ANNEX 1

Improved standard for testing of composite brake blocks for winter condition– a literature survey on braking performance and influencing factors

© The Swedish Transport Agency
Väg och järnväg/ Department of Road and Railways
Enhet Spårtrafik/Rail Unit

The report is an annex to REPORT. Improved standard for testing of composite brake blocks for winter conditions - testing at the Becorit winter brake bench of two K type brake blocks with designation Dnr TSG 2023-8756.

The report is available on the Swedish Transport Agency’s website www.transportstyrelsen.se

Designation	Dnr TSG 2023-8756
Author	Södergård Sten-Olov
Month Year	December 2025. Corrigendum February 2026

Reproduction is authorized provided the source is acknowledged.

1 Foreword

The purpose of this project is to be able to increase and permanently stabilize the safety when running freight trains equipped with composite brake blocks during Nordic winter conditions. The goal of the project is to propose a supplement to the existing test procedure for approval of composite brake blocks. The predominant effort has been to concretely identify factors that influence the braking capability and transform these conclusions into test specifications in order to compose a better and more reliable test procedure that can duplicate and reflect the real environment factors.

A second, and consecutive, objective is to reduce or even remove the operational adaptations that railway companies are forced to introduce as a result of vehicles being equipped with composite brake blocks and thereby maintain a functional and cost-effective capacity utilization. With more reliable brake blocks, operational safety can thus be improved.

The Project has analysed and examined in detail lab- and field test information from documents from UIC, ERA, EN standards, Transportstyrelsen, Green Cargo and from the open literature. The work has also taken into account in detail winter braking rules/guidelines used by Green Cargo and Hector Rail, two of Sweden’s freight companies, and outlines the winter conditions in which braking performance problems occur.

The main findings after having examined the literature, rules and regulations together with results from different tests can be grouped into the following categories: temperature intervals regarding environment as for the material, especially wheels; braking distance calculations and their evaluation, especially regarding reference tests; influence of braking parameters used for conditioning of the brakes; and finally, mechanisms for degraded winter braking performance.

Borlänge December 2025 Corrigendum February 2026
Sten-Olov Södergård
Internationell samordnare järnväg /International affairs/LL M

2 Summary

The Swedish Transport Agency aims at providing a basis for an improved testing procedure for composite brake blocks to mitigate today's situation with occasionally and suddenly degraded braking performance in certain, but frequently or probably occurring, winter conditions. Such degraded braking performance has been reported in Sweden, Finland and Norway. A background on today´s standard for winter testing of composite blocks is provided along with a survey on literature focusing on winter braking performance with emphasis on influencing parameters.

The main findings are that:

1) It has been considerable and long-term efforts that have led to today's approval procedure. It can be seen as a research and development project led by UIC, with major contributions from DB, SNCF, Green Cargo, Becorit, etc.
2) The testing procedures for approval of brake blocks have been developed based on line-tests featuring frequent full stop braking tests, which is uncharacteristic for normal operation. For this reason, the sensitivity of braking distances to implemented driver instructions, regarding exercising of the brake system, has not been considered. Testing by the Swedish Transport Agency has shown that this can be important for braking distances.
3) It is deemed that the temperature requirements for testing specify too high temperatures. The experience from normal operation is that degraded winter braking performance is not seen at the temperatures used at the controlled testing environments at winter testing in the wind tunnel and the ventilated brake rig. There are indications that temperatures $\lesssim -7$ ºC are required to trigger poor winter braking performance.
4) Early UIC reports discussed the rate of ice removal from brake block contact surfaces by wheel treads, suggesting that the ice-removing properties of a wheel tread could be important. As this is not explicitly considered at later stages in the development of the approval procedures, it is considered that this aspect requires further investigation to establish its tentative importance for poor winter braking performance. This implies the need to investigate wheel tread surface roughness, brake block to wheel contact pressures and ice properties, both at testing for approval and at field conditions.
5) The reference conditions used to assess winter braking performance in field tests were broadly defined during the development of approval procedures to include also the mild effects of swirling snow. This is despite the fact that the 'true' reference conditions, when re-analysing the data in this report, have shown that even mild effects can have a negative impact on braking performance. This means that the reference conditions used during development are actually biased towards winter braking, which has been shown to affect the average distances and standard deviations used for comparison and evaluation.

At the end of the report, results from some relevant studies on small-scale testing and numerical simulation are provided. Additionally, reflections are given on the upcoming transition from UIC leaflets to EN standards relevant for brake block certification in winter conditions. Finally, a tentative improved winter testing programme is outlined, based on the UIC 541-4 programme for certification of winter testing in the air-conditioned Becorit test bench.

3 Table of Content

4 Background and aim

Braking performance related to deficient winter braking caused by the introduction of composite brake blocks on tread braked freight trains is discussed in the present report. It is part of a project with overall aim to improve the procedures for approval of composite brake blocks. This is achieved by starting out from the groundworks of today´s testing procedures and guiding documents and by summarizing the state-of-the-art regarding winter braking.

At the onset of the work, a broad search was performed on winter braking issues in general, which revealed issues with the pneumatic braking system in North America where air leakage on wagons which can render wagons having reduced braking performance, see e.g. [Ref. 41]. Interestingly, cold wheel detectors at the bottom of long grades are used for identifying wheels and wagons with poor braking performance for later inspection. However, no reports on winter related braking performance issues caused by decreased block–wheel friction could be found. Nevertheless, in the report [Ref. 40] by the Transportation Safety Board of Canada it is mentioned that “Contaminants such as snow and ice can reduce the coefficient of friction”. There are CBBs on the north American market with cast iron inserts in the composite friction material where the manufacturer states that this will improve winter performance.

In the following, braking performance related to winter braking of brake blocks of types K and LL is discussed and analysed in detail. Information has been extracted from documents from UIC, ERA, EN standards, Green Cargo, Transportstyrelsen and from the open literature.

5 Braking performance and winter conditions

In the following today´s approval procedure for winter braking performance is detailed along with testing campaigns performed for developing this procedure. This is followed by a summary of results from additional field test campaigns performed at a later stage in Finland and in Sweden.

5.1 Testing of brake blocks and braking performance

Wagons shall fulfil TSI WAG [Ref. 1] and TSI Noise [Ref. 2] and are therefore tested according to UIC 541-4 [Ref. 5] or the corresponding EN16452 [Ref. 3]. Demonstration of winter braking properties of composite brake blocks are in UIC 541-4 given by

- Appendix A, Test Program A5_a for demonstration on the air-conditioned Becorit test bench in Recklinghausen,
- Appendix A, Test Program A5_b for demonstration in in the RTA Climatic Wind Tunnel Vienna, and
- Appendix G for test runs.

The requirements for approval are:

1) For the ”simplified braking test” of a test run, the average brake distances from 100 km/h and 120 km/h may for winter tests at snow levels 3 to 5 not vary more than ±10 % as compared to dry conditions (snow level 0). Additionally, the quotient of the standard deviation and the average braking distance shall not exceed 20 % to ensure that the braking distance is representative at a considered speed. Testing at 60 km/h is also performed but the results are “for information purposes, to monitor the plausibility and comparability of the efficiency between reference tests and winter tests”. Maximum allowed axle load of test wagon is 7 ton.

2) For RTA Climatic Wind Tunnel Vienna tests, the average brake distances from 100 km/h and 120 km/h may not vary more than ±15 % as compared to dry conditions. Starting temperature of wheel at tests is ”< 0 °C” and ambient temperature is -10 °C. The simulated axle load is 7 ton. Wind speed is 10 km/h.

3) For Becorit brake bench tests, the average brake distances from 100 km/h and 120 km/h may not vary more than ±15 % as compared to dry conditions when assessing one test programme. For three test programmes[1] the permitted deviation is ±10 %. Starting temperature of wheel should be below -3 °C at 19 min prior to actual winter stop test with a test chamber temperature of -7 ±2 °C. The wheel temperature at start of actual winter test is thus between -7 ±2 °C and -3 °C, depending on cooling conditions. For winter braking performance, the standard stipulates no requirements on standard deviations or on extreme values of braking distances. The simulated axle load is 5 ton for K blocks and 5,26 ton for LL blocks.

The requirements for approval for regular braking (i.e. not winter braking) according to EN 16834 [Ref. 8] require that 1) the quotient of the standard deviation and the average braking distance shall not exceed 3 % and 2) the difference between the extreme braking distance and the average shall be less than 1,95 times the standard deviation. If the latter requirement is not met and the number of tests is higher than 5, the extreme value should be rejected. This rejection of extremes is also implemented for the RTA Climatic Wind Tunnel Vienna tests.

For the winter test program on the brake bench the criteria in EN 16452 [Ref. 3], L.4, are expressed as a deviation of the average value over a test programme:

- The permitted deviation of the average value over a test programme (100 km/h) is ± 15 %.
- The permitted deviation of the average value over three test programmes (100 km/h) is ± 10 %.
- The permitted deviation of the average value over a test programme (120 km/h) is ± 15 %.
- The permitted deviation of the average value over three test programmes (120 km/h) is ± 10 %.

Results from tests for approval of brake blocks using a block configuration having a larger wheel contact area is considered valid also for configurations having a smaller contact area, implying that the contact area is an important parameter.

The bedding of the brake blocks for testing according to the simplified braking procedure seems not to be well specified, whereas at RTA Climatic wind tunnel states at least 95 % and at brake bench tests it should be 100 % bedded-in brake blocks.

Considering the above testing and the requirements on braking distances it is found:

- There are requirements on differences in *average braking distances* for all three testing procedures, although with somewhat different percentages (10 % and 15 %).

[1] The test procedure initially proposed had three ”programmes” in which testing was first made with one set of brake blocks and secondly a new set of brake blocks was used. Thirdly, testing was again made with the first set of brake blocks. This has later been removed from the testing procedure, but the requirement has not been removed.

- There are requirements on *standard deviations* only for the ”simplified braking test” and for the Climatic tunnel tests, although very differently implemented. No requirement on standard deviation for the brake bench test.
- There are no requirements on extreme braking distances at all as long as the standard deviation is within limits. For Climatic tunnel tests, there is the possibility of removal of extreme values according to standard braking procedures in line with IRS 50444-1 [Ref. 61] and EN 16834 [Ref. 62].

It is generally unknown[2] which of the three above procedures for approval that has been employed for the brake block types that today are approved for winter braking. Such information would be valuable for pin-pointing issues embedded in the approval procedures for brake blocks as the prerequisites for testing are somewhat different.

5.2 History of braking performance testing in winter conditions – efforts by UIC

Early work on winter braking performance was summarized already 1983 in the report ORE B126 RP7 [Ref. 25], including both results for disc brakes and tread brakes. Focussing on tread braking, the report provides results for cast iron[3] brake blocks in addition to some sinter and organic composite brake blocks. Tests in Vienna ARSENAL test facility for cast iron indicate a 38% increase of braking distance at low speed (30 km/h) when having 1,7 mm ice thickness at beginning of tests[4], resulting in an ice removal rate of 37,2 mm/km. The ice removal rates for sinter composite materials were similarly between 8,3 and 8,8 mm/km and organic composite materials gave between 9,9 and 10,8 mm/km. The rate of ice removal is thus significantly slower for composite blocks than for cast iron blocks by a factor between 3,5 and 4,5[5]. Similar testing with an initial ice layer from 100 km/h gave *no* increase of braking distance with cast iron brake blocks, which could be interpreted as a very high ice removal rate at 100 km/h. Trends of increased ice removal rates were also indicated at 100 km/h for organic composite blocks as relative increase of braking distances went down. However, no quantitative assessment was made at the higher speed as ice layer thickness was not measured.

In the report by the European Railway Agency (ERA) from year 2020 [Ref. 9], the work on winter performance of freight wagon brake blocks of composite type is outlined with focus on blocks that fulfils the TSI Noise [Ref. 2] requirements. It is a substantial amount of work in the form of line tests, brake rig tests and wind tunnel tests that have been performed in the work led by the UIC. The work could be characterized as research and development at which brake block types and testing procedures have simultaneously been progressed. In some reports, e.g. B126 DT381 [Ref. 30], also mechanisms for poor winter braking have been discussed, introducing concepts of “internal icing”, when moisture enters the porous friction layers and freezes there, and “external icing”, at which ice grows on the external parts of the blocks or as ice wedges on the lower parts of the blocks. The brake block manufacturer Becorit has been deeply involved in

[2] The brake block Cosid 810 was used at UIC testing during the development of the winter testing procedures and can for this reason be considered to be well documented.
[3] Cast iron grade P14
[4] It is not explicitly stated, but it is assumed that the ice was on the brake block contacting surface and not on the wheel tread, since such ice would be immediately removed by the rolling contact.
[5] In was in the report B126 DT381 [Ref. 30] stated that the ice removal rate is approximately 3 to 4 times higher when braking with for cast iron blocks than with composite blocks (with a reference to ERRI B126 / RP7 [Ref. 26], section 3.2.5).

the work and has especially contributed to the brake rig testing for winter conditions, see also Section 5.3.

The historic background in the ERA report [Ref. 9] will not be repeated here, but some relevant aspects and results will be highlighted in the following, which are deemed important for today's testing procedures.

1) The first brake block to be approved was the organic block of type Cosid 810 in 2004, see the report B126 RP33 on K-blocks. The report covers all aspects of the approval procedure, thus including also a section on winter braking. In short, it is stated that satisfactory results can be achieved for winter braking from 100 km/h and 120 km/h with organic composite brake blocks, i.e. Cosid 810, and that sinter brake blocks generally show a decrease in braking distances at winter conditions (and when wet), which is similar to the behaviour of cast iron. It should be noted that the overall discussion in the report focusses on *average* braking distances.
   a. In the report B126 DT395, appended tables give details of testing performed in Sweden 2002. The tables have been imported and analysed, see Appendix A. The *average* braking distances, that were tested for temperatures down to -8 °C, show little or no increase for speeds 100 km/h and 120 km/h. However, for 50 km/h, winter braking (levels 3-5) gives a 7 % increase in average braking distance and a 16 % increase in *maximum* braking distances as compared to the reference taken as levels 0 and 1.
      i. One should here note that according to UIC 541-4 only testing condition 0 should be used for reference conditions. Based on this, no reference test was performed at 50 km/h. The use of reference condition 0 instead of merging conditions 0 and 1 give negligible differences regarding results for 100 km/h. However, for braking from 120 km/h there is a large difference: For conditions 0 and 1, the standard deviation and also the longest (extreme) braking distance are substantially larger than for conditions 0. This means that conclusions in the report regarding standard deviation and extremes are based on an improper / flawed reference braking distance.
      ii. In more detail for 120 km/h, using condition 0 as reference means that the standard deviation for mild winter conditions (1 and 2) is more than three times the one at reference conditions; 17,4 % vs 4,7 % of average braking distance. This is however still within the 20 % required in UIC 541-4.
      iii. The average time between initiation of stop braking applications were in average 14 minutes. The short time between stop braking tests means that effects from brake conditioning according to locomotive driver instructions was not investigated.
   b. Detailed results from tests in Sweden 2002 on braking for Cosid 810 in report B126 DT412 (Table 5) also gives information on the extreme measured prolongation of winter braking distances as compared to reference tests (considered as snow 0 and 1, despite that according to UIC 541-4, only conditions 0" should be used for reference conditions), being 40 % longer for 50 km/h, 8 % longer for 100 km/h and 5 % longer for 120 km/h. Brake testing is generally not performed for service braking (pressure drop 0,8 bar with time to full pressure 7-8 s), but for fast brake (same pressure drop but time to build-up 3-4 s).

