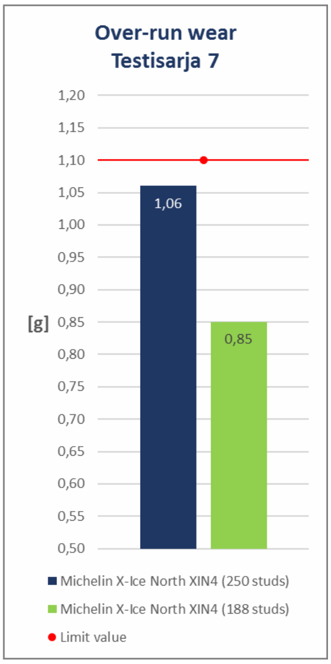
Test series 5 compared the Nokian Hakkapeliitta 8 when it is equipped with its full number of studs (190 studs) and 25% fewer studs (142 studs). The results (Figure 17) demonstrate that its ice grip (avg.) decreased by 5% after the number of studs was reduced. Over-run wear decreased by 12%.
Over-run wear with both numbers of studs was very small.

Figure 18. Number of studs reduced by 25%, Nokian Hakkapeliitta 9

Test series 6 compared the Nokian Hakkapeliitta 9 when it is equipped with its full number of studs (190 studs) and 25% fewer studs (142 studs). The results (Figure 18) demonstrate that its ice grip (avg.) decreased by 8% after the number of studs was reduced. Over-run wear decreased by 26%.

The effect that the number of studs present had on over-run wear was clearly greated with the Hakkapeliitta 9 than with the Hakkapeliitta 8, even though both models featured the same number of studs.





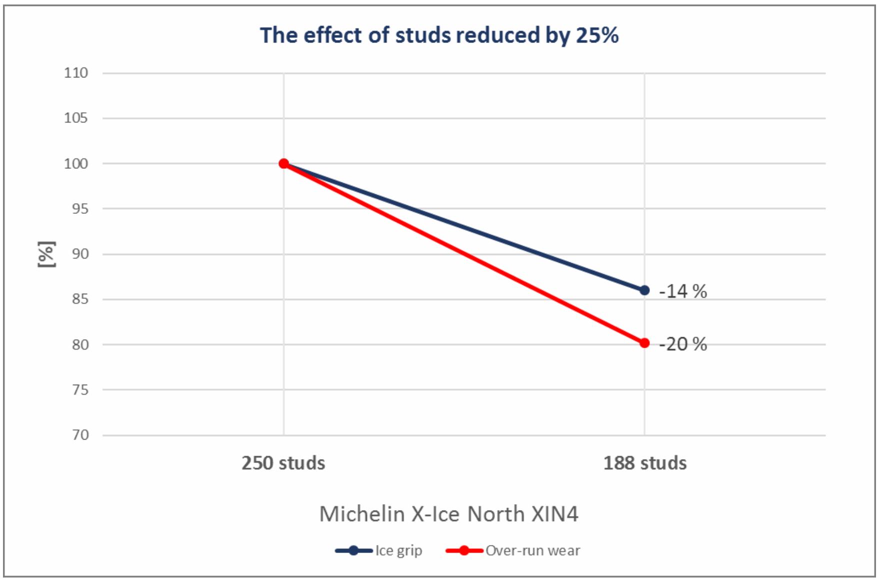
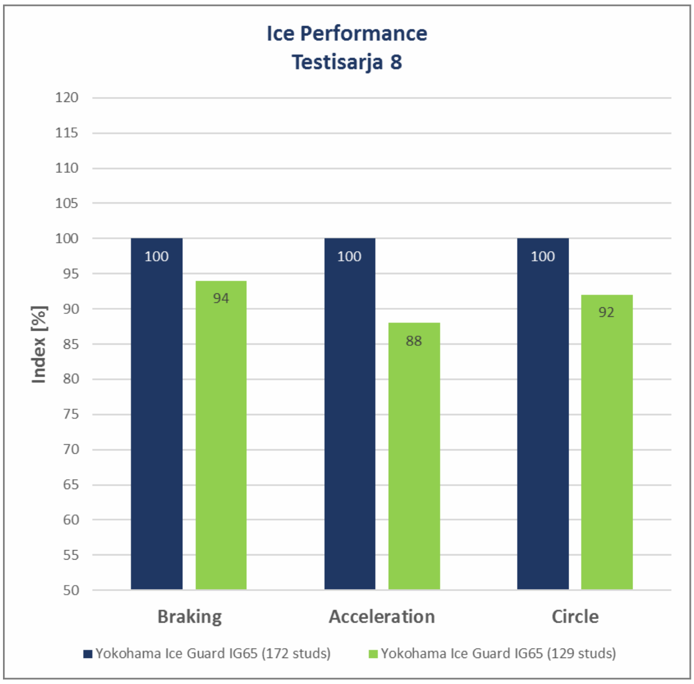
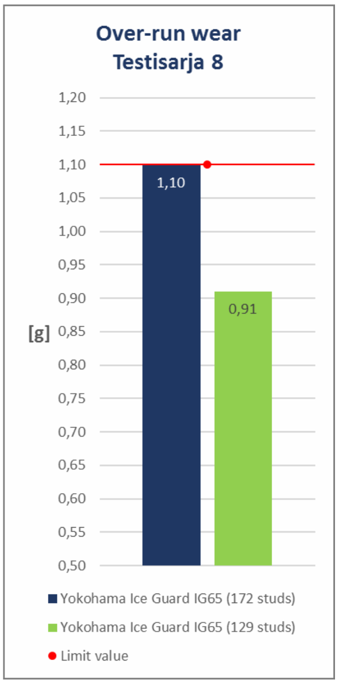


Figure 19. Number of studs reduced by 25%, Michelin X-Ice North XIN4

Test series 7 compared the Michelin X-Ice North XIN4 when it is equipped with its full number of studs (250 studs) and 25% fewer studs (188 studs). The results (Figure 19) demonstrate that its ice grip (avg.) decreased by 14% after the number of studs was reduced. Over-run wear decreased by 20%.





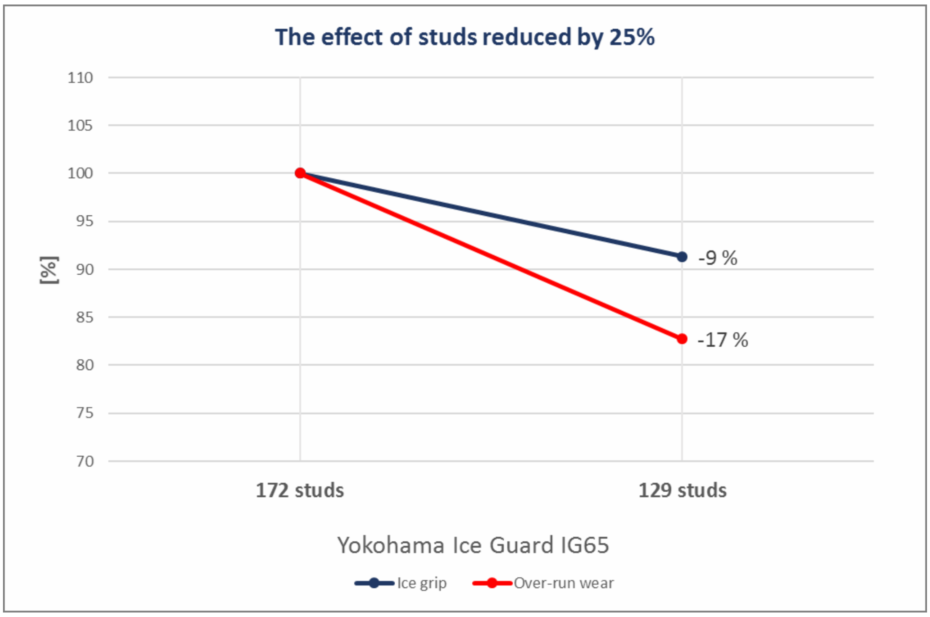


Figure 20. Number of studs reduced by 25%, Yokohama Ice Guard IG65

Test series 8 compared the Yokohama Ice Guard IG65 when it is equipped with its full number of studs (172 studs) and 25% fewer studs (129 studs). The results (Figure 20) demonstrate that its ice grip (avg.) decreased by 9% after the number of studs was reduced. Over-run wear decreased by 17%.

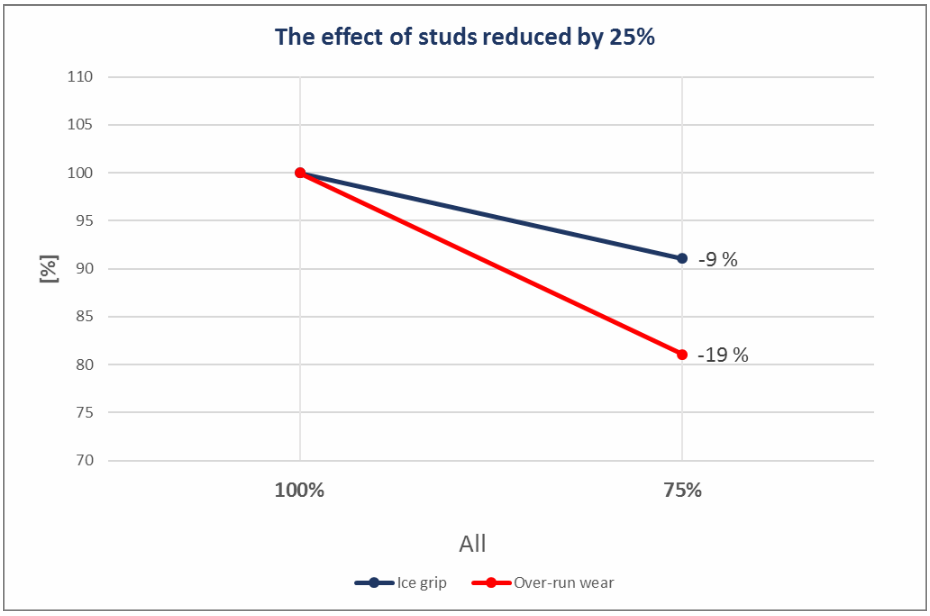


Figure 21. Number of studs reduced by 25%, average for all tyres

Figure 21 presents the average result for all stud number tests.
A reduction of 25% in the number of studs used reduced ice grip (avg.) by 9% on average. Correspondingly, over-run wear decreased by 19%.