2) The work on LL blocks was summarized in the report B126 RP36 of 2009, detailing organic block IB116* and sinter block C952. No data are given for updated C952-1, but it is expected to perform as the C952 “according to manufacturer´s statement”.
   a. IB116* testing in Sweden 2009 is presented in report B126/DT435. No temperature information is given in the report. The time between tests is between 2 min and 28 min (average 8 min if excluding times larger than 1 h), generally alternating between 120 km/h and 100 km/h. Detailed graphs can be found in Appendix B. The short time between stop braking tests means that effects from brake conditioning according to locomotive driver instructions were not investigated (usage guidelines for LL brake blocks provided in UIC 541-4 [Ref. 5] prescribe a brake applications being performed every 10 to 15 min). Based on historical data from Trafikverket metrological stations[6] in the area, it was found that testing was performed *down to* about -10 °C.
   b. C952 testing in Sweden 2004 is presented is detailed in B126 DT411. The tables have been imported and analysed, see in Appendix C. Winter conditions at 100 km/h gave average braking distance 737 m (5 % longer than reference) with a standard deviation of 46 m (7 % of average) for the 27 stops, which show an extreme braking distance of 846 m that occurred for the first braking on the last day. Reference tests gave average distance 703 m with standard deviation 46 m.
      i. The temperatures at winter tests were between -12 and -1 ºC and the time between tests between 3 min and 23 min (average 9 ºmin if excluding times larger than 1 h), generally alternating between 120 km/h and 100 km/h, with one stop from 60 km/h.
      ii. The reference conditions are again based on Snow conditions 0 and 1, which at 100 km/h impacts the results since Snow condition 1 has an average braking distance of 734 m, which is similar to the value stated for Snow conditions 2 to 5. If only snow conditions “0” are considered as reference, the average distance for reference conditions drops from 703 m to 685 m and the standard deviation drops from 46 m to 38.
      iii. Using Snow conditions “0” as reference would mean that the average winter braking distance for Snow conditions 2 and larger increases by 8 %. Moreover, average winter braking distance for Snow conditions 3-5 increases by 13 % as compared to reference conditions “0”, which is outside the 10 % allowed by the UIC 541-4. Maximum braking distances are 755 m for snow condition 0 (reference condition), 828 m for snow conditions 0 and 1, and 846 m for snow conditions 2 or larger. For the reference condition, there is a trend for increasing braking distances with decreasing temperature by about 1,8 meters per °C.
      iv. The short time between stop braking tests means that effects from brake conditioning according to locomotive driver instructions could not be investigated.

[6] Personal communication from Victoria Moberg, Trafikverket, to Tore Vernersson, 2024-09-03. Data provided for VViS stations at Bergfors, Avvakko, Svappavaara and Porjus.

3) Winter testing as part of the UIC EuropeTrain project in the period December 2010 to September 2012 concluded that braking performance in terms of full retardation “never normally” go below 90 %, but in extreme cases it could be 85 %. The tests were performed using a train having wagons with mixed organic / sinter composite, but also cast iron brake blocks. The test train had a locomotive and 26 wagons (8 loaded and 18 unloaded wagons) in a first campaign and 30 wagons (10 loaded and 20 unloaded) in a second campaign. The total weight[7] of the unloaded wagons is for the latter about 560 ton and the loaded wagons are 900 ton. Considering that winter braking problems is an issue for empty wagons mainly, the 15 % drop in full retardation could for example imply a complete loss of braking on 3 unloaded wagons, or a 50 % loss on 6 unloaded wagons. Hence, the EuropeTrain winter testing should not be used as evidence for proper functioning of individual LL block types.

4) In-service test were performed by Becorit, AAE and Green Cargo using LL composite brake blocks, together with some cast-iron braked wagons for comparison, between Luleå and Borlänge[8] during three years (October 2008 to October 2011). According to the presentation “Winter properties of composite brake blocks” [Ref. 10], the tests were performed with loaded wagons Luleå - Borlänge having an axle load 22,5 – 25 ton and on the return the wagons go empty with axle load 5,3 ton. Three trains daily, each with 2 locomotives and 26 wagons[9]. It is reported that no unusual braking distance extensions occured during the period as compared to cast iron. Operational rules for winter conditions were implemented at the tests.

5) Winter tests were performed in Finland in 2018 to study low-speed braking and in 2019 to study effects of operational rules. It can be noted that the VR tests were performed on a non-typical “closed” bogie[10] with tendencies for accumulating large amounts of snow and ice as compared to the more common Y25 bogie. For a general freight wagon setting, it is generally accepted that these tests for this reason have a low relevancy.

    a. The low-speed tests [Ref. 42] were performed using K-type sinter blocks C333 and cast iron blocks near Rovaniemi (northern Finland) and using IB116* organic LL blocks near Pieksämäki (central Finland). Brake pipe pressure reduction was 1,0 to 1,2 bar with blocks in 2 x Bgu configuration. Tests were performed using an unbraked locomotive and 5 wagons. A test was initiated by 20 km running at 90 km/h to accumulate snow, after which the locomotive was used to decrease the speed to 35 km/h, upon which low-speed tests were commenced. It was found that the average stopping distance was about 3 times longer for composite blocks than for cast iron. The maximum stopping distances were 3 and 4 times the one of cast iron for the sinter block and for the organic blocks respectively, and the increase in standard deviation were 6 and 4 times larger, see Table 1. In the Low-Speed report it is stated “*According to gained experience from field operation the snow and ice accumulation on the brake blocks can occur in two ways, either by flying or brought by the wheels. Accumulation by flying snow is more typical at higher speeds (above ~50 kph) when snow fly-off is stronger due to whirling air. In*

[7] Axle load empty 6 ton and loaded 22,5 ton.
[8] In Swedish the train is denoted “Stålpendeln”, tentatively in English the “Steel Shuttle”
[9] 30 wagons with LL C952-1 (2 x Bgu), 29 wagons with LL IB116* (2 x Bgu), 5 wagons with LL IB116*-combi (2 x Bgu), 4 wagons with cast iron P10 (2 x Bgu), 1 wagon with cast iron P14 as reference (2 x Bgu)
[10] K16 bogie “Lenkachsdrehgestell”, original design Linke Hofmann Busch

another way snow sticks to the wheel if the wheel has contact with snow and wheel temperature is close to 0°C."

Table 1 Stopping distances from 35 km/h according to VR tests

	Brake block material		
	C333	Cast iron	IB116*
Average stopping distance [m]	325	106	315
Standard deviation [m]	143	24	101
Maximum stopping distance [m]	614	157	504
Minimum stopping distance [m]	152	73	174

b. Line tests [Ref. 39] were performed using the CoFren C810 organic K-type brake block in 2 x Bgu configuration. The brake rigging efficiency on the wagons was measured to about 0,5, which is very low and this means that the resulting braking force acting on the blocks also is very low and can be considered as a worst-case scenario. The hypothesis was to enforce good braking performance by keeping the brake blocks free of snow and ice by regular conditioning braking. This proved not to be possible since warm wheels caused heavy snow build-up in the bogies which prevented proper movement of brake rigging and blocks. It was found that conditioning braking with vigorous brake applications (2 min applied brakes and 2 min released brakes with full service braking), kept the snow and ice soft and wet for air temperature between -5 °C and 0 °C. However, when the time of released brakes increased to 3 min the snow became icy and hard. The average stopping distances increased by 121 % at 100 km/h in winter conditions compared with results in reference conditions when the bogies were full of snow and ice. After melting of the ice in the bogies, the increase was 39 %.

5.3 Winter brake bench testing

In the report B126 RP37 "Issues of braking – winter properties of composite brake pads" from 2010, the work on winter braking is summarized, including field tests results and results from winter brake bench testing. Additionally, unsuccessful work on developing a wet program for test benches with aim to correlate with winter properties is reported.

The development of the Becorit winter brake bench, see Figure 1, was part of a wider campaign in which the results from the brake bench were compared to those from field tests. The brake bench snow equipment and testing procedure were updated until a proper correlation with test field results was found. The final version was calibrated by reproducing 1) the good winter properties of CoFren C810 (reference A) with average distance extension not exceeding ±8 % and 2) the poor winter properties of Jurid 816 (reference B) with average distance extension between 18 and 30 %.

It is presumed that the winter field testing for both the C810 block and Jurid 816 blocks were performed with short time between stop braking tests, as for other similar line tests. This means that effects from brake conditioning according to locomotive driver instructions were not considered.

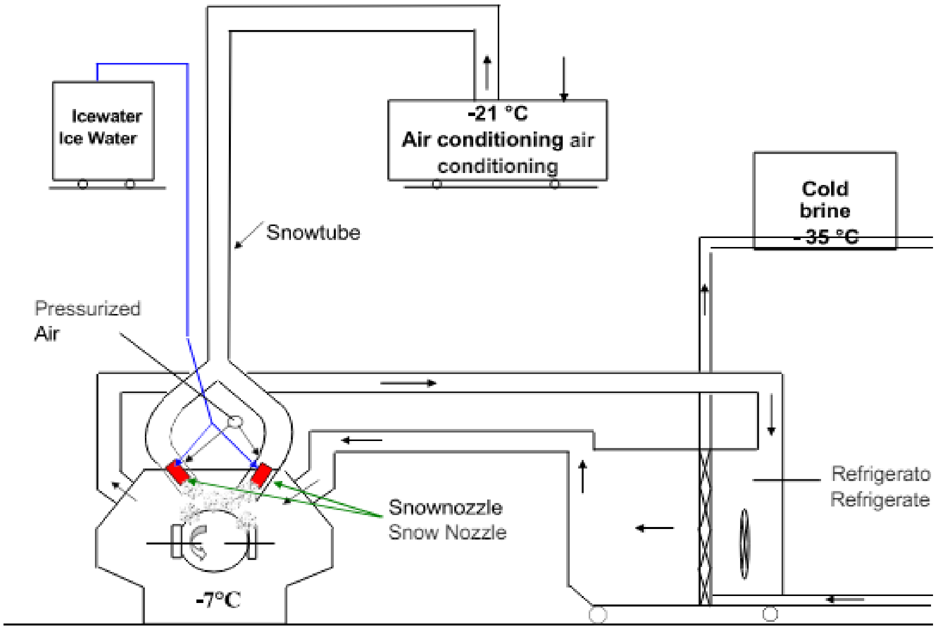


Figure 1 Schematic representation of the Becorit test rig (final iteration).

The winter testing procedure means testing in three runs, where one set of blocks is tested in the first run, another in the second and in the third the first set of blocks are again tested. The acceptance criteria for brake blocks for winter conditions are stated to be 1) the average extension of braking distance for the three runs must not exceed 10 % and, 2) the average extension of each run must not exceed 15 %.

Results for braking from 100 km/h for winter test bench and for field tests are given in the Table 2. The report also gives values for 120 km/h, but these values are not further discussed here. The table highlights the similarities between Becorit winter test bench and the winter field tests when it comes to average braking distance and also standard deviation of the braking distances. Extreme values are not considered in the comparison, except for that they contribute to the standard deviation.

Table 2 Data from report B126 RP37 used for verification of final iteration of Becorit winter brake bench. Note that the results for C810 and Jurid 816 were used for proving proper characteristics of the Becorit winter brake bench.

Block	Becorit winter test bench / braking from 100 km/h						
Type 2xBgu	Braking distance MW Reference (R) [m]	Stabw Braking Distance Reference [m]	Stabw Braking Distance Reference [%]	Braking distance MW winter (W) [m]	Stabw braking distance winter [m]	Stabw braking distance winter [%]	(W-R)/R [%]
Becorit							
929-1	489,02	37,9	**8%**	630	67,8	**11%**	**28,8%**
929-1 SG							
K 26	529,57	29,2	**6%**	626,7	108,1	**17%**	**18,3%**
K 26							
K 40	424	13	**3%**	425	20	**5%**	**0,2%**
IB 116* (LL)	441	19	**4%**	435	12	**3%**	**-1,4%**
Brake guy							
8675-1	620,50	13,7	**2%**	667,17	41,9	**6%**	**7,5%**
8675 H	434,06	9,9	**2%**	707,47	162,0	**23%**	**63,0%**
CoFren							
C 810	548,74	22,5	**4%**	524,51	33,7	**6%**	**-4,4%**
C 952 (LL)							
Honeywell							
Jurid 816	518,90	12,6	**2%**	646,00	40,6	**6%**	**24,5%**
Jurid 816 M	536	21	**4%**	567	17	**3%**	**5,7%**

Block	Field test / braking from 100 km/h						
Type 2xBgu	Braking distance MW Reference (R) [m]	Stabw Braking Distance Reference [m]	Stabw Braking Distance Reference [%]	Braking distance MW winter (W) [m]	Stabw braking distance winter [m]	Stabw braking distance winter [%]	(W-R)/R [%]
Becorit							
929-1							
929-1 SG	817	23	**3%**	1006	141	**14%**	**23,1%**
K 26	735	48	**7%**	880	36	**4%**	**19,7%**
K 26							
K 40	667	26	**4%**	654	23	**4%**	**-2,0%**
IB 116* (LL)	642	33	**5%**	632	32	**5%**	**-1,5%**
Brake guy							
8675-1							
8675 H	843	25	**3%**	1049	158	**15%**	**24,4%**
CoFren							
C 810	693	36	**5%**	676	32	**5%**	**-2,5%**
C 952 (LL)	703	46	**6%**	737	47	**6%**	**4,9%**
Honeywell							
Jurid 816	749	45	**6%**	892	98	**11%**	**19,1%**
Jurid 816 M	848	79	**9%**	938	85	**9%**	**10,6%**

5.4 Winter tests in Sweden arranged by Transportstyrelsen

The agency arranged winter testing of LL type brake blocks in the northern part of Sweden during five consecutive winters. The brake block configuration was 2 × Bgu[11] and the studied brake blocks were primarily the organic composite IcerRail / Becorit IB116* and the sinter composite CoFren C952-1. Tests were also performed on cast iron brake blocks, but only in single bogies.

The tests were generally performed on unloaded wagons at an axle load of 6,5 ton. Some few tests were performed using an axle load of 15 ton, but since these gave extremely high braking deceleration that resulted in wheel flats, testing of this was aborted not to jeopardize the entire test campaign. The wagons employed at testing were well maintained and had a dynamic brake

[11] Two brake blocks on each side of the wheel.

efficiency of about 88 %, which can be compared to 83 % stipulated for standardised calculation of braking performance of freight wagons.

Results are first presented for simplified brake testing, with a winter stop test being performed every 15 min, and after that for tests where short brake conditioning applications are implemented in between winter stop tests.

5.4.1 Simplified brake testing

Tests during the winter 2017–2018, see [Ref. 43] and [Ref. 44], were performed using wagons with a mix of cast iron and LL-type brake blocks, meaning that a comparison of braking distances resulting from the different types of brake blocks was not possible. The winter test performed 2018–2019 [Ref. 45], again employing wagons with mixed blocks types, were unfortunately delayed until April 2019, just after the winter had ended. A few days of testing were nonetheless performed as a precursor for the larger test campaign performed during the winter 2019–2020 for which the results were analysed and documented in a report [Ref. 46]. During this test campaign, a stop braking test was performed approximately every 15 minutes during each day of testing, which means that no additional conditioning braking between stops could be implemented. This testing thus corresponds to the “simplified brake tests” of report B126/DT435. The winter 2019–2020 was extremely mild also for the region of testing in the northern part of Sweden, with -8 °C being lowest temperature while testing organic composite block IB116* at high snow / winter indices, while it was -20 °C for sinter C952-1. For the tests performed, a tendency for increased braking distances with decreasing temperatures could be identified for the organic IB116* blocks, see Figure 2, however over a rather narrow range of temperatures. No such tendency could be found for the sinter C952-1 blocks, see Figure 3.

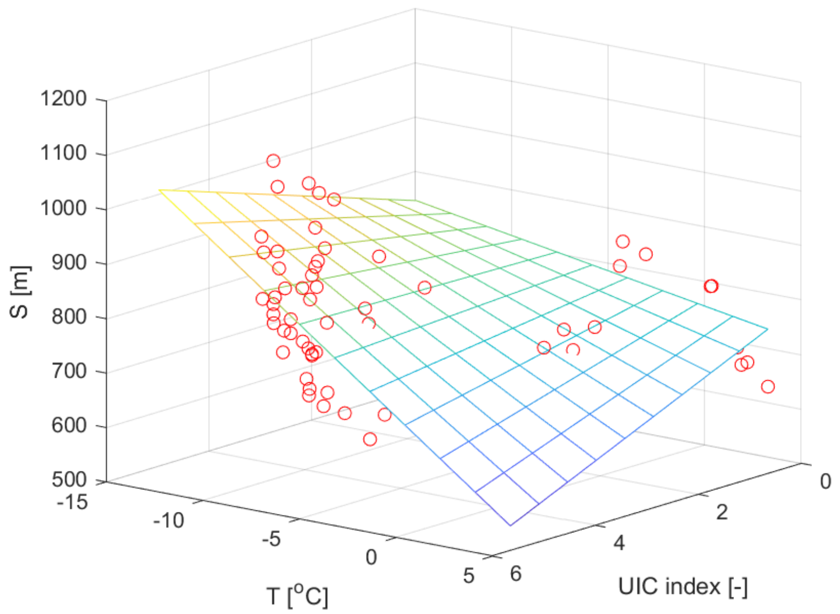


Figure 2 Braking distance results for organic composite LL blocks IB116 as function of air temperature and UIC winter index along with a fitted surface.*

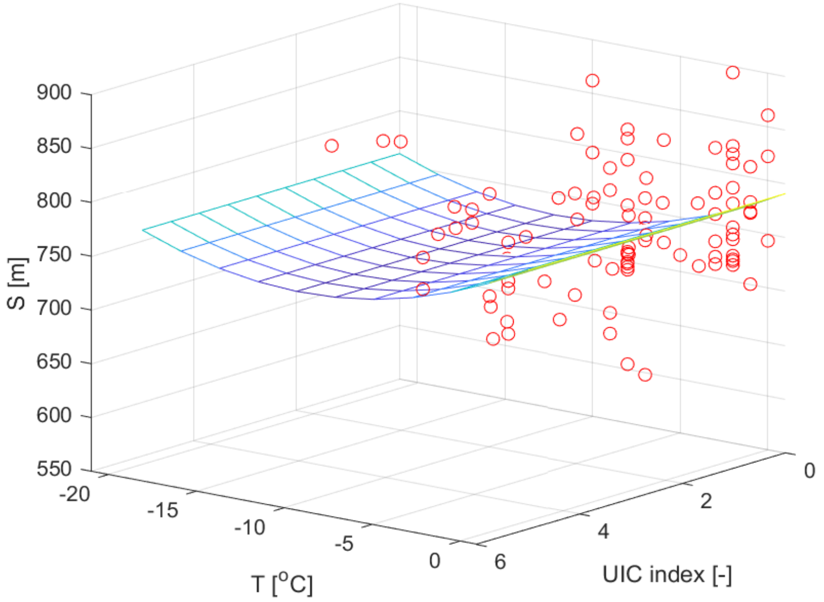


Figure 3 Braking distance results for sinter LL blocks C952-1 as function of air temperature and UIC winter index along with a fitted surface.