Even though the results of individual tests do differ from one another, the conclusion is clear. The effect that the reduction in the number of studs used has on ice grip is clearly smaller than its effect on over-run wear. This difference can be explained when we take into consideration that the over-run wear of a studless tyre has been observed to be only around 2% of the over-run wear of a studded tyre (Unhola et al. 2004, 28). However, a studless tyre still exhibits reasonable friction features when driven on ice. The share of studs in over-run wear is therefore almost 100%, but the share that studs have in relation to ice grip is noticeably smaller than this.

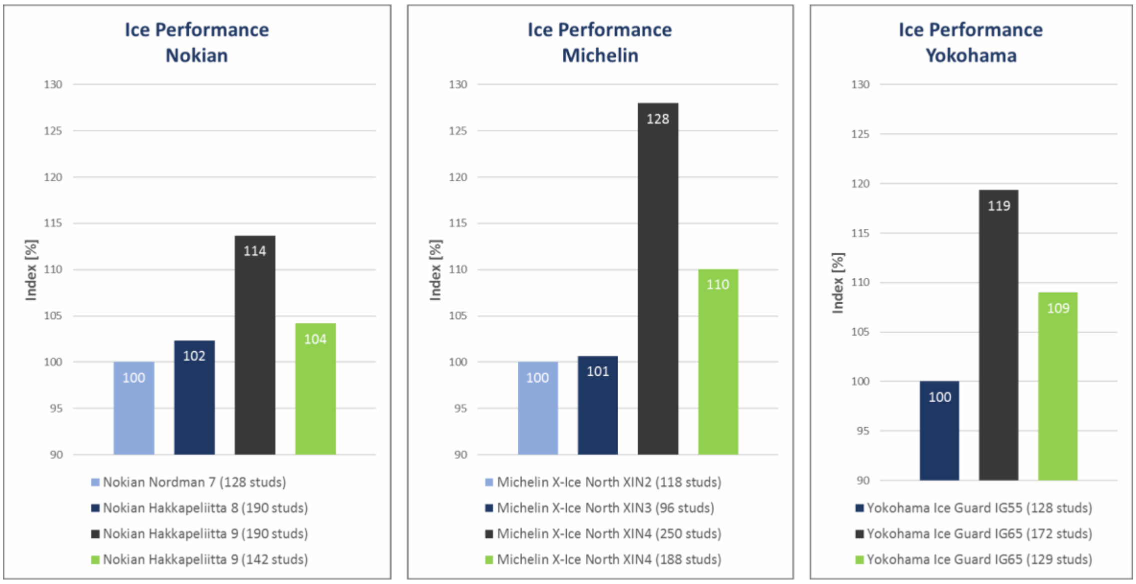


Figure 22. Product generation and stud number comparison

Figure 22 includes the product generations of three different manufacturers and presents their figures for ice grip (avg.) as well as the latest product's ice grip (avg.) with a reduced number of studs (-25%). For comparison, the descriptors also include the latest product with its full number of studs present. In each one of the three cases, the latest product with a reduced number of studs features more grip than previous product generations that include their stud numbers.

3.2 The stud force of a stud

Since the 1970s, when Finland began to impose regulations on studded tyres, stud force has been one of the key measures for type approval. The decree that entered into force in 2013 included the following limit values for stud forces: personal vehicle tyres 120 N, light truck tyres 180 N and truck tyres 340 N. An exception to this requirement is the type approval given on the basis of the over-run test, which includes stud force measurements but does not impose any limits to its value.

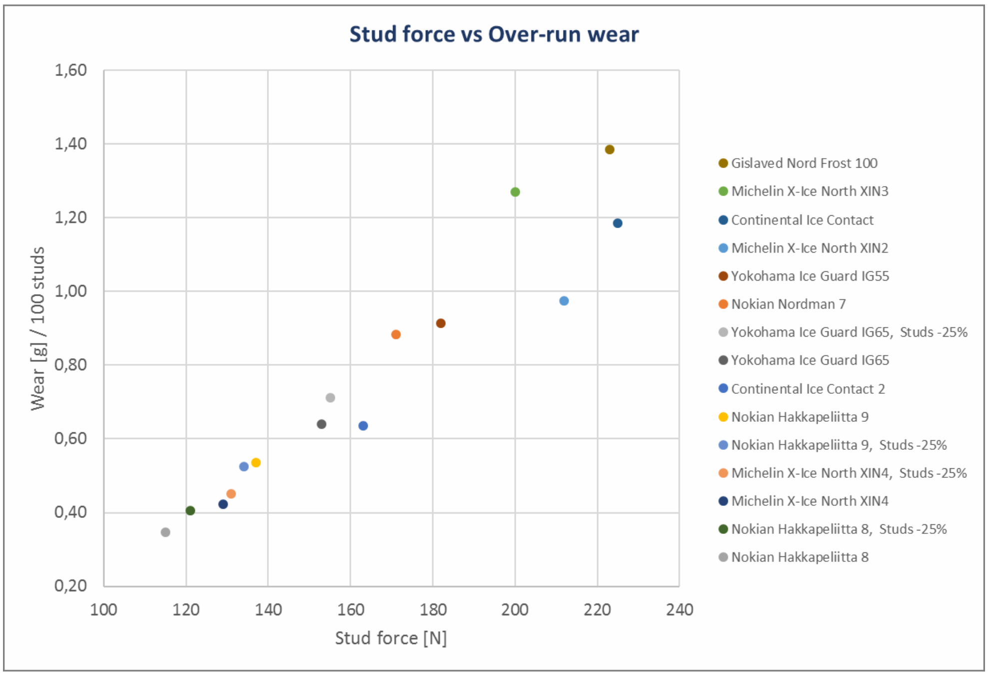


Figure 23. The relationship between stud force and over-run wear

Figure 23 presents the relationship between the stud force and over-run wear of every product included in the study. For the sake of comparison, the over-run wear of each tyre has been calculated for every 100 studs.

This study clearly demonstrates the correlation between stud force and over-run wear: when there is an increase in stud force, there is an increase in over-run wear. The figures for stud force also followed the number of studs present in the tyres in an inverse manner. When a tyre had a large number of studs, the stud force was smaller, and when a tyre had fewer studs, the stud force was larger.

Even though the majority of the tyres that were included in the study have been granted type approval on the basis of the over-run test, and thus were not subject to the limit on stud force, it should still be noted that only one of the measured products fell below the stud force limit that is based on the number of studs used (120 N).

Apart from one product, the stud force of every tyre in the study also exceeded the stud force declared in their type approval certificates (by 23 N on average). The Hakkapeliitta 8 was the only tyre to go below the value declared in its type approval certificate (declared value 160 N, measured value 118 N). Its stud force was the lowest out of all the products that were measured. This could also help explain its small result for over-run wear. In connection with this, we must state that at the time that the measurements were made, the tyres and their studs were older than they would have been when they were subjected to type approval. This could also have some effect on the measurement results.

3.3 Stud protrusion

3.3.1 Stud protrusion in new tyres

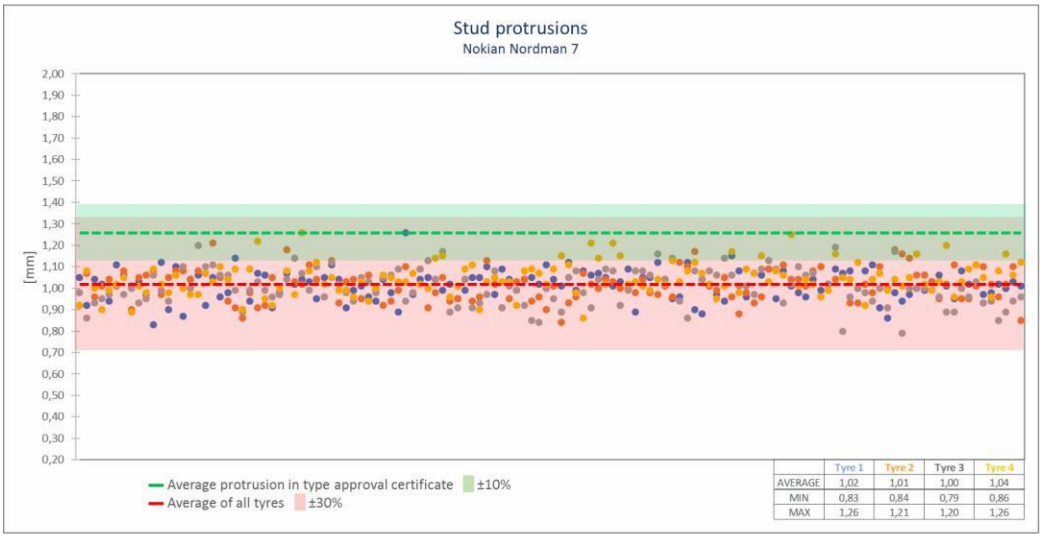
In Finland, the protrusion of studs is regulated with studded tyre regulations to ensure an adequate level of grip and limit road wear and environmental damage. The decree that entered into force in 2013 defined the following maximum levels for stud protrusions: personal vehicle and van tyres 1.2 mm and truck tyres 1.5 mm. These limits apply to tyres that have been approved on the basis of the type approval method that is based on stud numbers. Tyres that have been granted type approval on the basis of the over-run test are not subject to protrusion level requirements.

In 2014, an explanatory appendix on stud quality was appended to the method description for the over-run test. The tyre manufacturer was required to declare a target protrusion rate for the studs of the tyre in connection with the type approval test, which was then controlled during the type approval process. According to the decree, the average stud protrusion value of an undriven tyre should only be allowed to deviate by 10% from the target protrusion rate declared by the manufacturer, based on 20 consecutive studs and measured across the entire surface of the tyre. Correspondingly, the protrusion value of a single stud in the measured area is only allowed to deviate by 30% from the average protrusion value. After the over-run test, the average protrusion value is allowed to deviate by a maximum of 25% from the average protrusion value of an undriven tyre. These quality requirements are included in the standard for the over-run method (SFS 7503:2018).

Controlling the protrusion of studs is justified not only on the basis of road wear and environmental damage, but also on the basis of traffic safety. It is widely known that stud protrusion has an effect on a tyre's ice grip level. The sound caused by a tyre and the wear resistance of its studs also depend on the level of protrusion present. Even though the quality requirement for the studs used in the over-run test does not directly specify the protrusion level of mass-produced tyres, it is vital to ensure that no deviations are present one way or the other in mass production.

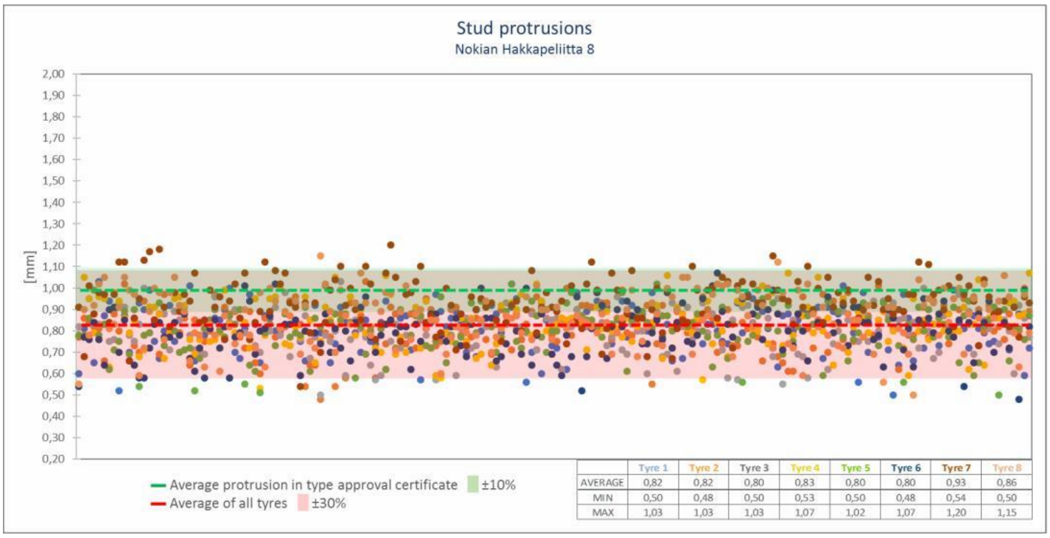
Figures 24–34 feature product-specific analyses of the stud protrusions present in undriven test tyres from the perspective of the quality of the studwork used. Almost all of the products featured in this study were type approved using the over-run method, and many of them before the explanatory appendix that was introduced in 2014. The products in question were thus not subject to any stud quality requirements in connection with the type approval process, and the manufacturers were not required to declare any target protrusion rates. However, to be able to generate a better overall picture, all of the products were included in the study.

If no target protrusion rate has been declared, the comparative figure for the products in question is taken from the stud protrusion average declared in the type approval certificate or from section 2 of the tyre stud decree (LVM 2003/408), which specifies an average protrusion limit (1.2 mm).



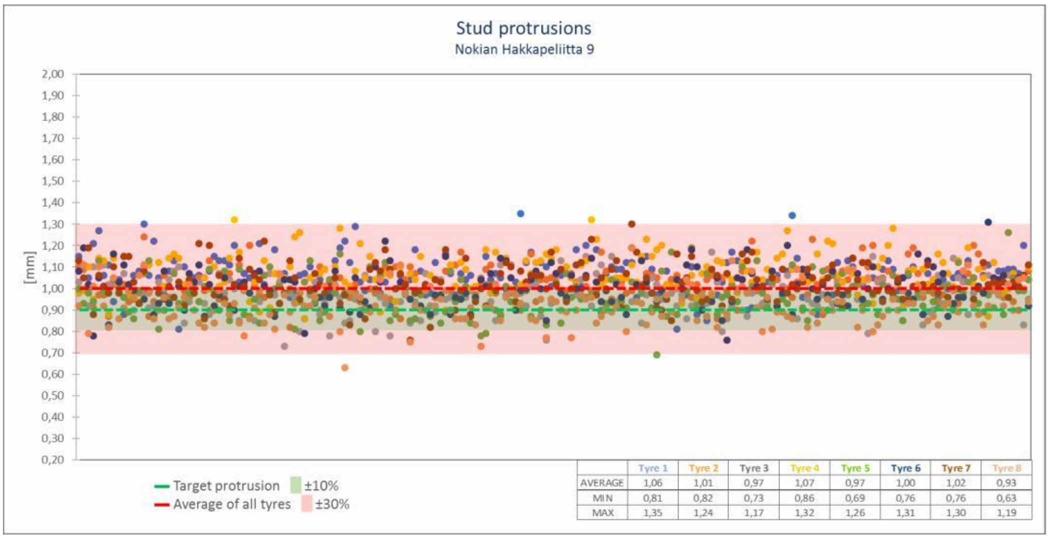
	Tyre 1	Tyre 2	Tyre 3	Tyre 4
AVERAGE	1,02	1,01	1,00	1,04
MIN	0,83	0,84	0,79	0,86
MAX	1,26	1,21	1,20	1,26

Figure 24. Stud protrusions, Nokian Nordman 7



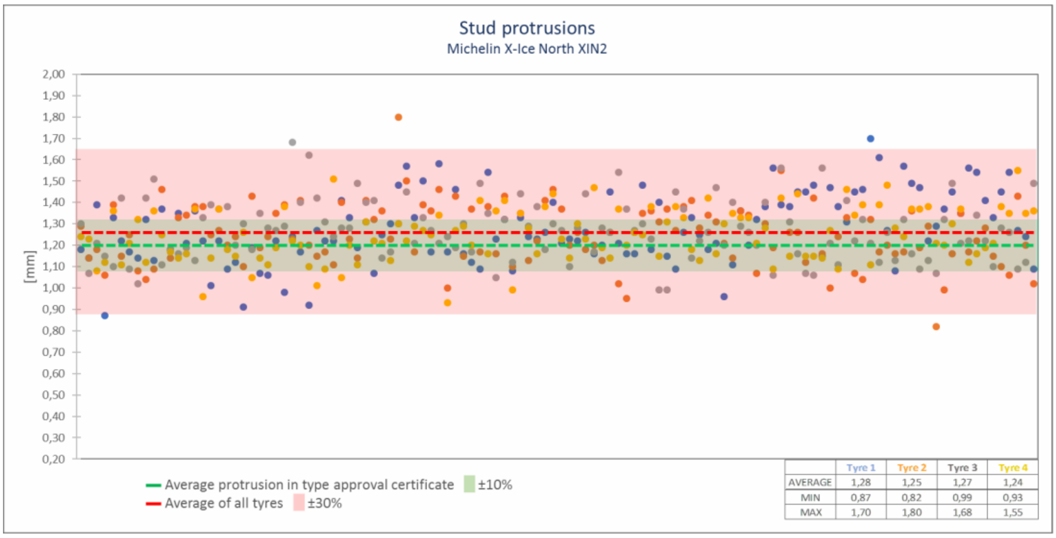
	Tyre 1	Tyre 2	Tyre 3	Tyre 4	Tyre 5	Tyre 6	Tyre 7	Tyre 8
AVERAGE	0,82	0,82	0,80	0,83	0,80	0,80	0,93	0,86
MIN	0,50	0,48	0,50	0,53	0,50	0,48	0,54	0,50
MAX	1,03	1,03	1,03	1,07	1,02	1,07	1,20	1,15