For the sinter brake blocks, see Figure 4, a constant or slight *decrease* in average braking distances is found for increasing snow whirling conditions (from R0 up to W5). Similarly, there is a trend of decreasing standard deviation of braking distances with increasing snow whirling. The average braking distance is 772 m for R0 and the averages for W1–W5 range between 753 m and 764 m.

For the organic composite brake blocks, see Figure 5, an increase in average braking distances is found for conditions with whirling snow (W1–W5) as compared to when no snow whirling is present (R0). The maximum braking distances are found for conditions W3 with an average braking distance being 25 % higher than for R0. Similarly, there is a trend of increase in standard deviation of the braking distances with increasing snow conditions (with exception W3 having low standard deviation). The average braking distance is 724 m for R0 and the averages for W1–W5 range between 792 m and 908 m. When revisiting the measured data in 2025, for the purpose of the present report, it is found that the deviating results for W3 could be correlated with having testing results only for a small temperature range between -15 °C and -8 °C, see Figure 6. The temperature at testing clearly impacted the results and highlights the importance of having a low testing temperature.

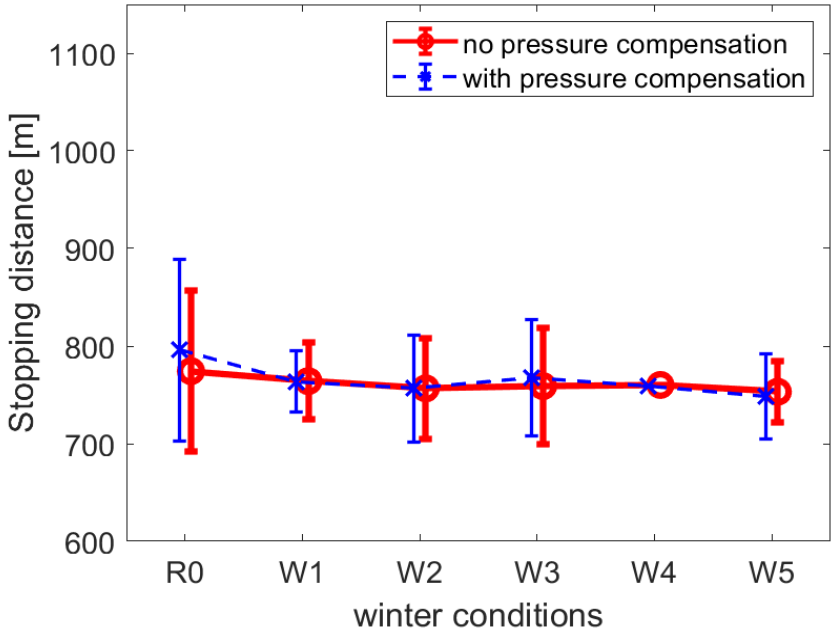


Figure 4 Results for sinter LL brake blocks C952-1. Average stopping distance indicated by circles or crosses, with bar indicating standard deviation, as a function of UIC winter conditions.

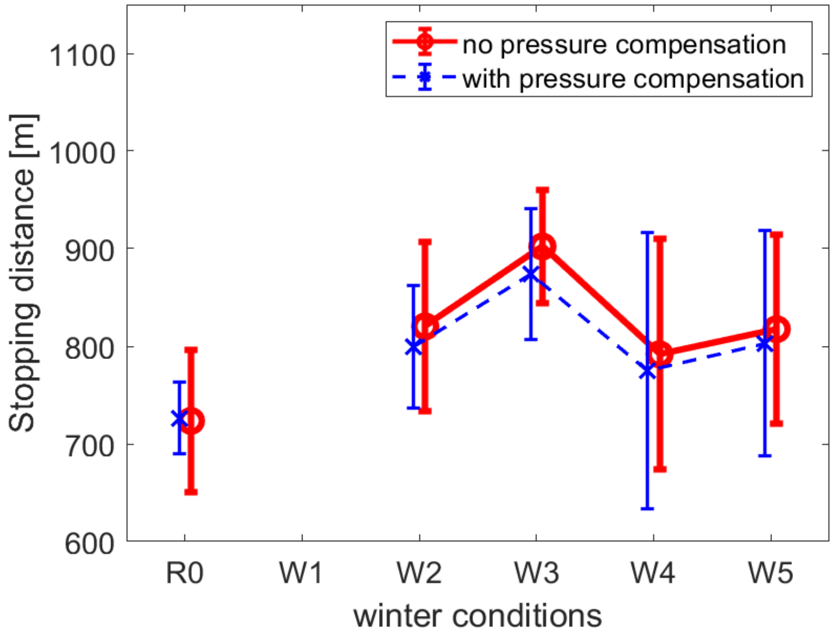


Figure 5 Results for organic composite LL blocks IB116. Average stopping distance indicated by circles or crosses, with bar indicating standard deviation, as a function of UIC winter conditions.*

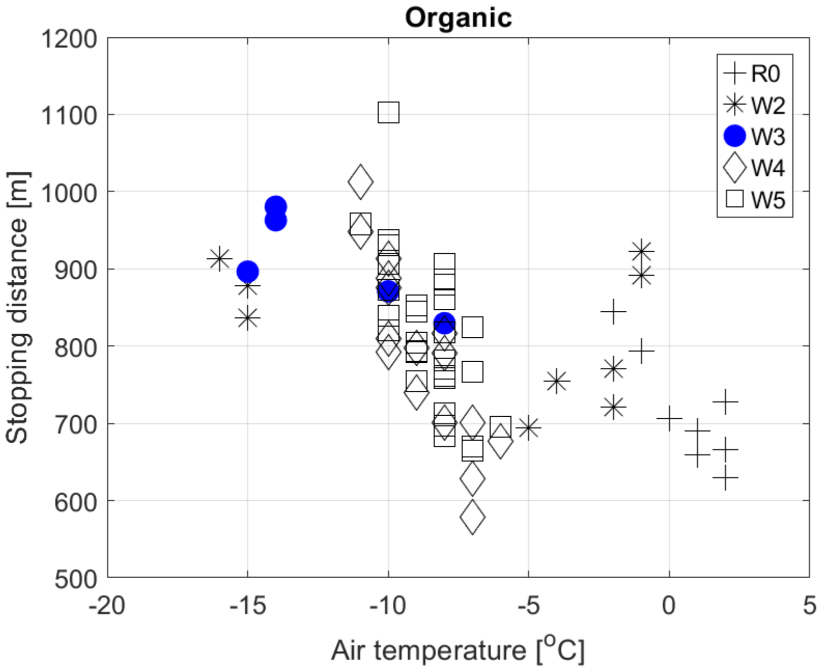


Figure 6 Results for organic composite LL block IB116 showing individual stopping distance as function of temperature and at the same time indicating winter conditions. Note the low-temperature range of W3 tests are highlighted using filled markers. No results were available for W1 conditions.*

In addition to the above stop braking tests of winter 2019-2020 for which the test train had uniform sets of brake blocks, in a second phase of the testing, bogie 1 of wagon 2 was equipped with cast iron blocks and, finally, in the third phase bogie 2 of wagon 2 was equipped with organic composite blocks IB116*. All other wagons / bogies then had sinter C952-1 brake blocks. Comparisons were made regarding brake friction forces and braking energies. Also studied was the braking performance with respect to the time delay from the instant of increase of the brake cylinder (pneumatic) pressure until the onset of the brake friction force for the individual brake block inserts.

An example of resulting time delays for sinter blocks are presented in Figure 7, separated into brake block in a leading[12] position in wheelset and a trailing position, along with the surfaces fitted to the data. Time until onset mostly range between 5 and 10 s, while some show higher time delays. For those, the highest time delays are found for either low temperatures or for high UIC indices. For cast iron material, Figure 8, the time delays generally range between 4 s and 8 s, with only exception two data points around 11 s occurring at high UIC index and lowest temperature (–10 ºC). For the organic composite blocks, see Figure 9, it can again be noticed that the there are some tendencies for increasing time delays for lower temperature and higher UIC indices.

[12] As compared to train travelling direction

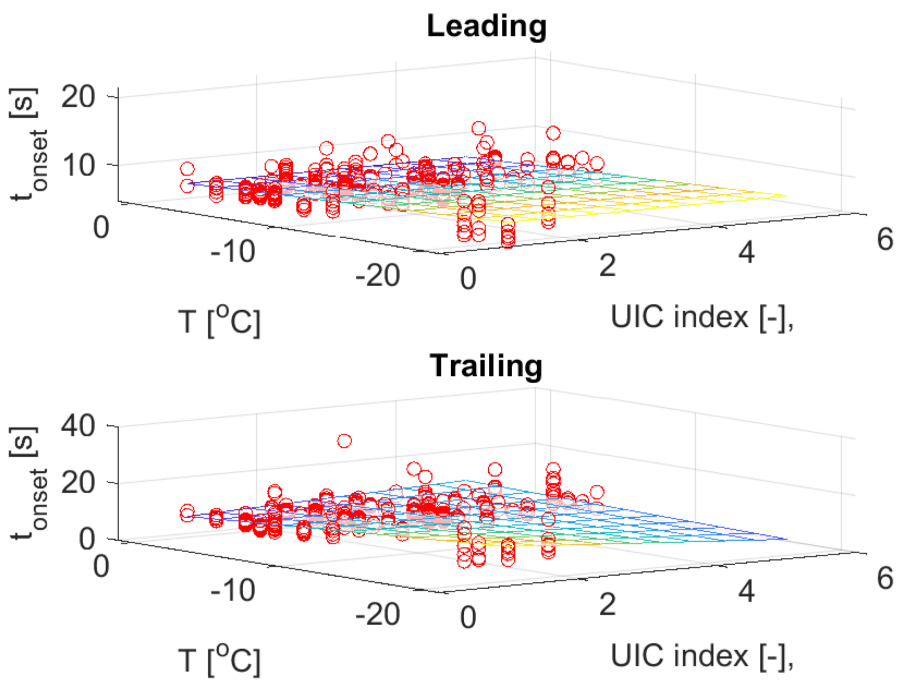


Figure 7 Sinter LL brake blocks C952-1: Calculated time delay until onset of brake friction forces as function of air temperature and UIC winter index. Results are given separately for brake blocks in leading and trailing position when considering the wheelset and the train travelling direction.

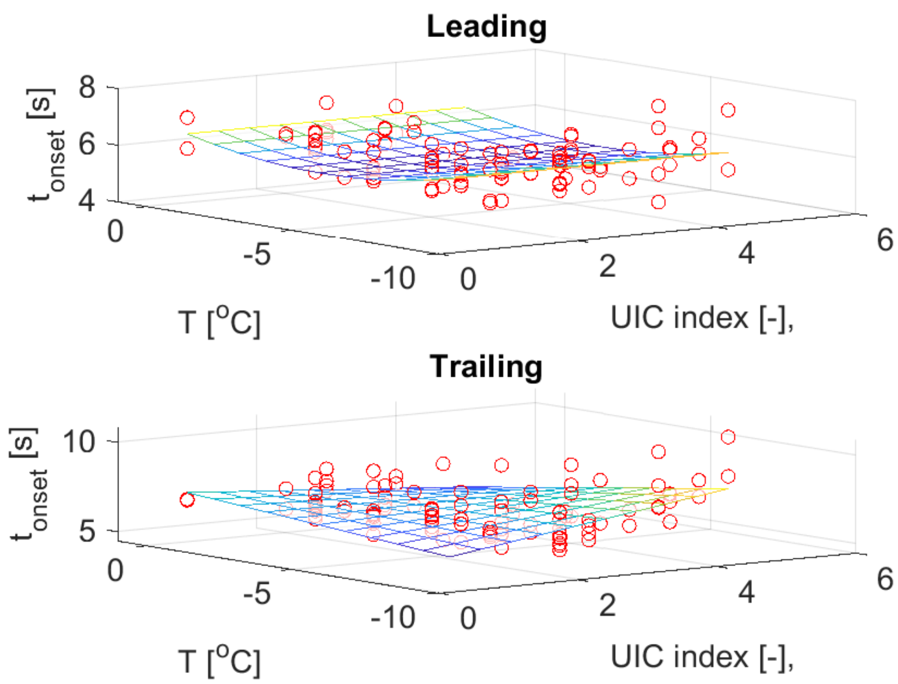


Figure 8 Cast iron brake blocks: Calculated time delay until onset of brake friction forces as function of air temperature and UIC winter index. Results are given separately for brake blocks in leading and trailing position when considering the wheelset and the train travelling direction.

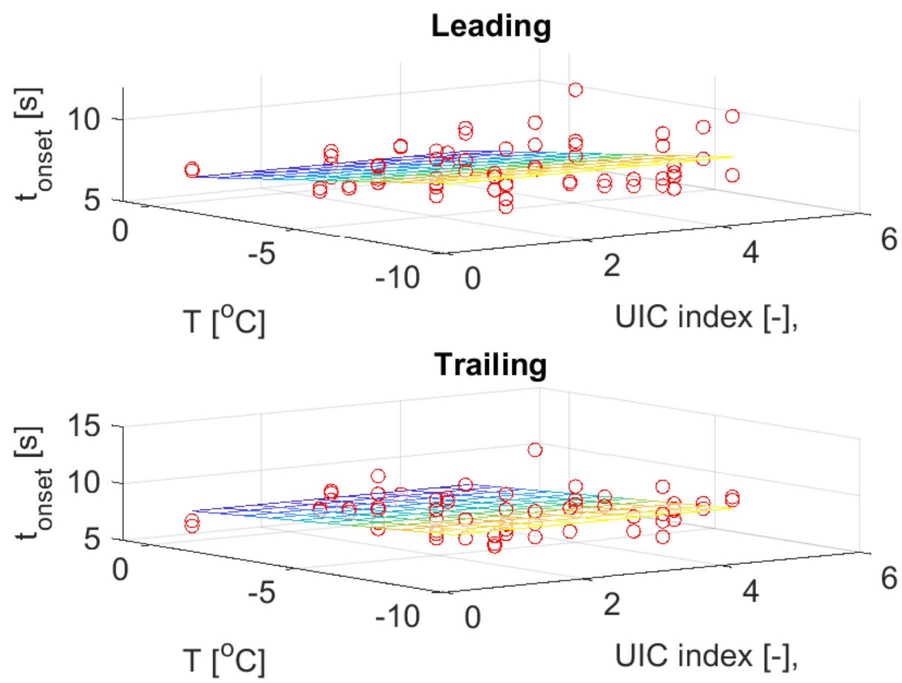


Figure 9 Organic composite LL brake blocks IB116: Calculated time delay until onset of brake friction forces as function of air temperature and UIC winter index. Results are given separately for brake blocks in leading and trailing position when considering the wheelset and the train travelling direction.*

5.4.2 Brake testing featuring brake conditioning

From January through to April 2021, similar to the two previous winters, a dedicated test train built-up by one locomotive and five test wagons, was employed for winter testing [Ref. 47]. One focus of the tests was to investigate the influence of locomotive driver instructions. Three types of locomotive winter driver instructions were employed. Two of the types represent proper driver behaviour that is in line with the usage guidelines for LL brake blocks provided in UIC 541-4 [Ref. 5] with short (10 to 15 s) brake applications being performed every 10 to 15 min. The third type represents driving without proper brake conditioning, meaning that the driver proceeds with no brake applications for a longer duration prior to a stop braking test. ”Normal“ brake conditioning means that every 10 minutes the brakes are applied for 13 s by main brake pipe reduction of 0,6 bar. ”Enhanced“ brake conditioning means that every 15 minutes the brakes are applied by reduction of 1,0 bar for 10 s. The improper “Provocative“ brake conditioning means to mimic a situation when brake conditioning partially fails[13]. It can be noted that ice and snow do build-up on the blocks during testing to a high degree and this is occurring when braking under all driver instructions, often in such amounts that the actual blocks cannot be seen, see details in the report [Ref. 47].