Figure 25. Stud protrusions, Hakkapeliitta 8



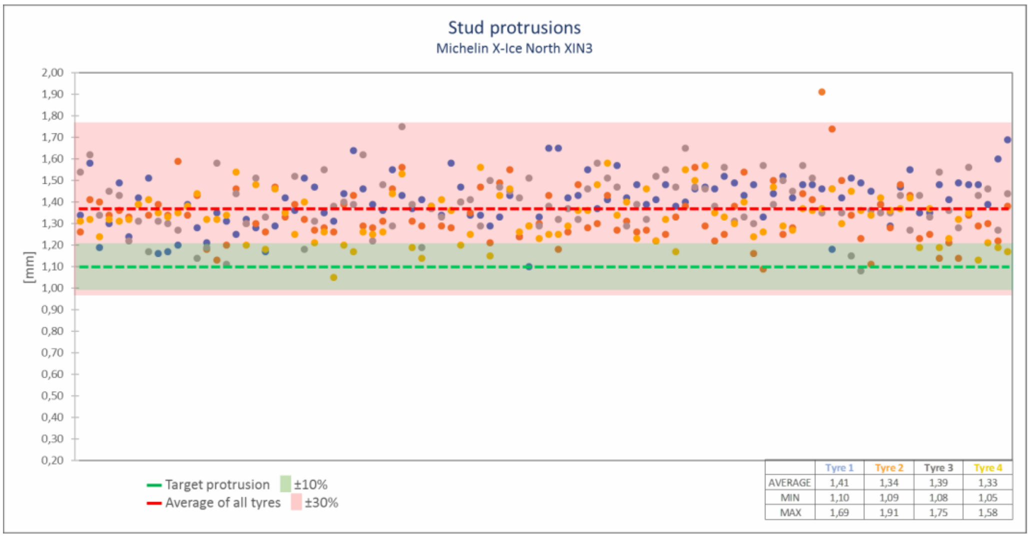
	Tyre 1	Tyre 2	Tyre 3	Tyre 4	Tyre 5	Tyre 6	Tyre 7	Tyre 8
AVERAGE	1,06	1,01	0,97	1,07	0,97	1,00	1,02	0,93
MIN	0,81	0,82	0,73	0,86	0,69	0,76	0,76	0,63
MAX	1,35	1,24	1,17	1,32	1,26	1,31	1,30	1,19

Figure26. Stud protrusions, Hakkapeliitta 9



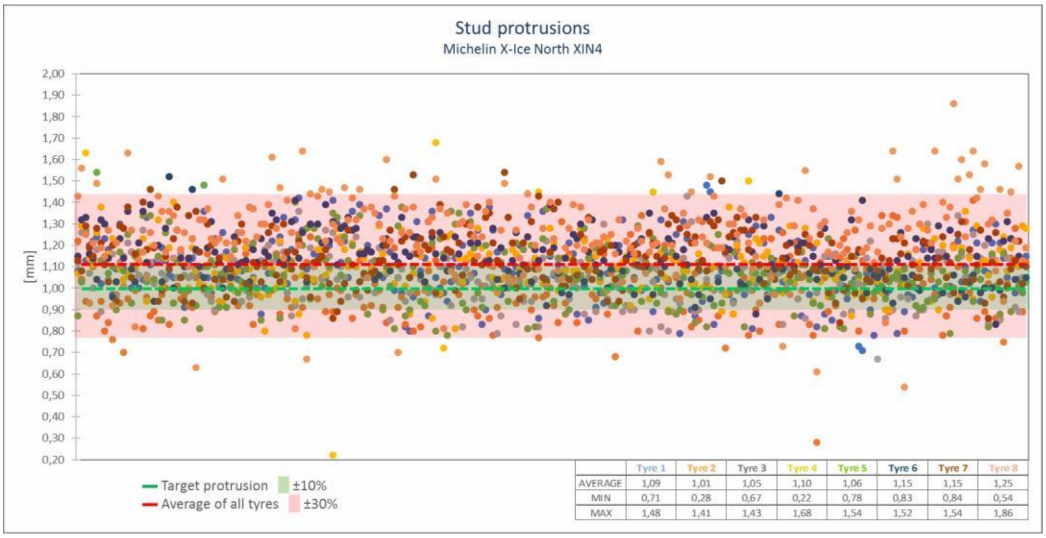
	Tyre 1	Tyre 2	Tyre 3	Tyre 4
AVERAGE	1,28	1,25	1,27	1,24
MIN	0,87	0,82	0,99	0,93
MAX	1,70	1,80	1,68	1,55

Figure 27. Stud protrusions, Michelin X-Ice North XIN2



	Tyre 1	Tyre 2	Tyre 3	Tyre 4
AVERAGE	1,41	1,34	1,39	1,33
MIN	1,10	1,09	1,08	1,05
MAX	1,69	1,91	1,75	1,58

Figure 28. Stud protrusions, Michelin X-Ice North XIN3



	Tyre 1	Tyre 2	Tyre 3	Tyre 4	Tyre 5	Tyre 6	Tyre 7	Tyre 8
AVERAGE	1,09	1,01	1,05	1,10	1,06	1,15	1,15	1,25
MIN	0,71	0,28	0,67	0,22	0,78	0,83	0,84	0,54
MAX	1,48	1,41	1,43	1,68	1,54	1,52	1,54	1,86

Figure 29. Stud protrusions, Michelin X-Ice North XIN4

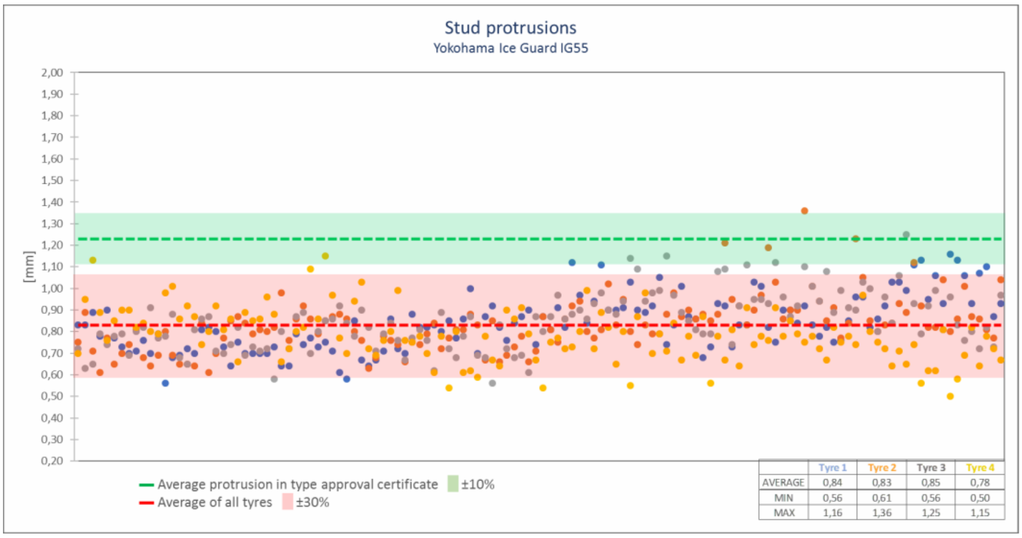


Figure 30. Stud protrusions, Yokohama Ice Guard IG55

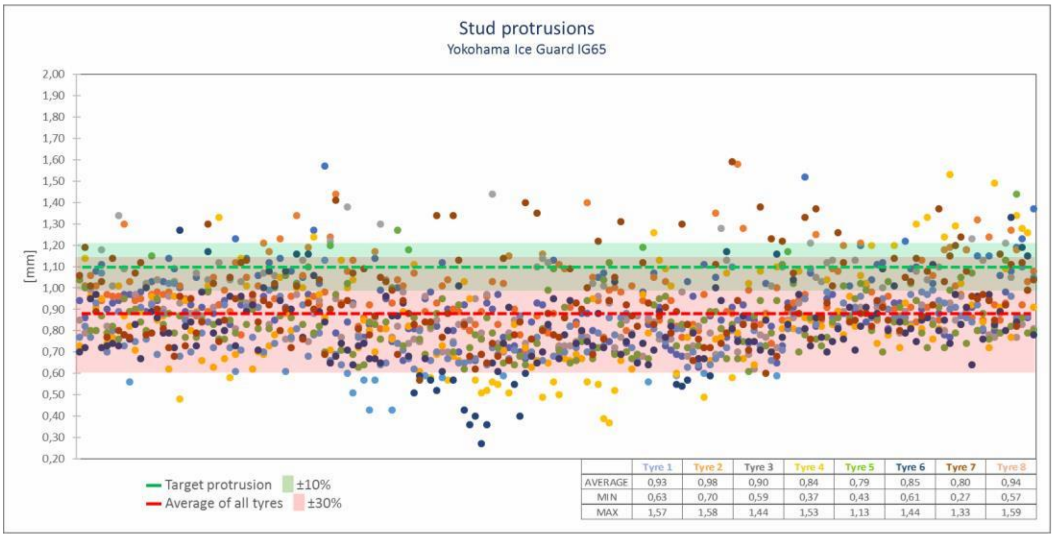
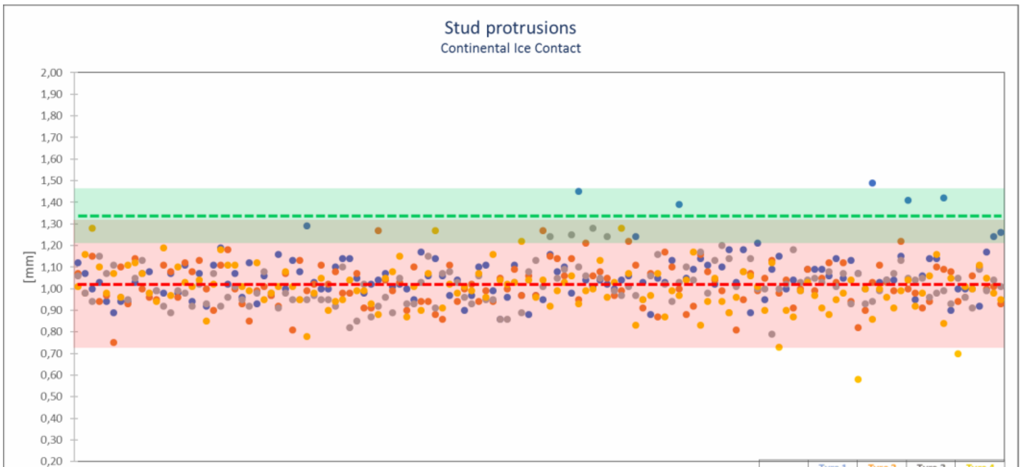
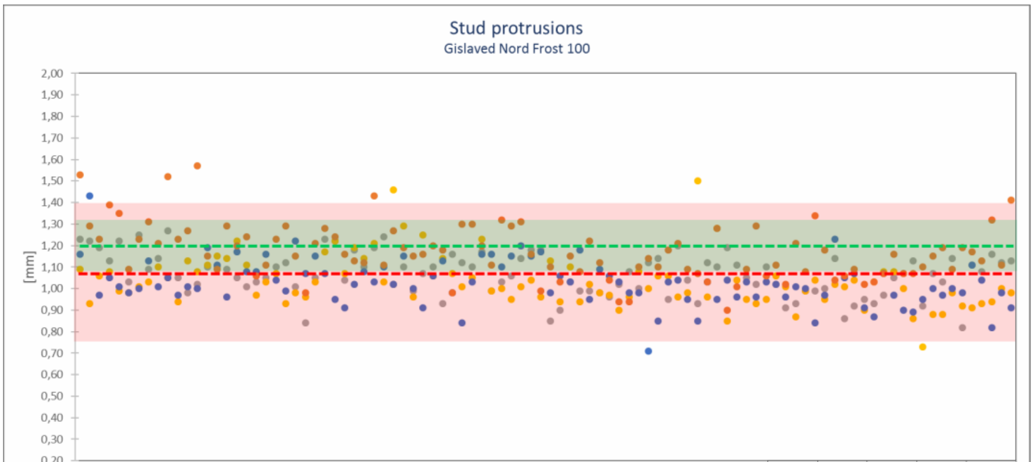