For unloaded wagons with an axle load of 6,5 ton (and a brake weight of 6,5 ton) it is found that perfectly bedded-in organic composite blocks IB116* behave rather well both when employing “Normal” driver instructions and “Enhanced” driver instructions, but also when using the “Provocative” driver instructions, see Figure 10. The stopping distances when using the normal driver instructions are the shortest (700 m to 860 m) and the braking distances show no trend of

[13] Normal brake conditioning up to first site for stopping test, no further brake applications until second stopping test.

increasing braking distances for situations with whirling snow. The enhanced instructions showed somewhat longer braking distances and there is a trend towards longer braking distance (increase by 9 % of average distance) for severe winter conditions W3–5 (with substantial amounts of whirling snow around the wagons). The longest stopping distances result from employing the provocative driver instructions with 11 % higher average distance as compared to the enhanced instructions and also with a larger spread of data (830 m to 1100 m). Tests with blocks IB116* were also performed with frequent stop tests and they resulted in much shorter braking distances than the ones using UIC driver instructions, ranging from 500 to 740 m. This latter case basically mimics the brake testing performed during the 2019–2020 test campaign and is not a realistic winter driving technique for railway freight traffic.

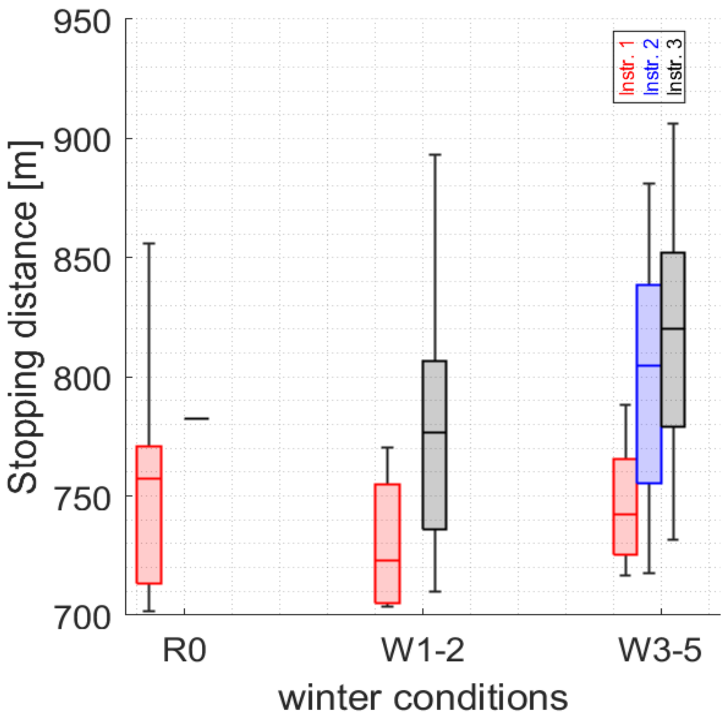


Figure 10 Overview of results for organic composite LL blocks IB116, separated into employed driver instructions. "Normal" driver instruction is denoted Instr. 1 (red), "Enhanced" driver instruction is Instr. 2 (blue) and "Provocative" driver instruction is Instr. 3 (black). Resulting stopping distances are indicated by box plots: the median (center line in box), the lower and upper quartiles (box exteriors), any outliers (computed using the interquartile range) marked by circles (in the present figure there are none) and the minimum and maximum values that are not outliers indicated by whisker endpoints.*

Unloaded wagons with an axle load of 6,5 ton equipped with sinter blocks C951-1 behave rather well when employing "Normal" driver instructions – the performance is in fact somewhat better than for the "Enhanced" driver instructions, see Figure 11, which was also the case for the organic composite blocks. Braking employing the "Provocative" driver instruction causes occurrences of substantially prolonged braking distances. For one such stop, two wagons more or less lost their braking capabilities as an effect of sudden loss of massive amounts of ice and snow that had accumulated between blocks and wheels. This resulted in almost a doubling of the braking distance.

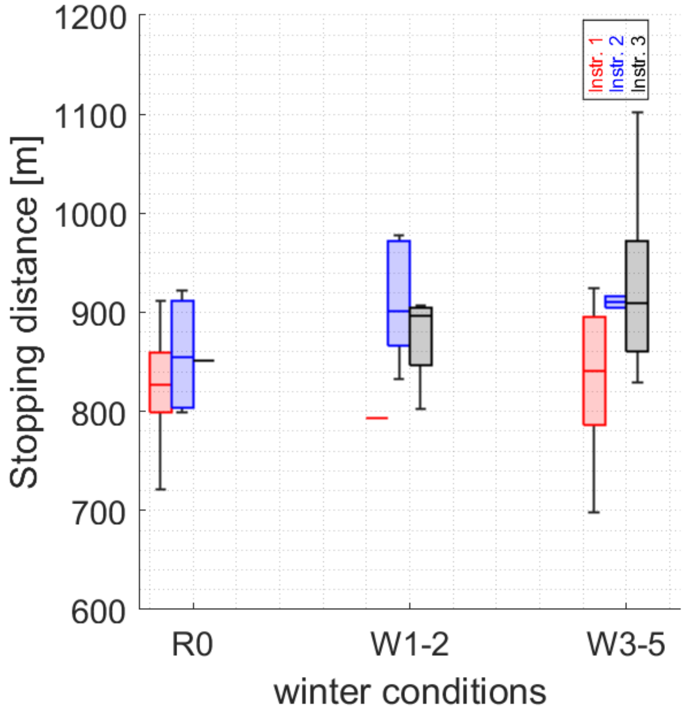


Figure 11 Overview of results for sinter LL blocks C952-1, separated into employed driver instructions. "Normal" driver instruction is denoted Instr. 1 (red), "Enhanced" driver instruction is Instr. 2 (blue) and "Provocative" driver instruction is Instr. 3 (black). Resulting stopping distances are indicated by box plots: the median (center line in box), the lower and upper quartiles (box exteriors), any outliers (computed using the interquartile range) marked by circles (in the present figure there are none) and the minimum and maximum values that are not outliers indicated by whisker endpoints.

One reason for the lower braking performance of the sinter brake blocks as compared to the organic composite blocks is that the time until the friction force reaches a significant level is almost double, see Figure 12 (left graphs) for an overview for organic composite blocks and Figure 12 (right graphs) for sinter blocks. The time delay is assessed as the time from start of the pneumatic pressure rise in the brake cylinder until the time at which the friction force reaches 50 % of the maximum friction force. The considered maximum force amplitude is the largest registered force for the entire stop for any block insert for the considered wagon and braking. It is found that there are significant differences between organic composite blocks and sinter blocks. The time delay for winter conditions is found to be 10–13 s for "Normal" and "Enhanced" driver instructions when using organic composite blocks, but 18–30 s for sinter blocks. The longer time of build-up of the friction forces for the sinter blocks correlate well with the longer presented brake distances for the sinter blocks. Longer time delays until the friction force is building up to a significant value is reducing the braking performance for the sinter blocks.

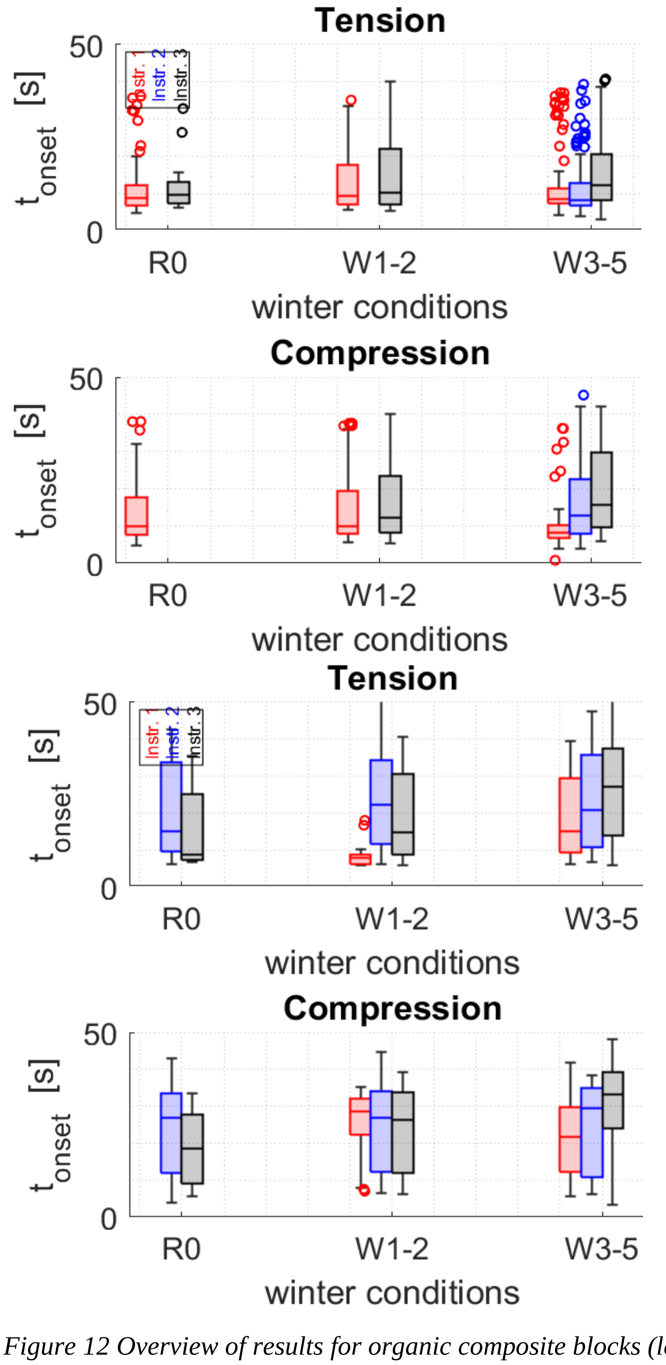


Figure 12 Overview of results for organic composite blocks (left) and sinter composite blocks (right), separated into employed driver instructions. "Normal" driver instruction is denoted Instr. 1 (red), "Enhanced" driver instruction is Instr. 2 (blue) and "Provocative" driver instruction is Instr. 3 (black). Resulting time delays till onset are indicated by box plots: the median (centre line in box), the lower and upper quartiles (box exteriors), any outliers (computed using the interquartile range) marked by circles, and the minimum and maximum values that are not outliers indicated by whisker endpoints.

5.5 Synthesis of braking performance investigations on LL brake blocks

Comparisons of resulting braking distances for different winter braking campaigns are presented in Figure 13.

For the organic IB116*, the results for simplified type of brake testing (repeated brake tests with no condition braking) according to Transportstyrelsen of 2019-2020 and the ones of UIC show rather different trends, see Figure 13 (top), with increasing braking distance by decreasing snow index for the latter and increasing for the former. One difference in testing is that the UIC brake testing is performed with a shorter time interval (less than 10 minutes) than the testing by Transportstyrelsen having about 15 min. As described previously, see Section 5.4.1, the deviating behaviour for the Simplified tests at winter condition 3 is caused by winter testing being performed for a narrow low-temperature range of between -15 °C and -8 °C, showcasing the importance of testing temperature. The results for when different driver instructions (brake conditioning types) are implemented are here found in-between the two simplified braking tests. One notable difference between the UIC results and the others is the relatively low standard deviation found as compared to the others. This indicates that the brake blocks are sensitive to the testing procedures.

For the sinter C952-1 brake blocks, see Figure 13 (bottom), the two types of simplified tests again show different trends, with decreasing braking distances for the Transportstyrelsen test campaign with increasing winter indices, while somewhat increasing for the UIC tests. There is a remarkable difference between the three brake conditioning types, in that the third type for which it is not possible to perform proper conditioning during a somewhat prolonged period, gives substantially longer braking distances *for all conditions*, but especially so for more severe winter conditions (indices 3-5). It is notable that for winter condition 3 that both the mean braking distance and the standard deviation are the largest observed for the block type.

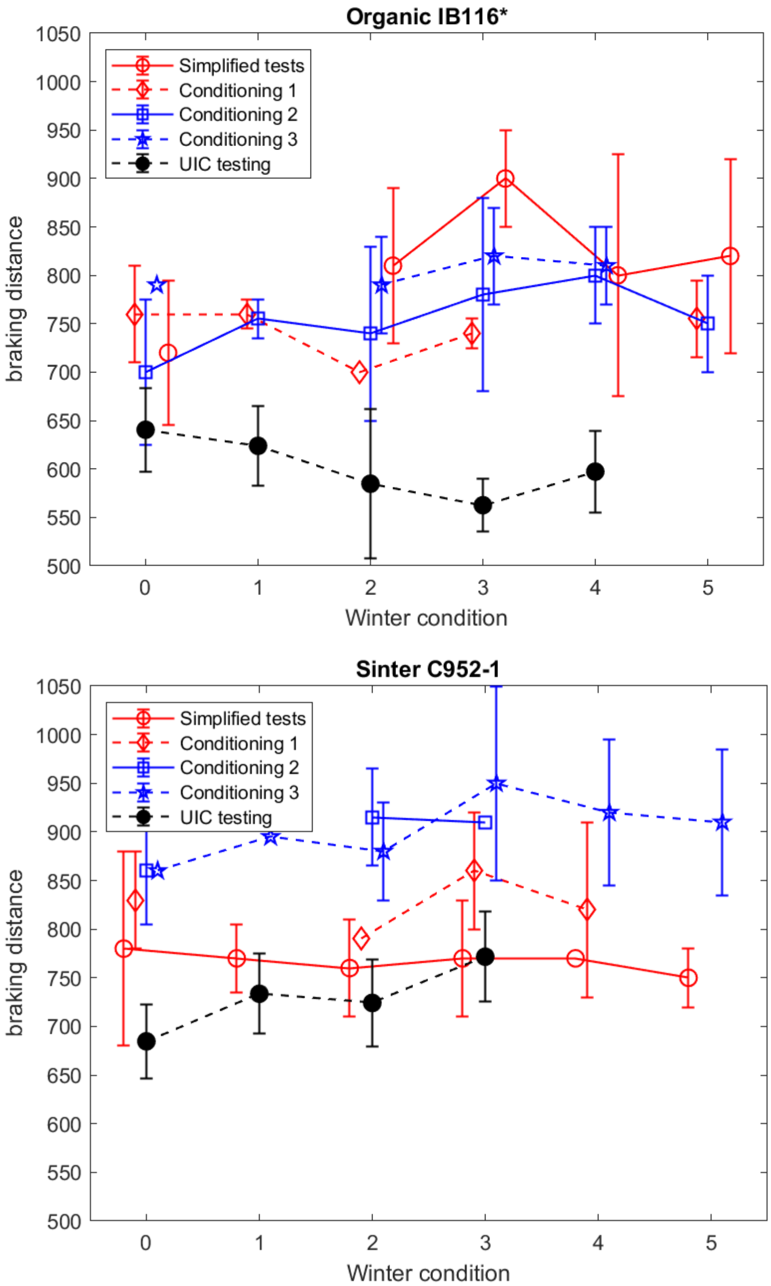


Figure 13 Comparison of results for LL brake blocks. Organic IB116 (top) and sinter C952-1 (bottom).*

6 Numerical simulations and reduced scale testing of winter braking

Two scientific studies have recently been performed in Sweden that are relevant for the understanding of the winter performance of composite brake blocks. The first one investigates the removal of ice in the form of melting from brake block exterior by braking under the presumption that that frictional heat is generated over the entire brake block (nominal) contact area. The second one investigates braking for the situation when ice is initially present on the entire brake block contact area with the wheel, with the inherent decrease in brake friction, to the state when braking with high friction initiates when the ice is removed from the contact.

Additionally, in a final section, results are presented from pin-on-disc testing and material investigation efforts performed recently to investigate the possibility to investigate winter braking performance using small-scale testing.

6.1 Ice removal from block exterior by melting

A thermal model is presented in [Ref. 48], that sets out from a situation where blocks and holders are externally covered with a layer of ice, which in some way has accumulated prior to braking. It is presumed that no ice has accumulated between wheel and brake block, meaning that heat is generated over the entire contact surface of the brake block. The melting of the ice layer for tread braking is simulated, and the degree of ice removal is assessed using a mixed axisymmetric and three-dimensional representation of components, see Figure 14.

Results for removal of a 5 mm ice layer on brake block and on block holder when using brake blocks from cast iron, sinter material and organic composite material are shown in Figure 15 for the 2 x Bgu brake block configuration since this constitutes a more severe situation with less expected de-icing of the parts as compared to the 2 x Bg case. A comparison of the de-icing ratios for cast iron and sinter blocks indicate that these two block types behave in a rather similar way, with the cast iron blocks being slightly superior. The results are to be expected since they have similar properties with respect to thermal conductivity and diffusivity. The reason for the cast iron brake block to be slightly superior lies in the particular block-to-wheel heat partitioning properties of this material that makes a higher part of the heat to enter these brake blocks.

The studied organic composite brake blocks have inferior thermal conduction properties as compared to the two metal-based cast iron and sinter materials. This effectively delays de-icing of the brake blocks and the holder for the studied braking load cases. The cast iron brake blocks are for example fully de-iced after a 30 kW drag braking cycle of 1 min duration whereas the organic blocks are less than 20 % de-iced for the same braking case. For the organic composite block, only the areas closest to the block–wheel contact are de-iced and the remaining parts preserve their ice-layers and can tentatively be subjected to further build-up of ice as the train continues rolling after braking. The sensitivity of the organic composite material to thermal properties was studied by increasing the thermal conductivity of the material from the original value 1,5 W/m°C. It was found that for accomplishing a complete de-icing of the brake block holder for the most severe of the here studied braking load cases (15 min at 30 kW), a thermal conductivity of somewhat higher than 10 W/m°C is required for organic composite brake blocks.

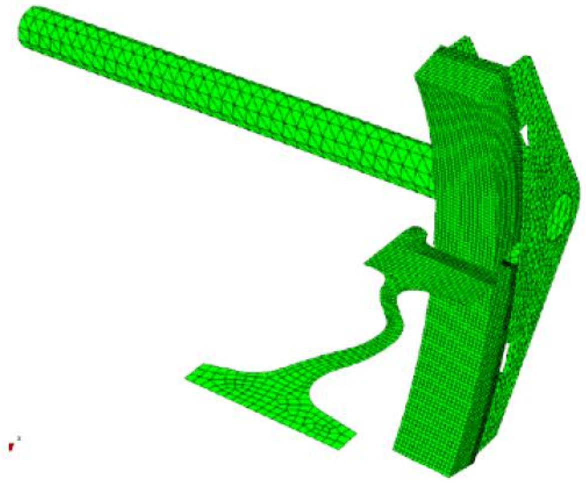


Figure 14 Combined axisymmetric FE meshes of wheel and 3D models of block for study of wheel and block temperatures at tread braking for a 2 x Bgu block configuration.

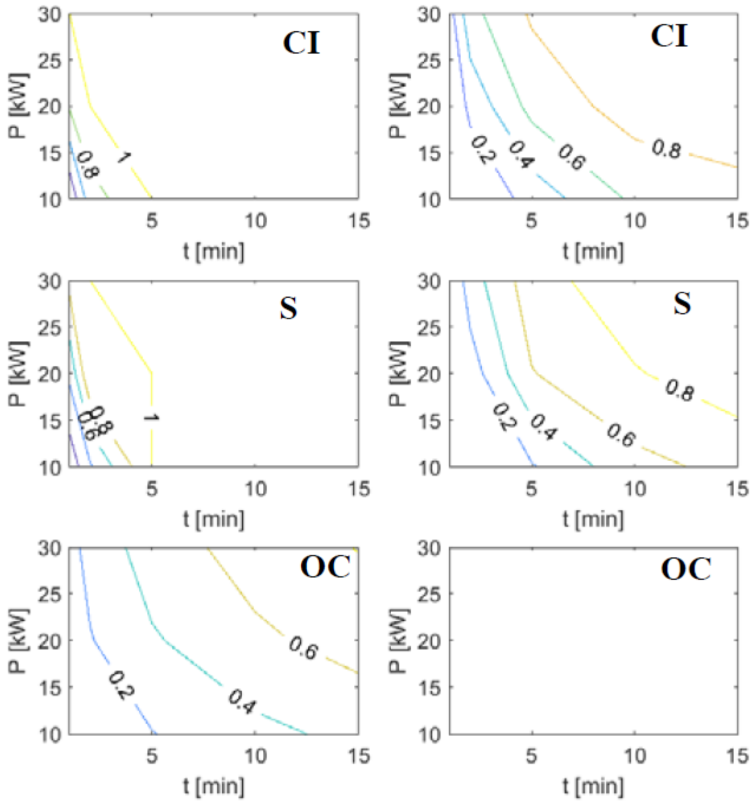


Figure 15 Ratio of de-icing of external surfaces of brake block (left column) and brake block holder (right column) for brake block materials CI being cast iron material, S Sinter composite and OC Organic Composite.

6.2 Ice removal from friction surface by crushing

The situation with ice in-between brake blocks and wheel at the on-set of braking was studied numerically for a freight setting in [Ref. 49], see Figure 16, investigating the influence on braking distances. It is presumed that heating is generated between the ice layer on brake block and the wheel tread, with a low coefficient of friction 0,03. This heating acts as to increase the temperature of the ice until it reaches a temperature at which its strength is lower than the applied brake normal pressure. The ice is then assumed to instantly be crushed and its effect revoked and conventional braking is activated with coefficient of friction 0,2. The simulated results in Figure 16 show the effect from the delayed onset of brake friction on braking performance. Braking from 100 km/h with a 3 mm ice layer results in an increased braking distance by 11 %[14] as compared to reference conditions when braking at -15 °C. It can here be noted that the increased braking distance doesn't correspond to experience from real operation where the increase is far higher. The report confirms the operational experience that high braking power is an advantage. The effect from ice can be seen to be stronger at lower speeds where the stopping distance from 25 km/h is increased by 107 %.

It shall be pointed out that the ice thickness in the calculations [Ref. 49] is far thicker, 2-6 mm, than observed in real operation which is << 1 mm.

It can here be commented that the properties of ice can vary significantly [Ref. 50]. For instance, the ice grain size will affect the tensile strength significantly, whereas the compressive strength is affected to a lesser extent.

[14] See [Ref. 49], Figure 7.

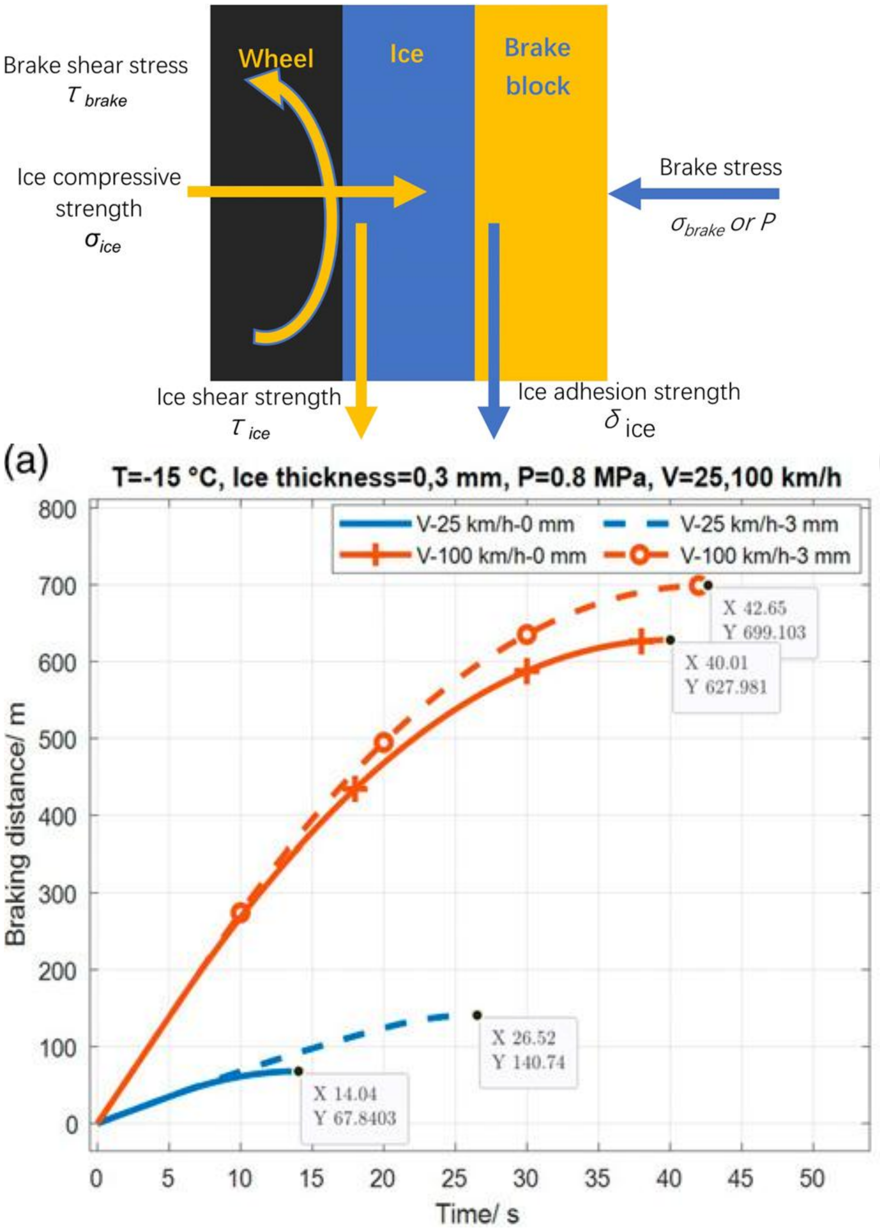


Figure 16 Top: Modelling assumption on ice layer stresses and strengths[15]. Bottom: Calculated results for braking distances vs time when braking for speeds 25 km/h and 100 km/h with and without a 3mm ice layer[16].

[15] See [Ref. 49], Figure 3.
[16] See [Ref. 49], Figure 6 (a).

6.3 Reduced scale tests

Reduced scale tests are somewhat problematic when it comes to tribological tests as it is widely known that full scale tests cannot readily be scaled down without compromising aspects of the results. However, the results can nevertheless be informative regarding mechanisms at play and give hints on tribological performance.

The winter properties of cast iron and four composite brake blocks relevant for the Stockholm Public Transport were reported in 2016 [Ref. 51]. A pin-on-disk testing device in a climatic chamber was used for testing at speed 1,8 m/s and nominal contact pressure 0,8 MPa at temperature -2 °C. Snow was applied to the disc during testing to investigate the friction response. It was found that the response to added snow significantly differed between the materials, both regarding change in coefficient of friction at snow addition and the time until friction is recovered after snow addition. It is found that the composite material that produces the smoothest surface on the disc could lead to easier separation of the surfaces by the melting water and a lower friction. The material structure of the pin composite material had an effect and also machining of the pin contacting surface. For the present report and relevance for freight wagon winter testing it should be noted that the study perhaps has more similarities to wet tests rather than winter tests since snow cannot enter the sliding contact. It should here again also be noted that this is a pin-on-disk test and not a brake block test.

The low temperature performance of cast iron, sinter and organic composite brake blocks was studied in a pin-on-disk study in 2019 [Ref. 52]. The sinter material showed a constant coefficient of friction between -30 °C and +10 °C, while the organic composite showed a reduction by about 40 % when the temperature decreased from +10 ºC to -30 ºC. It was discussed that the organic composite contains a large proportion of phenolic resin, which is prone to absorb water, which could act to produce an ice condensation layer on the block that lowers the coefficient of friction at lower temperatures.

As part of the work by Transportstyrelsen, tests were performed at Luleå University on cast iron and composite brake block materials [Ref. 53]. The latter comprised organic materials IB116* and Jurid J822 [Ref. 58] [Ref. 59] and sinter materials CoFren C952 and CoFren C333 [Ref. 57]. Tests were performed at room temperature and -15 °C in a block-on-ring tester, starting out from non-conformal contact between friction material, which means that wear-in of the blocks occurred during the test. The nominal contact pressures ranged between 0,3 and 0,6 MPa. It is found that all materials showed very low coefficients of friction, ranging from 0,04 to 0,10, when tested under icy conditions, while non-icy conditions gave between 0,25 and 0,65 when tested at the same temperature in vacuum, see Figure 17. It is noted that the ice that developed on the disc surface as the test chamber was cooling down tended to melt after the specimens were engaged. Testing with cast iron brake blocks gave a surface roughness with up to millimetre sized amplitude variations. This implies that any ice formation on the cast iron brake block will be quickly removed abrasively by the tread contact. When using composite blocks, the surface is very smooth and does not provide the same possibility to remove any ice. Testing was also performed regarding water absorption by soaking block materials in water. It was found that cast iron absorbs no water, whereas the composite materials due to its inherent porosity can retain water, which could promote ice layer formation. The increase in weight is 0,3 % for C952, 0,6 % for both IB116* and C333, and 1,9 % for Jurid 822.

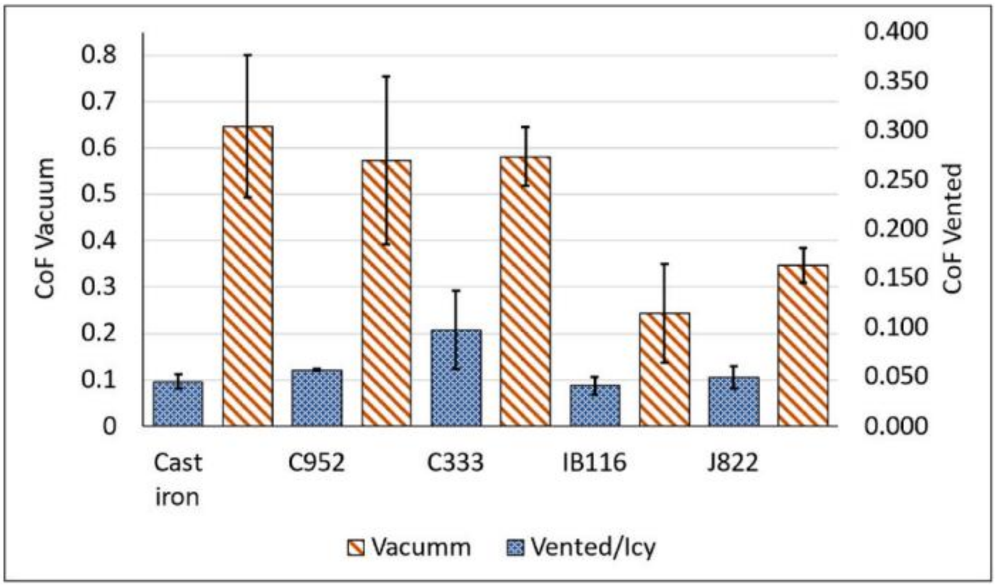


Figure 17 Average coefficient of friction for brake block materials at -15°C in vented/icy conditions and in vacuum with no ice. Note the different vertical scales for the two types of testing.

7 Operational experience from CBBs in winter conditions in Sweden

In the risk assessment regarding composite brake blocks in Swedish winter conditions [Ref. 11], different wagons and operational situations were compared. Experience shows that sudden and strong degradation of the brake performance, and difficulties to restore brake performance, is more common

a) for wagons at low axle load,
b) for wagons with low (surface) pressure between Composite Brake Blocks (CBB) and wheel,
c) at conditions with windblown snow and at temperatures below -10 °C. There are observations from temperatures ≤ -7 °C, but there are no certain observations regarding degraded brake performance on freight wagons at temperatures between 0 and -5 °C.

The frequency levels were in [Ref. 11] estimated for two examples of freight operations, with results that indicated a frequency of occurrence between
10^{-4} and 10^{-3}. Based on the standard EN 50126 [Ref. 64] such events are labelled using a frequency level of "*Probable*", and exemplified by "*Will occur several times. The event can be expected to occur often*." and over a 30 year period expected to happen about 15 to 150 times.