Figure 31. Stud protrusions, Yokohama Ice Guard IG65



	Tyre 1	Tyre 2	Tyre 3	Tyre 4
AVERAGE	1,06	1,02	1,01	1,00
MIN	0,86	0,75	0,79	0,58
MAX	1,49	1,27	1,28	1,28

Figure 32. Stud protrusions, Continental Ice Contact



	Tyre 1	Tyre 2	Tyre 3	Tyre 4
AVERAGE	1,06	1,03	1,03	1,17
MIN	0,82	0,73	0,71	0,90
MAX	1,27	1,50	1,43	1,57

Figure 33. Stud protrusions, Gislaved Nord Frost 100

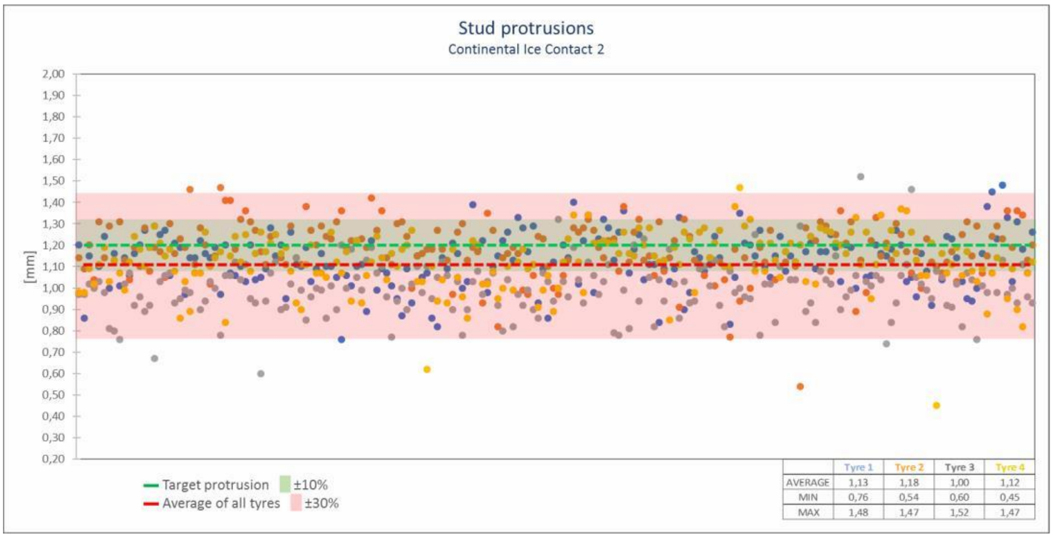


Figure 34. Stud protrusions, Continental Ice Contact 2

There was very little variation in average protrusion rates for individual test tyres under each product. However, when compared to the protrusion value declared in the type approval certificate, only a few products were able to remain within the 10% variance range when it came to their average protrusion rates.

The deviations in individual stud protrusions varied across different manufacturers. The products manufactured by Nokian featured the least variance in protrusion values. When the protrusion rates were surveyed across the span of the entire circumference, almost every tyre featured a few individual studs whose protrusion value did not fit within the 30% variance range. It is therefore entirely random whether the 20 consecutive studs, which area measured during the type approval process based on the over-run method, will include these types of individual studs. The majority of inspected tyres would inevitably include them in the area that is measured. When the variance in stud protrusions was reviewed across products generations, no consistent change could be detected in the quality of the studding used. Based on the results of this study, the quality requirements for the studding of new tyres set by the over-run test are not fulfilled in mass production.

The features of the components used in a tyre have some effect on how the stud will be set when it is added to the tyre. However, stud protrusion is caused primarily by three factors; the size of the stud hole, the size of the stud and the studding process. The manufacturing accuracy rates related to these factors do not depend on the target protrusion rate. From the perspective of quality, when it comes to new tyres, it would be more justified to introduce fixed variance figures rather than any percentage-based limit values for the protrusion rates observed during the over-run method. Currently, a larger protrusion level is allowed to feature a measurably larger variance range, while a smaller rate is only allowed a smaller range. However, this change would not be very significant, as a specific protrusion level (of around 1 mm) has already become the standard for these types of products.

3.3.2 Changes in stud protrusions

Based on the ice grip measurements conducted in this study, the test tyres exhibited a fairly limited change in stud protrusion rates. The single largest increase in an individual tyre's protrusion level during the grip tests was 0.15 mm.
The average increase in protrusion was under 0.1 mm/tyre for every product.

During the over-run test, stud protrusion values tend to increase. As a consequence of repeated acceleration and braking situations, the studs are subjected to more movement in comparison to the rubber. During an over-run test, the tyre's tread is often subjected to more wear than its studs. All of the test tyres that were included in this study met the requirements for changes in protrusion set by the over-run test (max. ±25%). Some of the tyres exhibited very little change. Some of the tires even featured a slight decrease in protrusion during the test. The over-run tests were done using a four-wheel drive car, which is widely known to be the most favourable when it comes to protrusion change rates. In addition, the testing temperatures were fairly low and the course was wet during the majority of the test runs. It is widely known that tyre wear is very low in these types circumstances.

4. OVER-RUN TEST

Since the over-run test plays a central role in the type approval process for studded tyres and in many studies on the road wear caused by studded tyres (such as in this study), this chapter will focus on the test in more detail, based on the perspective of the reliability of the results that it provides. The over-run method has been in development for several decades, mainly thanks to the efforts of Timo Unhola and Risto Alkio. The goal has been to develop a method that can be used to measure road wear. The main focus of the development work for the method has been on the practical implementation and replicability of the test. A great deal of effort has also been placed on measurement accuracy and minimising the scatter present in the test's results, and the development work has been very successful when it comes to these areas. However, less attention has been paid to studying the correlation between the test method and actual road wear. During this time, when basic principles for the method were established and the method has been taken into widespread use, both studs and studded tyres have changed in many ways.

Previous studies have detected some studded tyre parameters that are connected to road wear. These parameters are stud weight, stud protrusion, stud force and the number of studs used. New studded tyres feature a significant increase in the number of studs used when compared to previous tyres. One of the tyres in the study even featured a stud weight (1.23 g) that was greater than what has been observed in several decades. None of the manufacturers we know have decided to decrease the number of studs they use in their new products, while the expectation during the drafting process of the decree amendment was the opposite. However, the over-run wear figures that have been measured using the over-run method have demonstrated no signs of growth.

Some doubts have been cast on the correlation between the results generated by the over-run method and actual road wear. The Academy of Finland Researcher Ari Tuononen has stated that the over-run method "does not depict actual road wear in any way" (Tuononen 2017, 13). The developer of the over-run method, Timo Unhola, mentioned in his report published in 2015 that the comparison between actual road wear has been assessed once, in connection with the ASTO rock material test road experiment that was arranged between 1989 and 1991. The conclusion of this study was that the results do not indicate any clear dependencies. What is notable is that the study that Unhola refers to used stone cylinders as its test material, which do not correspond with the current type of over-run test stones that are used. (Unhola 2015, 16-17)

The over-run test is an accelerated road wear test (Unhola 2015, 12). In other words, the test increases the loss in mass of the stones used in the test when compared to the loss in mass of regular road surfaces with the same amount of driving. This is achieved by sawing the upper surface of the stones, resulting in a situation where the edges of the protrusions formed on the stones are more susceptible to the formation of cracks. As a result of this, the wear event emphasises such tyre and stud factors that do not have a corresponding effect on actual road surface wear.