7.1 Comparation between different wagon types – an example

In the risk assessment [Ref. 11] there is a comparation between 2 different wagon types, which were operated with organic CBBs of the type J822 and the type C810, in the same area of Sweden. Due to differences

- in tara/axle load, in unladen state[17],
- brake system[18], and
- brake configuration[19]

the (surface) pressure between CBB and wheel was significantly different for the two wagon types. The wagon with low contact pressure had extremely poor behaviour in winter conditions whereas the wagon with high contact pressure had excellent winter performance. The ratio in contact pressures could be approximated to 2,9 times[20] in unladen state. In addition, both wagon types had good winter performance in laden state. The wagon with low pressure had the same poor winter performance with organic CBBs type J822. However, [Ref. 11], shows better performance with sintered CBBs, type C333[21].

It shall be pointed out that the above case with good winter performance for CBB type C810 is outside of the requirements, and the case with poor winter performance fulfils the requirements. The reason being that the implemented configuration 1 x Bg is not included for C810 in UIC 541-4, Appendix M [Ref. 6], and the EC declaration of conformity of interoperability constituents [Ref. 19]. Note also that the case with J822, and poor winter performance, fulfils the

[17] Axle load, unladen: Sggrrs,: 4,7 ton. Taimn091: 7,25 ton
[18] Actual brake percentage in unladen state: Sggrrs,: 102 %. Taimn091: 121 %. Both wagons have KE-GP-A brake system Note that it is allowed to have a brake percentage between 100 % and 125 % (in unladen state).
[19] Brake block configuration: Sggrrs,: 1 x Bgu. Taimn091: 1 x Bg
[20] Approximation of ratio: $\frac{7{,}25ton}{4{,}7ton} * \frac{121\%}{102\%} * \frac{2*250mm}{1*320mm} \approx 2{,}9$
[21] [Ref. 11] included winter experience until and including winter 2020/2021. However, Hector Rail can confirm significant better winter performance for waggons which has exchanged CBBs to C333.

requirements in UIC 541-4, Appendix M [Ref. 6] and the EC declaration of conformity of interoperability constituents regarding J822 [Ref. 20].

7.2 Example of brake performance in winter conditions

A limited study was performed by Hector Rail [Ref. 54] to investigate different exercising techniques at degraded braking performance in winter conditions.

The diagram below shows:

- Brake percentage (measured with the national train safety system, ATC2, used in Sweden and Norway). The diagram is based on measurements from brake cycles performed with or without indirect brake active on the locomotive. Values are then recalculated as if the locomotive where included (when loco brake was not active).
- Yellow horizontal line shows the nominal brake percentage for the train (including locomotive). The nominal brake percentage is 101 %,
- The yellow crosses show the measured and recalculated brake percentage for the train.
- Train consists of 1 locomotive and 12 wagons, Sggrs (with 8 axles per wagon). Wagons are equipped with brake block J822.
- The locomotive in use was a Siemens Vectron X4-E B99 equipped with ATC2 (not ETCS+SE/NO). It shall be noted that the locomotive has not any tendency to get degraded brake from low temperature and snow in this type of operation.
- Timeline, x-axle, shows time between 01:15 and 02:15, 2018-03-23.
- Temperatures during the test day varied between -10 ºC and -24 ºC. Ambient temperature for the brake cycles in the diagram is approximately -15 ºC.

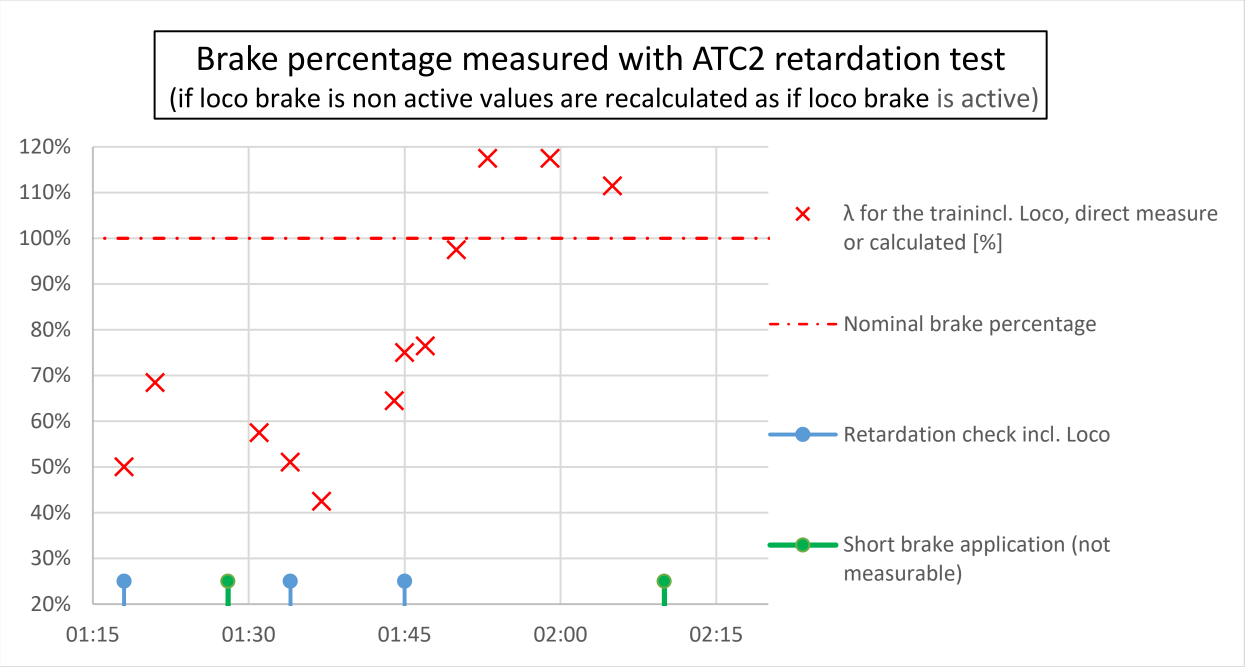


Figure 18. Examples of variation in retardation during approximately 1 hour of operation

The conclusion is that

- A very strong degradation of the brake system can occur, i.e. yellow crosses below the horizontal line with the nominal brake performance.
- With very strong exercising of the brake system can acceptable values be reached. Note that these values are above the nominal value. However, it shall be noted that it is allowed to have a brake percentage in empty state between 100 % and 125 %. Typically, these wagons have a brake percentage in that range in empty state (in conditions without winter).
- Degradation of brake performance can occur rapidly and, in this case, not manageable with only exercising. Note that the wagons are today modified with other brake blocks of the type C333.

It shall be noted that purpose with the test [Ref. 54] was to investigate different exercising techniques, not establishing a very accurate value of the brake percentage at degradation due to winter conditions.

7.3 Example of ice building up on different brake blocks

It has been observed that on certain types of brake block there will be a significant build up of ice around the brake blocks. There are no indications that the build-up of ice around the block influence the brake performance. However, same type of brake blocks that have a strong build-up of ice around the block will also, commonly, have a thin layer of ice on the friction surface. This thin layer of ice has most likely a strong negative effect on the braking performance.

The photos below shows:

- Brake block C333 and J822, on empty Sggrrs wagons.
- The brake blocks have been in operation in the same train.
- The train had empty wagons with both brake systems based on C333 an J822.

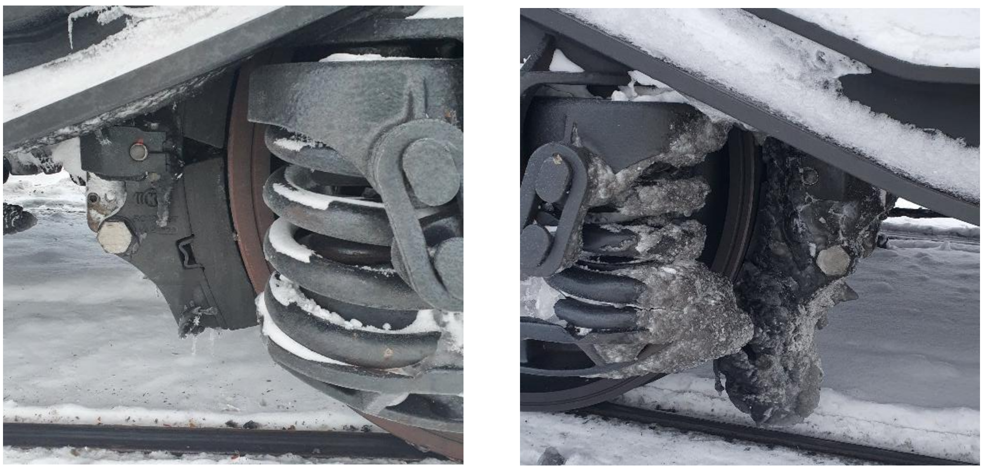


Figure 19. C333 brake block to the left and J822 brake blocks to the right.

The build-up of ice significantly varies with the type of brake block.

7.4 Specific rules for Sweden

Because of the operational experience has Transportstyrelsen issued national rules [Ref. 65] regarding brake performance in severe snow conditions, which states that there shall be a reduction in the brake performance with 25 % until it is proven that the brake performance will not be significantly reduced by severe snow conditions. This is applicable for the authorisation of a freight wagon.

It shall be noted that the reduction in brake performance can be reduced significantly more than 25 % in real operation.

7.5 Experience from heavy haul with CBBs in winter conditions

There are a lot of differences between normal UIC operation and the operation in northern Sweden and Norway on Malmbanan. For example, is the axle load 31 ton, v_{max} for loaded trains is only 60 km/h.

The operator, LKAB[22], tested CBBs since the mid-1990s. They have tested both sintered and organic brake blocks. The sintered brake blocks are the ones in use today, since they have the best winter performance- Today are the following brake blocks in use

- CoFren M133AA mix S153 (285x90x50 mm) for wagon Fanoo, and
- CoFren M135AA mix S104 (for 20-25 years) which will be replaced by CoFren LL301AA C952-1 mix 584 (320x80x60 mm) (used 1 year) for wagon Uadk.

8 Mechanisms for reduced braking performance

Some mechanisms relevant for reduced braking performance when it comes to winter conditions are discussed and related to previous work. In a final section, their relevance for composite brake blocks are discussed.

8.1 Water on block contact surface

The work by UIC confirmed that the performance at wet braking can be different from winter braking for some brake block types, whereas it can also be similar to winter braking for other block types, see section 5.2. For this reason, water in the frictional contact is at least not the sole cause for the differences found when it comes to braking performance in winter and in reference conditions.

Based on this and the finding that organic brake blocks of the Transportstyrelsen tests of 2020-2021 operate well when being externally entirely covered in ice and snow, it is deemed not important to completely try to remove ice and snow from brake blocks / block holders of a freight train. The modelling presented in Section 6.1 additionally explains that removal of ice/snow from organic brake blocks is very difficult, being a result from their poor heat conduction properties. The same modelling also suggests that the differences between sinter blocks and cast iron blocks are minor, which further points to this mechanism being less important for proper winter braking since cast iron brakes well during winter conditions.

[22] Information given from LKAB, Engineer Heavy Haul Wagons department via e-mail 2025-12-17.

8.2 Reduced friction by low temperatures

Braking distances when using the simplified test procedure (i.e. braking every 15 min) show an increase in braking distances with a decrease in temperature for sinter blocks C952 for reference conditions when testing by UIC as given by report B126/DT411. Also in the test by Transportstyrelsen for winter 2019-2020, longer braking distances could be found when temperatures in the range between -15 °C and -8 °C were combined with moderate snow conditions (W3), although admittedly, the temperatures were not very low. In tests in which different brake conditioning types were investigated, no clear dependency on average braking distance could be identified.

It can be noted that low-temperature testing (ambient temperature -7°C) without snow manufacturing is performed as part of brake bench test testing for brake block approval. Result from such tests could shed some light on this aspect of braking performance.

8.3 Ice on block contact surface

According to B126 RP7 (of 1983) [Ref. 26], ice removal rates from brake blocks can be of importance. It was found that treads of wheels braked using cast iron brake blocks provide higher ice removal rates from the brake block frictional surfaces than do wheel treads braked using composite brake blocks. The tests were performed at a low speed of 30 km/h, but the results at higher speeds indicate similarities to the result at low speeds. Moreover, the numerical model presented in Section 6.2, which builds on the presence of an ice layer on the frictional surface that is removed at braking, gives results that in general are consistent with the time delays until onset of the brake friction forces presented in the Transportstyrelsen test campaigns of both 2019-2020 and 2020-2021. The model, in its simplicity, suggests removal of ice by crushing based on increased temperature resulting from ice (on blocks) to wheel frictional heating.

A more detailed list of mechanisms for ice removal are:

1) Abrasive wear of ice on brake block contact surface introduced by tread of passing (rotating) wheel.
    a) Ice is removed from the contact surface by the uneven wheel surface (tread roughness, asperities) and ice debris is forming by brittle failure.
    b) It is well known from research on noise emission from railways that treads of wheels braked using composite blocks have very low roughness/waviness, whereas high roughness is known for cast iron brake blocks.
2) Wear of ice by frictional heating causing water to melt (and perhaps to re-solidify) under a state of lubricated friction.
3) Mechanical crushing to remove ice-layer from brake block is controlled by ice stress-state and ice strength. The stress depends on load on brake block, contact area, block elasticity together with block-to-wheel conformity.

One should here remember the reason for introducing the LL brake blocks is that the wheel treads have very low roughness / waviness, which in turn results in very low rolling noise. In contrast, cast iron brake blocks have very high roughness/waviness of treads. The very reason for this ice removal capability of cast iron brake blocks could be through abrasive removal of the ice resulting from the uneven tread of the wheels braked, which in turn also is responsible of the elevated rolling noise emitted from such wheels.

It is well known that wear in general is sensitive to temperatures and it is likely the case also here with tentatively several interacting mechanisms. A decrease in temperature for the here studied ice wear could hypothetically for the three above mechanisms respectively mean 1) increased hardness of the ice-layer and thus a lower abrasive wear rate, 2) increased heating required for melting of the ice, and 3) higher strength of the ice and stiffer block material leading to increased resistance to crushing.

In total there is a possibility that the increased time for removal of ice from brake block contact surfaces at low temperatures is a main reason for the longer braking distances. This hypothesis aligns well with the identified increase in time until onset of a proper friction when the block material directly can contact the wheel tread, without ice.

As described above, wear of ice on blocks is affected by wheel tread roughness/waviness, which is a result of the interaction block–wheel and wheel–rail. In this regard one could note the following:

1) In Noise TSI [Ref. 21], the “acoustic roughness”, is measured in one-third octave bands from centre band wavelength 3,15 mm up to 200 mm after specified braking cycles in the UIC 541-4 brake block testing programme, thus disregarding possible effects from wheel–rail contact. To this end, roughness is measured on the wheel tread at no less than 8 lines, each spaced 5 mm. Upon measurement, the roughness values in each of the one-third octave bands are weighted using given coefficients to form a scalar indicator. If this factor is lower than “1” the brake block is approved, thus putting requirements only on the total acoustic roughness and not on the values in single one-third octave bands, which is reasonable as the aim is to limit noise emissions from rolling wheels[23].
2) It is unlikely that the scalar acoustic roughness factor is informative when it comes to inflicting wear of an ice-layer. However, the one-third band values could tentatively give guidance on wear characteristics.
   The surface roughness of the wheels at the test, or the compliance of with TSI Noise and EN 15610 [Ref. 63] for the wheels during the test is thus not specified in detail. Note that it is unclear if there is a need for such a compliance.
3) Roughness wavelengths shorter than given by the 3,15 mm one-third octave band are not assessed as part of requirements on acoustic noise. There are requirements on surface roughness for newly machined wheels (typically Ra ≤ 12,5 μm), but this is of no interest for wheels in service that are subjected to block and rail contact. The running surface of a CBB braked wheels in normal operation is, typically, very polished and smooth. It is for this reason of interest to compare surface roughness of wheels in operation with the running surface of wheels during the tests for brake block approval.

[23] Additionally, a list of brake blocks is given that are exempted from an EC declaration of conformity until September 2033. This list seems to cover brake blocks most of the brake block types in use today (e.g. C333, C810, J816M, C952-1, IB116*).

8.4 Mechanisms vs composite brake blocks

Considering the varying properties of composite brake blocks regarding e.g. frictional behaviour, temperature characteristics and mechanical behaviour, it is foreseen that the winter braking behaviour is dominated by one of the above mechanisms, or by interacting mechanism.

For instance, there is a large difference in the brake application force of LL brake blocks, used as retrofit solutions for cast iron brake blocks, and K blocks. This can e.g. be exemplified by the brake block application forces used at winter testing according to UIC541-4, Appendix A5_a, where LL blocks are tested for 16 kN and K blocks for 9 kN. Moreover, there are large differences in brake block thermal properties, where for instance an organic composite material can have a thermal conductivity of 5 W/m°C and a sinter material can have 65 W/m°C [Ref. 66]. In total, this means that composite brake blocks constitute an inhomogeneous group of friction components that should not be expected to perform in similar ways when it comes to mechanisms controlling winter braking performance.

9 Operator mitigation of deficient winter braking performance

An overview is firstly given regarding usage guidelines for the European network and after that continuing with winter usage of brake blocks to finalize with in detail operational rules as implemented on the Swedish network by freight operators Green Cargo and Hector Rail.

9.1 General usage guidelines for composite brake blocks

Recommendations for brake operation, monitoring and maintenance of wagons with CBBs are described in UIC 541-4 [Ref. 5], section 2.2, and IRS 40421 [Ref. 12], section 1.6.

The IRS 40453 [Ref. 18], regarding *"Procedures for air brake test effected with a traction unit"* does not include any specific winter recommendations, but the additional recommendations from IRS 40421 and UIC 541-4 fits into the procedures.

Note that EN 16452 [Ref. 3], which corresponds to UIC 541-4, neither include any recommendations for brake operation, monitoring and maintenance.

The TSI OPE AMOC *"on checks and tests before departure, including brakes and check during operation"* [Ref. 14] does not give any usage guidelines regarding specific winter requirements or recommendation. However, the AMOC refers to

- UIC 541-4,
- a risk assessment from the Swedish NSA, Transportstyrelsen [Ref. 11], and
- a JNS report regarding unintended brake applications with LL blocks[24] [Ref. 22],

for the use of composite brake blocks.

Application of operational measures are discussed in

- COMMISSION STAFF WORKING DOCUMENT Report – Operations with rail wagons equipped with composite brake blocks in Nordic winter conditions [Ref. 13], and
- ERA Report. Task force on the winter performance [Ref. 9].

[24] The JNS report does not cover sudden loss of brake performance for CBB, but it notes the winter problem with air pipes which has water traps. This topic is not covered in the present report.

9.2 Brake conditioning in winter conditions

In the “Usage guidelines for composite brake blocks” [Ref. 24] and UIC 541-4 [Ref. 5] it is stated that when over half the wagons on a train are fitted with composite (LL) brake blocks, the effect of the brake during service brake applications from starting speeds of less than 50 km/h may be weaker than a train consist braked with cast-iron brake blocks alone. To compensate for this effect, either the brakes should be applied earlier or the pressure in the main brake pipe should be reduced to a greater degree. This applies to all weather conditions.

The following recommendations are provided for the use of composite K [Ref. 23] and LL [Ref. 24] blocks:

1. Definition of winter conditions from a braking perspective:
- *the temperature is below 0°C and*
- *there is windblown snow on the tracks and/or*
- *the tracks are snow or ice-covered and/or*
- *there is a significant build-up of snow or ice on the wagons in service*

2. Measures to guarantee brake performance
- *Before moving stabled trains or parts of trains, a full brake application should be carried out (pressure drop in main brake pipe ~ 1,5 bar).*
- *During the brake test prior to leaving the departure station, the train should be checked to ensure that the blocks on either side are released.*
- *During departure it should be checked that all the wheels on the train are rolling freely.*
- *After leaving the departure station, the driver should carry out a service brake application before the full timetable speed has been attained, if possible without using the dynamic brake of the locomotive, to check whether braking performance is satisfactory.*

If the train decelerates normally, the brake should immediately be released. If the brake is less effective than expected and if this can be ascribed to the prevailing winter conditions, the brake should be released and then fully applied again, so as to warm up the friction elements. If brake performance is much lower than expected, an emergency brake application should be carried out until the train is immobilised, and during the rest of the journey the friction elements should be kept warm by means of periodic brake applications.

In addition to this, it is stated that if the brake performance is much lower than expected, an emergency brake application should be carried out until the train is immobilised, and during the rest of the journey the friction elements should be kept warm through periodic brake applications. Accordingly, a brake application should be carried out:
- *every 10 to 15 minutes or*
- *every 20 to 30 km.*

An effort has been made as part of the present work to numerically investigate the effect on wheel and brake block temperatures from such periodic brake applications. Based on input data on brake applications from the last test campaign by Transportstyrelsen, wheel temperatures were calculated as part of a parametric study using a thermal model developed previously at Chalmers Railway Mechanics. Generic parameters for block – wheel heat partitioning are here used and the results are presented in “*Annex 1. Appendix D. Thermal analysis of impact from brake applications of locomotive driver”* for periodic brake applications in which four different wheel diameters ranging from fully worn (840 mm) to new (920 mm) and for four different initial (and ambient) temperatures (-20°C, -15°C, -10°C, -5 °C) are studied. The results show the wheel tread and brake block background temperatures, in-between periodic brake applications, only are slightly affected, with calculated increases in temperatures of only a few degrees centigrade.

9.3 Operational rules in Sweden

RUs[25] in Sweden have operational rules for brake operation, monitoring and maintenance included in their Safety Management Systems (SMS). The following sections provide a review and comparison with usage guidelines noted in section 9.1 and the operational rules regarding CBBs in winter conditions from Hector Rail [Ref. 16], and Green Cargo [Ref. 17]. Comments are given on the operational rules.

9.3.1 Information to driver and RUs operational centre regarding train composition

UIC 541-4, section 2.2.1 states that *"The train driver shall be informed as to the number of wagons braked with composite blocks in the train (K and LL blocks)".*

IRS 40421, section 1.6.2, states that *"The train driver shall be informed if the train is fitted with disc brakes or composite brake".*

Hector Rail states [Ref. 16], that if 50 %, or more, of the number of axles in the trainset are braked with CBBs, then shall the trainset be handled as a CBB train, with certain operational rules. Train list to the driver includes information about the brakes[26].

Green Cargo states [Ref. 17] that all trainsets shall be treated as CBB trains.

The reason why the RUs have slightly different rules depend on the differences in their operation. For example,

- for block trains where only cast-iron brake blocks (GG) are used, and where this is fully ensured, it would be very unfavourable to use the CBB rules, particularly in winter conditions. This is particularly important for unloaded trains where there is a need for strong exercising of the CBBs and if such actions are taken on a train with cast-iron brake blocks there will be an increased risk for wheel flats or shelling, flaking and cavities, on the wheels,
- for mixed trains in international traffic, there is a risk for faults regarding type of brakes, and to mitigate the risk of running a train without additional operational rules regarding CBBs, in winter conditions, Green Cargo assumes that all trains have CBBs.

However, actions are taken by the RUs based on if there are CBBs in the trains.

9.3.2 Definition of winter conditions from a CBB perspective

Definition of winter from a braking perspective is given in UIC 541-4, 2.2.1.3, 1, as when

- "*the temperature is below 0°C and*"
- *"there is windblown snow on the tracks and/or"*
- *"the tracks are snow or ice-covered and/or"*
- *"there is a significant build-up of snow or ice on the wagons in service"*

IRS 40421, section 1.6.1, have a definition, where the first three bullets are included, but the 4th bullet is excluded.

[25] Railway Undertakings
[26] Composite K and LL blocks, cast-iron brake blocks (GG) or disc brakes (D). Note that cast iron brake blocks are allowed in Sweden, Norway (and Finland).

Hector Rail and Green Cargo use a definition that corresponds to UIC 541-4. However, there is no experience of, if the 4th bullet above, is of importance or not.

It shall also be pointed that out that sudden and strong degradation of the brake performance hasn't been identified at the temperature limit, 0 °C, see section 7. However, there are uncertainties in temperature observations, and temperatures change along the line, therefore is it judged, by the RUs, that the limit "below 0 °C" gives an acceptable margin, to when the problems start to occur. This means that RUs starts with the mitigations according to the definition in UIC 541-4.

9.3.3 Full service brake before moving a stabled train

UIC 541-4, 2.2.1.3, 2, 1st bullet, states that *"Measures to guarantee brake performance"* is: *"Before moving stabled trains or parts of trains, a full brake application should be carried out (pressure drop in main brake pipe ~ 1,5 bar)."*

The recommendation above can also be found in IRS 40421, 1.6.2, 1st section.

Hector Rail performs the full service brake[27]. Green Cargo performs the brake as a fast brake[28].

However, testing shows that there is no impact, nor any improvement in the braking performance, of such a brake cycle at standstill. Freight wagons, with CBBs, with an identifiable thin or thick[29] ice layer, has been braked with a full service brake. Impact on the ice layer, or the next brake application at v > 0 km/h, has not been improved. Neither will several brake and release cycles at standstill have any impact or improvement. Neither are there any reports identifying impact of this recommendation.

There is a need for understanding of the background and the proof of improvements regarding this recommendation and rule implemented by the RUs.

9.3.4 Check of released brake blocks on both sides of the train

UIC 541-4, 2.2.1.3, 2, 2nd bullet, states that *"During the brake test prior to leaving the departure station, the train should be checked to ensure that blocks on either side are released."*

The recommendation above can also be found in IRS 40421, 1.6.2, 2nd section.

Hector Rail have this as an operational rule. Green Cargo checks the release of blocks on one side of the train but haven't got the rule on checking both sides currently.

This rule has been debated in Sweden, and this recommendation can be of some importance, for wagons with cast-iron brake blocks, since there is a high risk that this type of brake blocks freeze to the wheels (which will lead to wheel flats). Experience shows that this risk is far lower with CBBs, most likely because of the smoother surface of the wheel.

There is a need for understanding of the background and the proof for this recommendation and rule implemented by the RUs.

[27] Main air pipe reduction 1,5 bar
[28] Emptying the main air brake pipe (from drivers brake valve)
[29] A thin ice layer is an ice layer that is hardly identified visually but can be identified by scratching on the brake block friction surface with a pen or a knife. Thickness is << 1 mm. Thin ice layers can commonly be identified on CBBs, if there is windblown snow, and temperatures at 10 °C or below. A thick ice layer is approximately 1-5 mm. The experience is that this is rare.

9.3.5 Check that all the wheels are rolling freely

UIC 541-4, 2.2.1.3, 2, 3rd bullet, states that *"During departure it should be checked that all the wheels on the train are rolling freely."*

Hector Rail and Green Cargo uses this operational rule.

This requirement regarding, "rolling test", is a mandatory, basic rule, with or without, CBBs, that has always existed in railway operation, both for passenger and freight trains. It is of highest importance for several reasons. However, it shall be noted that if one compares a cast-iron braked train, and a CBB braked train, in winter conditions, then it is of higher importance for the cast-iron braked train, since the probability that brake block freezes to wheel is much higher in latter case, see section 9.3.4.

9.3.6 Service brake application before full timetable speed

UIC 541-4, 2.2.1.3, 2, 4th bullet, states that "*After leaving the departure station, the driver should carry out a service brake application before the full timetable speed has been attained, if possible, without using the dynamic brake of the locomotive, to check whether braking performance is satisfactory."*

Nearly the same is stated in IRS 40421, 1.6.2, 4th section, 1st sentence; *"After leaving the departure station, once approximately 50 % of the timetable speed has been attained, the train driver is to check whether braking performance is satisfactory by carrying out a full brake application, without using the dynamic brake of the locomotive if possible."*

There are small differences between UIC 541-4 and IRS 40421:

- UIC 541-4 states that a "*service brake application"*[30] shall be performed and IRS 40421 states that a "*full brake application"*[31] shall be performed.
- UIC 541-4 states that this shall be performed *"before the full timetable speed has been attained"* and IRS 40421 states that this shall be performed *"once approximately 50 % of the timetable speed has been attained"*.

Service brake application before the full timetable speed, with CBB trains, is performed by Hector Rail and Green Cargo with some differences:

- Hector Rail performs a full service brake application (i.e. 1,5 bar main pipe reduction) before the full timetable speed has been attained (i.e., speed definition similar to UIC 541-4). Hector Rails uses also full service brake, see below, for CBB trains.
- Green Cargo performs service brakes with main pipe reductions between 1,0 and 1,5 bar before the full timetable speed has been attained, but, if possible before 50 km/h is reached (i.e., 50 % or less than the typical timetable speed, which corresponds to IRS 40421).

Similarities are that

- dynamic brake is not used at this service brake,
- after the service brake application, if it is approved, then is a retardation test performed (on lines with class B train safety system, ATC2). The retardation test measures the brake percentage of the train. This test is performed as soon as possible from timetable speed or approximately 90 km/h. In winter conditions with wagons having CBBs there it is often a

[30] Service brake application does not declare how much main pipe pressure shall be lowered
[31] Full brake application can be interpreted as a full service brake (i.e., lowering the main pipe pressure with 1,5 bar)

need for a few exercising cycles before one can reach timetable speed and perform the retardation test. Note that the retardation test can be performed with service brake between 1,0 bar and 1,5 bar. Hector Rail always perform it with full service brake when the train consists of wagons with CBBs. Green Cargo perform it with a main pipe reduction of 1,0 bar or 1,5 bar. Note that if there are uncertainties, or a not approved result, then shall the retardation test be performed with full service brake.

The experience is that this service brake test, and the retardation test, is of highest importance for trains with CBBs.

9.3.7 Actions to be taken if brakes are less effective than expected

UIC 541-4 [Ref. 5], 2.2.1.3, states that *"If the train decelerates normally"* (at the service brake test described in 9.3.6) *"the brake should immediately be released. If the brake is less effective than expected and if this can be ascribed to the prevailing winter conditions, the brake should be released and then fully applied again, so as to warm up the friction elements."*
"If brake performance is much lower than expected, an emergency brake application should be carried out until the train is immobilised, and during the rest of the journey the friction elements should be kept warm by means of periodic brake applications."

Hector Rail and Green Cargo apply rules according to above. In addition, a retardation test is performed, see 9.3.6. If retardation is lower than expected, then

- exercising is performed, see 9.3.9, and
- speed is reduced. Speed can be increased later if brakes reach normal performance.

If retardation is

- so low that service brake test, clearly shows that brakes are strongly degraded, or
- if retardation test shows that the brake percentage of the train, λ, is < 61 %, and
- despite exercising according to 9.3.9,

then the train must be stopped. When brake percentage, λ, is $22 < \lambda \leq 60$ % then the speed restriction is between 20 and 40 km/h[32]. At $\lambda \geq 61$, the speed restriction is $V_{max} \geq 70$ km/h. Note that typical freight trains operate with V_{max} 100 km/h in Sweden. The retardation test in the class B train safety system is an accurate identification of the brake performance of the train[33] and in most cases are low brake percentage identified through the retardation test before incidents.

9.3.8 Use of dynamic brake

UIC 541-4 [Ref. 5], 2.2.1.3, 2, 4th bullet states that service brake test described in 9.3.6 above shall be performed *"without using the dynamic brake of the locomotive"*. IRS 40421 [Ref. 60], 1.6.2, 4th section, gives the same recommendation.

This is implemented by Hector Rail and Green Cargo as an operational rule.

Hector Rail has identified that there is a need for excluding the dynamic brake in winter conditions for all CBB braked trains. This is particularly important for unloaded trains, with low axle load, where the locomotive brake performance, including dynamic brake, is high. By not using the dynamic brake will the wagons with CBBs absorb a larger amount of brake energy from a brake cycle. This will reduce degradation of the brakes and degraded CBB brake systems will have a larger possibility to be restored. Hector Rail has therefore implemented a rule, that

[32] A Vmax between 20 and 40 km/h means, in reality, that the train must be stopped.
[33] Best accuracy is reached if full service brake is applied, and if retardation test is performed from initial speed, V0, $80 \leq V0 \leq 120$ km/h. Note that V0 are typical freight train speeds in Sweden and Norway and that this is how Hector Rail and Green Cargo is performing the test for freight trains.

during winter conditions, with CBB wagons, shall the dynamic brake not be in use, except for fast brake[34], when dynamic brake will automatically be active[35]. This rule has slightly improved handling of CBBs in winter conditions.

9.3.9 Exercising of the brake systems

UIC 541-4, 2.2.1.3, states that *"If brake performance is much lower than expected, an emergency brake application should be carried out until the train is immobilised, and during the rest of the journey the friction elements should be kept warm by means of periodic brake applications. a brake application should be carried out:*

- *every 10 to 15 minutes, or*
- *every 20 to 30 km".*

If in spite of all these measures, the driver considers the deceleration insufficient, the train should only continue at a reduced speed. The driver should inform the regulator of the decision by radio".

IRS 40421, 1.62, states, in principle, the same; *"If the brake is less effective than expected and if this can be ascribed to the prevailing winter conditions, the brake should be release and then fully applied again, so as to warm up the friction components."*

Hector Rail and Green Cargo have implemented rules that covers exercising. Exercising of the brake system is always performed, when there are winter conditions, and when the train is CBB braked[36]. Rules act on time (not distance).