For example, when the frame of a stud hits the edges of a test stone, this may cause a more pronounced amount of wear on the test stones when compared to actual surface wear. In addition, the areas that are susceptible to the formation of cracks are very small when compared to the entire surface area of the test stone. This means that, for example, a smaller stud diameter will hit the groove of the over-run stone without causing any wear to the test stone, but would still likely affect the surface of a road constantly when it is in contact with the road. The development of studs and studded tyres focuses on minimising over-run wear, but, in reality, these solutions may serve to increase road surface wear.

Since the goal of both previous and the upcoming tyre stud decree − for the purposes of which this study also serves as its background material − is to decrease road wear while maintaining an adequate level of road security, it would be of primary importance to initiate a study on the reliability of the over-run method when it comes to measuring actual road surface wear.

It is typical that, during the seasons when studded tyres are used, the limit values for small particle emissions are exceeded in urban regions. By the end of 2018, the Helsinki Region Environmental Services Authority HSY stated that the use of studded tyres in the Helsinki Metropolitan Area could be detected in measurements since the middle of November and that the daily limit values for small particle emissions were exceeded in the areas that featured the largest amount of traffic (HSY 2018). In the over-run test, figures for wear are measured using road speeds (100 km/h). However, the most problematic areas for street dust are located in urban areas, where speed limits are notably lower. It is for this reason that the correlation between the over-run test and actual surface wear should be examined using both typical road speeds and urban area speed limits.

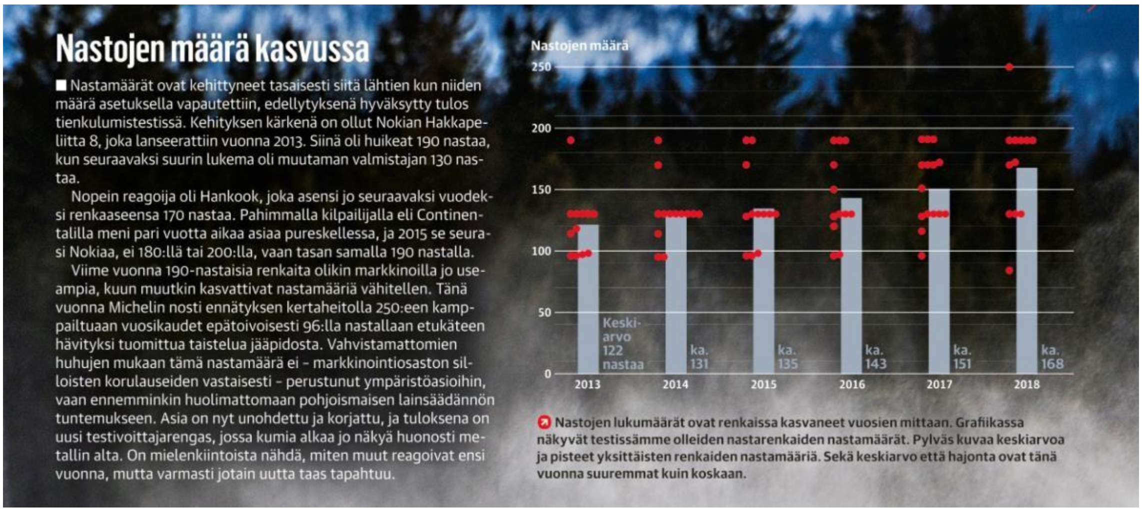
5. SUMMARY

The aim of the study was to create a setting where the effects of the decree amendment of 2013 could be evaluated and to also allow for the results of the study to be utilised in the preparation work for the upcoming decree amendment. The purpose was to study how the ice grip features and over-run wear of the tyres that are currently on the market have changed and to assess how the ice grip features and over-run wear change in situations where the number of studs is reduced.

At the same time, the study will also provide researched information for the background work of the ongoing Trafi regulation drafting process on whether the grip features of the tyres that have been changed in this way remain at a usable and safe level for use in winter conditions. Even though the study had to limit the number of products to a fairly small selection, their market coverage is expansive and they are a good representation of how tyres will be developed in the future.

The purpose of the amendment to the decree was to decrease the road wear caused by studded tyres. The most significant change for the entire studded tyre industry has been the introduction of the over-run test, i.e. the road wear test, as an alternative approval method. For the first time in the history of the studded tyre, a tyre could be type approved on the basis of its product characteristics instead of any stud-specific limits. Tyre manufacturers have been keen to adopt the over-run test as their approval method of choice. When their product development processes are provided with more liberties, they have been able to generate significant enhancements to the performance of their tyres, especially when it comes to ice grip. This change has been particularly evident in the significant increase in the number of studs used.

We estimate that this trend is set to continue.



Nastojen määrä kasvussa

■ Nastamäärät ovat kehittyneet tasaisesti siitä lähtien kun niiden määrä asetuksella vapautettiin, edellytyksenä hyväksytty tulos tienkulumistestissä. Kehityksen kärkenä on ollut Nokian Hakkapeliitta 8, joka lanseerattiin vuonna 2013. Siinä oli huikeat 190 nastaa, kun seuraavaksi suurin lukema oli muutaman valmistajan 130 nastaa.

Nopein reagoija oli Hankook, joka asensi jo seuraavaksi vuodeksi renkaaseensa 170 nastaa. Pahimmalla kilpailijalla eli Continentalilla meni pari vuotta aikaa asiaa pureskellessa, ja 2015 se seurasi Nokiaa, ei 180:llä tai 200:lla, vaan tasan samalla 190 nastalla.

Viime vuonna 190-nastaisia renkaita olikin markkinoilla jo useampia, kuun muutkin kasvattivat nastamääriä vähitellen. Tänä vuonna Michelin nosti ennätyksen kertaheitolla 250:een kamppailtuaan vuosikaudet epätoivoisesti 96:lla nastallaan etukäteen hävityksi tuomittua taistelua jääpidosta. Vahvistamattomien huhujen mukaan tämä nastamäärä ei – markkinointiosaston silloisten korulauseiden vastaisesti – perustunut ympäristöasioihin, vaan ennemminkin huolimattomaan pohjoismaisen lainsäädännön tuntemukseen. Asia on nyt unohdettu ja korjattu, ja tuloksena on uusi testivoittajarengas, jossa kumia alkaa jo näkyä huonosti metallin alta. On mielenkiintoista nähdä, miten muut reagoivat ensi vuonna, mutta varmasti jotain uutta taas tapahtuu.

Nastojen lukumäärät ovat renkaissa kasvaneet vuosien mittaan. Grafiikassa näkyvät testissämme olleiden nastarenkaiden nastamäärät. Pylväs kuvaa keskiarvoa ja pisteet yksittäisten renkaiden nastamääriä. Sekä keskiarvo että hajonta ovat tänä vuonna suuremmat kuin koskaan.

Figure 35. Rising number of studs used (Antila, Tekniikan Maailma 17/2018, 27)

6. CONCLUSIONS

- When the number of studs was decreased by 25% in current and new products, it lowered over-run wear by an average of 19% and ice grip features by an average of 9%.
- When different product generations made by the same manufacturer were compared, it was noted that even when the number of studs used in the newest product was reduced by 25%, its ice grip features remained better than in the tyres from previous product generations.
- According to our study, there is a clear correlation between stud force and over-run wear.
- The requirement placed by the over-run approval process for the uniform quality of studding is challenging to achieve in mass production. However, we do not feel that this is a very large problem from the perspective of consumers.
- The protrusion averages of the studs used in the tyres that were inspected differed from the stud protrusion figures presented in the type approval certificates. We feel that this is a problematic situation. A mass-produced product should correspond to the type approval for this figure as well.
- From the perspective of the quality of the studding used, the limit that is set for the variance range in stud protrusion would be better defined as a fixed range instead of a percentage-based range.
- The correlation between the current over-run method and actual road wear has not been studied. We recommend investigating the matter using both road and urban area speed limits.
- If the wear limits used in the over-run method are reduced, the emphasis on the scatter present in the results of the over-run test must be taken into account. Due to this reason,

we recommend retaining current gram-based limits while increasing the number of overruns used in the over-run test (currently 200 runs).

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8. APPENDICES

Appendix 1. Tyre delivery inspection records. 2 pages

Liite 1 (1/2)

Tyre size	Name	Tyre no.	DOT code and/or week of manufacture	Country of manufacture	E-approval	Tyre weight [kg]	Hardness [ShA]	Stud amount
205/55R16 94T XL	Michelin X-Ice North XIN2	1.	22WC 7W6X 1211	Russia	E2 0207402	9,245	62	118
205/55R16 94T XL	Michelin X-Ice North XIN2	2.	22WC 7W6X 1211	Russia	E2 0207402	9,260	62	118
205/55R16 94T XL	Michelin X-Ice North XIN2	3.	22WC 7W6X 1211	Russia	E2 0207402	9,285	62	118
205/55R16 94T XL	Michelin X-Ice North XIN2	4.	22WC 7W6X 1211	Russia	E2 0207402	9,185	62	118
205/55R16 94T XL	Michelin X-Ice North XIN3	1.	22WC OUAX 2317	Russia	E2 0207402/0212509 S2WR2	9,595	57	96
205/55R16 94T XL	Michelin X-Ice North XIN3	2.	22WC OUAX 2417	Russia	E2 0207402/0212509 S2WR2	9,590	57	96
205/55R16 94T XL	Michelin X-Ice North XIN3	3.	22WC OUAX 2417	Russia	E2 0207402/0212509 S2WR2	9,620	57	96
205/55R16 94T XL	Michelin X-Ice North XIN3	4.	22WC OUAX 2417	Russia	E2 0207402/0212509 S2WR2	9,630	57	96
205/55R16 94T XL	Michelin X-Ice North XIN4	1.	DOT OK1X 2818	Russia	E2 0207402	9,730	57	250
205/55R16 94T XL	Michelin X-Ice North XIN4	2.	DOT OK1X 2818	Russia	E2 0207402	9,735	57	250
205/55R16 94T XL	Michelin X-Ice North XIN4	3.	DOT OK1X 2818	Russia	E2 0207402	9,760	57	250
205/55R16 94T XL	Michelin X-Ice North XIN4	4.	DOT OK1X 2818	Russia	E2 0207402	9,725	57	250
205/55R16 94T XL	Michelin X-Ice North XIN4	5.	DOT OK1X 2818	Russia	E2 0207402	9,720	57	250
205/55R16 94T XL	Michelin X-Ice North XIN4	6.	DOT OK1X 2118	Russia	E2 0207402	9,835	57	250
205/55R16 94T XL	Michelin X-Ice North XIN4	7.	DOT OK1X 2118	Russia	E2 0207402	9,905	57	250
205/55R16 94T XL	Michelin X-Ice North XIN4	8.	DOT OK1X 2018	Russia	E2 0207402	9,770	57	250
205/55R16 94T XL	Nokian Nordman 7	1.	DOT 60CP 2418	Russia	E4 0285470/+02S2WR2	8,990	57	128
205/55R16 94T XL	Nokian Nordman 7	2.	DOT 60CP 2418	Russia	E4 0285470/+02S2WR2	8,910	57	128
205/55R16 94T XL	Nokian Nordman 7	3.	DOT 60CP 2418	Russia	E4 0285470/+02S2WR2	9,080	57	128
205/55R16 94T XL	Nokian Nordman 7	4.	DOT 60CP 2418	Russia	E4 0285470/+02S2WR2	8,900	57	128
205/55R16 94T XL	Nokian Hakkapeliitta 8	1.	DOT YLCP 3418	Finland	E4 0262823/+02S2WR2	9,050	55	190
205/55R16 94T XL	Nokian Hakkapeliitta 8	2.	DOT YLCP 3418	Finland	E4 0262823/+02S2WR2	8,990	55	190
205/55R16 94T XL	Nokian Hakkapeliitta 8	3.	DOT YLCP 3418	Finland	E4 0262823/+02S2WR2	9,050	55	190
205/55R16 94T XL	Nokian Hakkapeliitta 8	4.	DOT YLCP 3418	Finland	E4 0262823/+02S2WR2	9,030	55	190
205/55R16 94T XL	Nokian Hakkapeliitta 8	5.	DOT YLCP 3418	Finland	E4 0262823/+02S2WR2	9,080	55	190
205/55R16 94T XL	Nokian Hakkapeliitta 8	6.	DOT YLCP 3418	Finland	E4 0262823/+02S2WR2	9,110	55	190
205/55R16 94T XL	Nokian Hakkapeliitta 8	7.	DOT YLCP 3418	Finland	E4 0262823/+02S2WR2	9,100	55	190
205/55R16 94T XL	Nokian Hakkapeliitta 8	8.	DOT YLCP 3418	Finland	E4 0262823/+02S2WR2	9,015	55	190
205/55R16 94T XL	Nokian Hakkapeliitta 9	1.	DOT 60CP 2218	Russia	E4 0291156/+02S2WR2	8,810	55	190
205/55R16 94T XL	Nokian Hakkapeliitta 9	2.	DOT 60CP 2218	Russia	E4 0291156/+02S2WR2	8,805	55	190
205/55R16 94T XL	Nokian Hakkapeliitta 9	3.	DOT 60CP 2218	Russia	E4 0291156/+02S2WR2	8,800	55	190
205/55R16 94T XL	Nokian Hakkapeliitta 9	4.	DOT 60CP 2218	Russia	E4 0291156/+02S2WR2	8,810	55	190
205/55R16 94T XL	Nokian Hakkapeliitta 9	5.	DOT 60CP 2218	Russia	E4 0291156/+02S2WR2	8,910	55	190
205/55R16 94T XL	Nokian Hakkapeliitta 9	6.	DOT 60CP 2218	Russia	E4 0291156/+02S2WR2	8,890	55	190
205/55R16 94T XL	Nokian Hakkapeliitta 9	7.	DOT 60CP 2218	Russia	E4 0291156/+02S2WR2	8,795	55	190
205/55R16 94T XL	Nokian Hakkapeliitta 9	8.	DOT 60CP 2218	Russia	E4 0291156/+02S2WR2	8,715	55	190
205/55R16 94T XL	Gislaved Nord Frost 100	1.	VL0F CNV8 2315	Russia	E4 0264526/025075 S2WR2	10,070	69	96
205/55R16 94T XL	Gislaved Nord Frost 100	2.	VL0F CNV8 2315	Russia	E4 0264526/025075 S2WR2	10,045	69	96
205/55R16 94T XL	Gislaved Nord Frost 100	3.	VL0F CNV8 2315	Russia	E4 0264526/025075 S2WR2	10,070	69	96
205/55R16 94T XL	Gislaved Nord Frost 100	4.	VL0F CNV8 2315	Russia	E4 0264526/025075 S2WR2	10,000	69	96
205/55R16 94T XL	Continental Ice Contact 2	1.	CPOF CUJ6 3218	Germany	E4 0278772	10,300	56	190
205/55R16 94T XL	Continental Ice Contact 2	2.	CPOF CUJ6 3218	Germany	E4 0278772	10,225	56	190
205/55R16 94T XL	Continental Ice Contact 2	3.	CPOF CUJ6 3218	Germany	E4 0278772	10,260	56	190
205/55R16 94T XL	Continental Ice Contact 2	4.	CPOF CUJ6 3218	Germany	E4 0278772	10,225	56	190
205/55R16 94T XL	Yokohama Ice Guard IG55	1.	TK8K YYY2517	Russia	E4 0267221	10,510	59	128
205/55R16 94T XL	Yokohama Ice Guard IG55	2.	TK8K YYY2517	Russia	E4 0267221	10,505	59	128
205/55R16 94T XL	Yokohama Ice Guard IG55	3.	TK8K YYY2517	Russia	E4 0267221	10,590	59	128
205/55R16 94T XL	Yokohama Ice Guard IG55	4.	TK8K YYY3117	Russia	E4 0267221	10,575	59	128
205/55R16 94T XL	Yokohama Ice Guard IG65	1.	TK8K YYY3018	Russia	E4 0298728	9,755	58	172
205/55R16 94T XL	Yokohama Ice Guard IG65	2.	TK8K YYY3018	Russia	E4 0298728	9,760	58	172
205/55R16 94T XL	Yokohama Ice Guard IG65	3.	TK8K YYY3018	Russia	E4 0298728	9,815	58	172
205/55R16 94T XL	Yokohama Ice Guard IG65	4.	TK8K YYY3018	Russia	E4 0298728	9,820	58	172
205/55R16 94T XL	Yokohama Ice Guard IG65	5.	TK8K YYY3118	Russia	E4 0298728	9,815	57-58	172
205/55R16 94T XL	Yokohama Ice Guard IG65	6.	TK8K YYY3018	Russia	E4 0298728	9,795	58	172
205/55R16 94T XL	Yokohama Ice Guard IG65	7.	TK8K YYY3118	Russia	E4 0298728	9,895	57-58	172
205/55R16 94T XL	Yokohama Ice Guard IG65	8.	TK8K YYY3118	Russia	E4 0298728	9,885	57-58	172
205/55R16 94T XL	Continental Ice Contact	1.	CPOF NVVD 3813	Germany	E4 0248678/010992SW	9,985	64	130
205/55R16 94T XL	Continental Ice Contact	2.	CPOF NVVD 3813	Germany	E4 0248678/010992SW	10,120	64	130
205/55R16 94T XL	Continental Ice Contact	3.	CPOF NVVD 3913	Germany	E4 0248678/010992SW	10,100	64	130
205/55R16 94T XL	Continental Ice Contact	4.	CPOF NVVD 3813	Germany	E4 0248678/010992SW	10,055	64	130

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Tyre size	Name	Tyre no	Target protrusion [mm]	Measured protrusion [mm] average of all	Measured min [mm]	Measured max [mm]	Std deviation [mm]	avg vs target [%] (limit±10%)	min vs avg [%] (limit 30%)	max vs avg [%] (limit 30%)	Measured stud weight [g]	Measured stud length [mm]	Measured stud body length [mm]	Measured bottom flange diameter [mm]	Measured pin diameter [mm]
205/55R16 94T XL	Michelin X-Ice North XIN2	1.	1,20	1,28	0,87	1,70	0,16	6,61	32,00	32,88	0,95	11,1	9,9	Ø 8,0	Ø 2,4
205/55R16 94T XL	Michelin X-Ice North XIN2	2.	1,20	1,25	0,82	1,80	0,14	3,98	34,28	44,25					
205/55R16 94T XL	Michelin X-Ice North XIN2	3.	1,20	1,27	0,99	1,68	0,14	5,69	21,94	32,46					
205/55R16 94T XL	Michelin X-Ice North XIN2	4.	1,20	1,24	0,93	1,55	0,12	4,03	25,50	24,16					
205/55R16 94T XL	Michelin X-Ice North XIN3	1.	1,10	1,41	1,10	1,69	0,12	27,85	21,78	20,17	0,97	11,1	9,7	Ø 8,8	Ø 2,4
205/55R16 94T XL	Michelin X-Ice North XIN3	2.	1,10	1,34	1,09	1,91	0,13	21,74	18,61	42,63					
205/55R16 94T XL	Michelin X-Ice North XIN3	3.	1,10	1,39	1,08	1,75	0,13	26,77	22,55	25,49					
205/55R16 94T XL	Michelin X-Ice North XIN3	4.	1,10	1,33	1,05	1,58	0,11	20,66	20,89	19,04					
205/55R16 94T XL	Michelin X-Ice North XIN4	1.	1,00	1,09	0,71	1,48	0,14	8,85	34,77	35,97	1,23	11,0	9,8	Ø 6,5	Ø 2,0
205/55R16 94T XL	Michelin X-Ice North XIN4	2.	1,00	1,01	0,28	1,41	0,14	0,86	72,24	39,79					
205/55R16 94T XL	Michelin X-Ice North XIN4	3.	1,00	1,05	0,67	1,43	0,12	5,06	36,23	36,11					
205/55R16 94T XL	Michelin X-Ice North XIN4	4.	1,00	1,10	0,22	1,68	0,14	9,69	79,94	53,16					
205/55R16 94T XL	Michelin X-Ice North XIN4	5.	1,00	1,06	0,78	1,54	0,14	6,14	26,51	45,09					
205/55R16 94T XL	Michelin X-Ice North XIN4	6.	1,00	1,15	0,83	1,52	0,12	14,83	27,72	32,37					
205/55R16 94T XL	Michelin X-Ice North XIN4	7.	1,00	1,15	0,84	1,54	0,13	14,50	26,64	34,49					
205/55R16 94T XL	Michelin X-Ice North XIN4	8.	1,00	1,25	0,54	1,86	0,19	25,19	56,86	48,58					
205/55R16 94T XL	Nokian Nordman 7	1.	1,26	1,02	0,83	1,26	0,07	-19,36	18,31	24,01	0,98	10,9	9,5	9,7 / 7,7	3,3 / 2,6
205/55R16 94T XL	Nokian Nordman 7	2.	1,26	1,01	0,84	1,21	0,07	-19,51	17,17	19,31					
205/55R16 94T XL	Nokian Nordman 7	3.	1,26	1,00	0,79	1,20	0,08	-20,32	21,31	19,53					
205/55R16 94T XL	Nokian Nordman 7	4.	1,26	1,04	0,86	1,26	0,08	-17,15	17,62	20,70					
205/55R16 94T XL	Nokian Hakkapeliitta 8	1.	0,99	0,82	0,50	1,03	0,11	-17,62	38,69	26,29	0,84	10,0	8,7	8,5 / 7,3	2,6 / 1,9
205/55R16 94T XL	Nokian Hakkapeliitta 8	2.	0,99	0,82	0,48	1,03	0,11	-16,85	41,69	25,12					
205/55R16 94T XL	Nokian Hakkapeliitta 8	3.	0,99	0,80	0,50	1,03	0,10	-19,23	37,47	28,82					
205/55R16 94T XL	Nokian Hakkapeliitta 8	4.	0,99	0,83	0,53	1,07	0,11	-15,77	36,44	28,32					
205/55R16 94T XL	Nokian Hakkapeliitta 8	5.	0,99	0,80	0,50	1,02	0,10	-19,00	37,65	27,19					
205/55R16 94T XL	Nokian Hakkapeliitta 8	6.	0,99	0,80	0,48	1,07	0,11	-18,79	40,30	33,08					
205/55R16 94T XL	Nokian Hakkapeliitta 8	7.	0,99	0,93	0,54	1,20	0,11	-6,18	41,86	29,19					
205/55R16 94T XL	Nokian Hakkapeliitta 8	8.	0,99	0,86	0,50	1,15	0,12	-13,34	41,72	34,05					
205/55R16 94T XL	Nokian Hakkapeliitta 9	1.	0,90	1,06	0,81	1,35	0,09	17,23	23,23	27,96	0,80 (center area stud)	10,1	8,6	8,4 / 7,5	2,6 / 1,8
205/55R16 94T XL	Nokian Hakkapeliitta 9	2.	0,90	1,01	0,82	1,24	0,08	12,51	19,02	22,46					
205/55R16 94T XL	Nokian Hakkapeliitta 9	3.	0,90	0,97	0,73	1,17	0,08	7,56	24,59	20,87					
205/55R16 94T XL	Nokian Hakkapeliitta 9	4.	0,90	1,07	0,86	1,32	0,09	18,53	19,38	23,74					
205/55R16 94T XL	Nokian Hakkapeliitta 9	5.	0,90	0,97	0,69	1,26	0,09	7,99	29,01	29,64	0,87 (shoulder area stud)	10,1	8,6	8,2	2,4
205/55R16 94T XL	Nokian Hakkapeliitta 9	6.	0,90	1,00	0,76	1,31	0,09	11,40	24,20	30,66					
205/55R16 94T XL	Nokian Hakkapeliitta 9	7.	0,90	1,02	0,76	1,30	0,09	13,59	25,66	27,16					
205/55R16 94T XL	Nokian Hakkapeliitta 9	8.	0,90	0,93	0,63	1,19	0,08	3,13	32,12	28,21					
205/55R16 94T XL	Gislaved Nord Frost 100	1.	(max 1,2)	1,06	0,82	1,27	0,10	-11,27	22,99	19,27	0,97	11,0	9,5	Ø 8,0	2,8
205/55R16 94T XL	Gislaved Nord Frost 100	2.	(max 1,2)	1,03	0,73	1,50	0,12	-13,80	29,43	45,02					
205/55R16 94T XL	Gislaved Nord Frost 100	3.	(max 1,2)	1,03	0,71	1,43	0,10	-14,37	30,91	39,16					
205/55R16 94T XL	Gislaved Nord Frost 100	4.	(max 1,2)	1,17	0,90	1,57	0,13	-2,45	23,12	34,12					
205/55R16 94T XL	Continental Ice Contact 2	1.	1,20	1,13	0,76	1,48	0,12	-6,22	32,47	31,51	0,77	9,8	8,5	8,0 / 6,8	2,8 / 2,0
205/55R16 94T XL	Continental Ice Contact 2	2.	1,20	1,18	0,54	1,47	0,13	-1,79	54,18	24,73					
205/55R16 94T XL	Continental Ice Contact 2	3.	1,20	1,00	0,60	1,52	0,12	-16,99	39,77	52,59					
205/55R16 94T XL	Continental Ice Contact 2	4.	1,20	1,12	0,45	1,47	0,13	-6,61	59,85	31,16					
205/55R16 94T XL	Yokohama Ice Guard IG55	1.	1,23	0,84	0,56	1,16	0,13	-31,75	33,30	38,17	0,89	10,9	9,5	8,7 / 7,5	3,0 / 2,4
205/55R16 94T XL	Yokohama Ice Guard IG55	2.	1,23	0,83	0,61	1,36	0,13	-32,18	26,88	63,03					
205/55R16 94T XL	Yokohama Ice Guard IG55	3.	1,23	0,85	0,56	1,25	0,13	-31,17	33,85	47,66					
205/55R16 94T XL	Yokohama Ice Guard IG55	4.	1,23	0,78	0,50	1,15	0,12	-36,46	36,03	47,14					
205/55R16 94T XL	Yokohama Ice Guard IG65	1.	1,10	0,93	0,63	1,57	0,16	-15,90	31,90	69,72	0,82	10,3	9,1	7,9 / 7,1	3,3 / 1,9
205/55R16 94T XL	Yokohama Ice Guard IG65	2.	1,10	0,98	0,70	1,58	0,15	-11,15	28,38	61,67					
205/55R16 94T XL	Yokohama Ice Guard IG65	3.	1,10	0,90	0,59	1,44	0,16	-18,14	34,48	59,92					
205/55R16 94T XL	Yokohama Ice Guard IG65	4.	1,10	0,84	0,37	1,53	0,22	-23,95	55,77	82,90					
205/55R16 94T XL	Yokohama Ice Guard IG65	5.	1,10	0,79	0,43	1,13	0,13	-28,58	45,27	43,83					
205/55R16 94T XL	Yokohama Ice Guard IG65	6.	1,10	0,85	0,61	1,44	0,14	-22,66	28,29	69,27					
205/55R16 94T XL	Yokohama Ice Guard IG65	7.	1,10	0,80	0,27	1,33	0,17	-27,01	66,37	65,66					
205/55R16 94T XL	Yokohama Ice Guard IG65	8.	1,10	0,94	0,57	1,59	0,19	-14,44	39,44	68,94					
205/55R16 94T XL	Continental Ice Contact	1.	1,34	1,06	0,86	1,49	0,11	-20,75	19,01	40,31	0,98	10,8	9,4	8,3 / 6,9	3,2 / 2,0
205/55R16 94T XL	Continental Ice Contact	2.	1,34	1,02	0,75	1,27	0,10	-24,03	26,33	24,75					
205/55R16 94T XL	Continental Ice Contact	3.	1,34	1,01	0,79	1,28	0,09	-24,43	21,98	26,41					
205/55R16 94T XL	Continental Ice Contact	4.	1,34	1,00	0,58	1,28	0,11	-25,26	42,09	27,80					

(orange) *Average of the measured protrusions of the type approval tyres (target protrusion not specified in type approval data)*

(blue) *Average of the measured protrusions of the type approval tyres (target protrusion not specified in type approval data), Type approval size 195/65R15*