To achieve efficient exercising of the CBBs Hector Rail performs it
- with service brake suppression[37], active on the locomotive[38],
- without dynamic brake, and
- with a full service brake (1,5 bar main pipe reduction).

In addition, Hector Rail performs exercising with warm braking (only applicable for some locomotive classes), as an alternative to above, which means that brakes can be applied on the wagons at the same time as traction is given from the locomotive[39].

Green Cargo performs exercising with regular service brake (main pipe reduction 1,0 to 1,5 bar).

The recommendations from UIC and the operational rules from the RUs are of highest importance. However, it can occur that some types of CBBs during winter conditions,

---

[34] Fast brake, in German Schnellbrems. Main air brake pipe is emptied from driver's valve.
[35] By blocking the dynamic brake from drivers brake valve at service brake, instead of blocking it in the machine room, and thereby keeping it, available for fast brake. This gives a small, but additional brake capacity available for emergency situations.
[36] Note that Hector Rail classifies a train as CBB braked when 50 % or more of the wagons have CBBs and Green Cargo assumes that all trains are CBB braked. See 9.3.1. However, most trains at Hector Rail have either 100 % CBBs or disc brakes, or 100 % cast iron brake blocks.
[37] Service brake suppression means that when a service brake is performed will the locomotive not have any mechanical brake. Mechanical brake on locomotive is only active at fast brake, emergency brake and System brake. German word is Nachbremsfunktion.
[38] Except for very short trains where brake suppression on the locomotive is obviously inconvenient. Exercising cycles can then be performed with a push button release of locomotives brakes. Note that locomotives are exercised manually, and separately, since there is some need for minor exercising of locomotives with disc brakes.
[39] Warm braking can be performed in 120 seconds for each cycle. It can be repeated directly after a cycle. Main pipe pressure ≥ 4,2 bar. Speed, 10 km/h ≤ V ≤ Vmax.

particularly in unladen state, will get degraded in such a degree that speed must be reduced, or train must be stopped, or incidents occur if there is a sudden degradation of the brakes.

9.3.10 Testing of the brakes in certain situations

UIC 541-4, 2.2.1.3, states that a service brake application "*should also be carried out before reaching:*

- *a terminus station,*
- *a long downward slope with a high gradient."*

Hector Rail and Green Cargo have implemented this rule, and on suspicion of degraded brakes (mainly based on previous brake or exercising cycle). Note also that on suspicion shall a retardation test be performed (on lines with class B train safety systems, ATC2).

9.3.11 Other measures of importance in winter operation

UIC 541-4, 2.2.1.3, 3, points out that other measures of importance in winter operations:

- *"The leak-tightness of the train is of particular importance in the brake tests.*
- *During maintenance and repair work, all water should be thoroughly removed from the pneumatic parts of the train.*
- *In case of a significant build-up of snow or ice on the wagons in service, either the equivalent conicity value or the alternative parameter of flange height (both defined in point 2.2.24.2 page 37) should be checked during maintenance and repair work (only LL blocks)."*

Measures above are in Sweden considered as general winter measures, and not specific measures for CBBs in winter conditions. The measures are implemented in Sweden. However, it can occur, mainly in international traffic, that both air leakage and water in the brake system can occur.

10 Today´s winter brake testing standards and a proposal for further investigations

10.1 Today´s winter testing

The general conditions for certification and use of composite brake blocks have historically been stipulated by the UIC 541-4 [Ref. 5], in which the winter braking brake bench testing has been detailed in Appendix A5 and test runs in Appendix G.

Today there is an overall transition from UIC codes to EN standards and brake blocks and braking performance is no exception. In the proposed preliminary standard prEN 16452 [Ref. 4], is requirements for *"Extreme winter conditions (freight wagons)*" defined and test procedures are given for test runs. It is further stated that the friction properties may also be tested at a test bench with a footnote that refers that the text comes from UIC 541-4. This means that the Becorit air-conditioned test bench and the RTA Climatic wind tunnel in Vienna must be acceptable according to the EN standard. However, the detailed testing specifications given in Appendix A5 of UIC 541-4 that relates to demonstration of winter braking properties in the said two test facilities have been removed from the proposed EN standard.

Regarding line testing for demonstration of winter braking properties as stipulated in the normative Annex I of prEN 16452 [Ref. 4], as compared to UIC 541-4, Appendix G, only minor changes can be found: 1) it is stipulated that emergency brakes shall be applied instead of service brake, 2) it is explicitly stated that bedding-in shall achieve contact surface area more than 85 %.

It shall be noted that it is not possible to get information about what test programs that was used for the certification of a composite brake block. Neither ERADIS nor UIC 541-4, Appendix M [Ref. 6] contains any information about the test procedure or the test results.

10.2 Transportstyrelsen preliminary winter testing proposal

Based on the findings in the current report, hypotheses have been formed on the reason for deficient winter braking performance. It is proposed to modify the Becorit air-conditioned test bench testing programme to evaluate these hypotheses by performing tests on two types of brake blocks: one type with deemed[40] poor winter braking performance and one with good performance. To this end, testing of winter conditions should consider:

1) Temperatures certainly below -7 ºC, with a target of -15 °C in order to ensure critical conditions (UIC 541-4 stipulates down to -7 °C).
2) Thin layers of ice should be present on brake block contact surfaces at winter testing.
   a. Simulation of snow drift (fly-off snow) also after braking when wheels and brake blocks are warm, implying that snow can melt and water can accumulate as ice on brake block contact surface. Snow production is stopped after braking when testing according to UIC 541-4.
   b. Ice on brake block contact surfaces could possibly be mimicked by direct spraying of water on cold brake blocks.
3) Testing at braking forces that are as low as seen in traffic (or according to lowest limit given in brake block certifications), which is lower than the forces stipulated in UIC 541-4.
4) Testing at normal train speeds for Scandinavian conditions, meaning 70 km/h and 100 km/h (UIC 541-4 stipulates 100 km/h and 120 km/h). It shall be noted that even for trains with V_{max} 100 or 120 km/h, it is not typical that the brake is applied at that speed, more common is 70 to 100 km/h.
5) Build-up of brake force of approximately 3 to 8 seconds. This will be established later together with Becorit. It shall be pointed out that UIC 541-4 [Ref. 5], Test Program A5_a use a brake build-up time of 8 ±0,2 s, Test Program A5_b uses a build-up time of 3-6 s and EN 16452 [Ref. 3], Test Program L.1 and L.2 uses a build-up time of 8 ±0,2 s. The draft, prEN 16452 [Ref. 4] defines that brake application shall be emergency brake (for testruns). Becorits recommendation is 3-4 s.

Details will be established after detailed discussions with Becorit and before testing starts.

11 Conclusions

The present report aims to be a reference document in discussions on how to improve today´s winter testing procedures of brake blocks. It outlines the early efforts on winter brake performance and describes the extensive work that has gone into developing today's procedures. The results and procedures are compared with the results of recent tests carried out by the Swedish Transport Administration using test trains similar to those used at the development of today's test procedures. The recent tests have used modern measurement systems, detailed instrumentation and high-performance post-processing computer power, which have provided new insights into winter braking performance. However, they have also highlighted the

[40] Based on experience from normal operation by Green Cargo and Hector Rail.

difficulties of scheduling and conducting tests during periods of winter conditions at the rather low temperatures ($\lesssim -7$ ºC and snow drift / fly-off snow) deemed relevant for provoking braking problems. The report also details the implemented winter braking rules/guidelines used by two of our freight companies in Sweden and outlines the winter conditions in which braking performance problems occur.

The work has identified the following issues that may be important in improving the approval procedures for brake blocks:

1) The simplified line tests used to develop today's test standard were carried out with short time intervals between stop braking tests. This is an extreme type of braking that is not feasible for normal operation.
    a) This type of repeated braking, with short periods of about 15 minutes between stops, has been shown in two successive winter test campaigns organised by Transportstyrelsen not to give winter braking distances that are representative for normal operation.
    b) Because of this, one can question the fidelity of the developed procedures for approvals and verifications of winter braking performance.
    c) Conditioning of brakes between stops, which is important according to operational guidelines, has not been investigated.
2) The results of the simplified line tests, which were used as a basis for the development of today's test standard, show irregularities in the calculated stopping distances for the C810 brake block. The reason for this is that braking distances from the reference conditions considered in today's standard and mild winter conditions have been combined to form reference braking conditions used for assessing more severe winter conditions. This is despite the fact that the stopping distances in mild winter conditions are longer than the true reference conditions without snow drift (fly-off snow).
3) Ice build-up on brake blocks is an issue that was discussed in early work in UIC reports, in normal operation and also at brake rig tests. This is not explicitly investigated in any type of brake block approval test. Ice removal from brake block friction surfaces by wheel treads with roughness / waviness representative of the type of brake block being tested is therefore not known. Ice removal rates could tentatively be related to the time delay before a relevant braking force is applied, in order not to confuse this braking performance reducing effect with the braking performance enhancing effect that can occur when braking at low temperatures without ice.
4) There is a difference between the locomotive driver's experience of braking problems in winter and today's winter performance certification tests. Braking problems are often experienced at temperatures $\lesssim$ -7 °C.
5) Field tests by the Swedish Transport Agency indicate that braking performance can be lower at temperatures below between -15 °C and -8 °C than for -8 °C and warmer.
6) The ambient temperature is down to -7°C for test on the Becorit test bench and -10°C for test in the RTA climatic wind tunnel. These temperatures are for the above two above reasons generally not representative for winter conditions at which braking problems occur. Moreover, the temperatures during testing are unknown and can for this reason not be compared to temperatures at field tests or normal operation.

7) There is no information on the wheel or brake block temperatures measured during the approval tests, which introduces uncertainty into the details of the test procedure. Again, it is not possible to make comparisons with temperatures related to braking performance in service or field tests.

8) The three test methods for winter approval of brake blocks have been developed to give equal braking performance through early comparative studies. However, they are inherently different and there is no information as to which was used for approval. Again, it is not possible to make comparisons with temperatures related to braking performance in service or field tests.

9) Tests by the Swedish Transport Administration have shown that winter braking performance depends on the driver's instructions regarding braking parameters used for conditioning of the brakes. This does not appear to have been investigated previously, and it is anticipated that driver instructions will require additional attention in the near future.

10) The Swedish freight operators Green Cargo and Hector Rail have implemented operational rules to mitigate winter braking problems:

    a) Green Cargo: All trains are treated as CBB trains and all UIC 541-4 operational rules are followed, with the minor exception that the control of released brakes before leaving a station is performed for one side of the train instead of both.

    b) Hector Rail: All trains having more than 50 % of the axles equipped with CBBs, then the train is treated as CBB train and then all UIC 541-4 operational rules are followed.

    c) All freight operators in Sweden have implemented the compulsory use of a retardation test using the ATC2 safety system to measure the brake percentage of the train when leaving the departure station. The braking performance of a train is thus always known at the beginning of each journey and on suspicion of reduced brake performance.

11) For the simplified 5 wagon brake test and for wind tunnel tests, there are requirements for the standard deviation of the tests, but none explicitly for extreme braking distances as long as they are within the range given by the average braking distance and 1,95 times the standard deviation. There is also a procedure for rejecting extreme stopping distances that do not fall within this range. This is potentially problematic, especially for tests with a test train[41], as it is the longest (extreme) stopping distances that increase the risk of passing a stop signal.

12) The brake elongation requirements for winter dynamometer testing are only given in terms of average braking distances. There are no requirements for standard deviations or extreme values.

[41] Based on statistics, measured extreme braking distances for a 5-wagon train are more representative for the behaviour of a longer train in normal operation at varying conditions, than testing on one axle or a wheel at controlled conditions.

13) Testing focusses on speeds 100 km/h and 120 km/h, thus disregarding lower speeds although large elongations in winter braking distances have been identified at 50 and 60 km/h. This is however in line with general testing procedures of brake weights according to IRS 50544-1 [Ref. 61] and EN 16384 [Ref. 62], in which relevant speeds are only 80 km/h and higher.

Based on the results in the present report, a proposal for a winter brake testing programme for use in the Becorit air-conditioned test bench was prepared.

12 References

[Ref. 1] Commission regulation (EU) No 321/2013 of 13 March 2013 concerning the technical specification for interoperability relating to the subsystem ‘rolling stock — freight wagons’ of the rail system in the European Union
Amended by:
Commission regulation (EU) No 1236/2013 of 2 December 2013
Commission regulation (EU) 2015/924 of 8 June 2015
Commission implementing regulation (EU) 2019/776 of 16 May 2019
Commission implementing regulation (EU) 2020/387 of 9 March 2020
Commission implementing regulation (EU) 2023/1694 of 10 August 2023
Commission implementing regulation (EU) 2025/2064 of 14 October 2025
(TSI WAG)

[Ref. 2] Commission regulation (EU) No 1304/2014 of 26 November 2014 on the technical specification for interoperability relating to the subsystem ‘rolling stock - noise’ amending Decision 2008/232/EC
Amended by:
Commission Implementing Regulation (EU) 2019/774 of 16 May 2019
Commission Implementing Regulation (EU) 2023/1694 of 10 August
(TSI Noise)

[Ref. 3] EN 16452:2015+A1:2019. Railway applications Braking - Brake blocks

[Ref. 4] DRAFT prEN 16452. Railway applications Braking - Brake blocks
October 2025. Will supersede EN 16452:2015+A1:2019

[Ref. 5] UIC 541-4. Composite brake blocks - General conditions for certification and use
6th edition, November 2020. Issued by UIC.

[Ref. 6] UIC 541-4 Appendix M. Composite brake blocks certified for international traffic.
Last update 31/03/2025

[Ref. 7] IRS 50548:2022, Ed2: Brakes – Requirements for friction test benches for the international certification of brake pads and brake blocks
Issued by UIC.

[Ref. 8] EN 16834 Railway applications – Braking – Brake performance, *CEN*, 2019

[Ref. 9] O Martos, K Pravdik and M Schroeder, Task force on the winter performance of composite brake blocks, *European Union Agency for Railways*, 2020-05-29

[Ref. 10] Stefan Dörsch, Speaker of UIC-working group composite brake blocks, Winter properties Composite Brake Blocks, Lille, 2018-12-12

[Ref. 11] Riskbedömning avseende bromsblock av komposit under svenska vinterförhållanden. Uppdaterad utifrån erfarenheter 2020-2021, Issued by: Transportstyrelsen (Swedish Transport Agency), Date: October 2021, ID: Dnr TSJ 2019-5343
https://www.transportstyrelsen.se/sv/om-oss/publikationer-och-rapporter/rapporter/rapporter-inom-jarnvag/riskbedomning-avseende-bromsblock-av-komposit-under-svenska-vinterforhallanden/
Translation of title: Risk assessment regarding composite brake blocks in Swedish winter conditions.

[Ref. 12] 1st edition, December 2021. Issued by UIC.

[Ref. 13] Subject: COMMISSION STAFF WORKING DOCUMENT Report – Operations with rail wagons equipped with composite brake blocks in Nordic winter conditions Report pursuant to Article 5(e) of Commission Implementing Regulation (EU) 2019/774 of 16 May 2019 amending Regulation (EU) No 1304/2014 as regards application of the technical specification for interoperability relating to the subsystem ‘rolling stock - noise’ to the existing freight wagons
No. Cion doc.: SWD(2020) 240 final
From: Secretary-General of the European Commission, signed by Ms Martine DEPREZ, Director
date of receipt: 21 October 2020, To: Mr Jeppe TRANHOLM-MIKKELSEN, Secretary-General of the Council of the European Union

[Ref. 14] Acceptable means of compliance on checks and tests before departure, including brakes and checks during operation, Operations and traffic management system TSI, Version 3, 17/12/2023,
European Union Agency for Railways, *(AMOC TSI OPE Checks and tests including brakes)*

[Ref. 15] Report . Task force on the winter performance of composite brake blocks
Version 1.0, 29/05/2020, Designation: ERA1177 V 1.0, European Union Agency for Railways

[Ref. 16] Extract from document: Broms, Document No, date, edition: 1.51.11, 20/12/2024, ed 20
Issued by: Hector Rail AB
(Extract from Hector Rail internal brake regulations which is a part of the RUs SMS)

[Ref. 17] Extract from document: Järnvägsföretagets säkerhetsbestämmelser del A
Dated: 2024, Issued by Green Cargo
(Extract from Green Cargo internal brake regulations which is a part of the RUs SMS)

[Ref. 18] IRS 40453. Procedures for air brake test effected with a traction unit
1st edition, December 2019. Issued by UIC.

[Ref. 19] EC Declaration of conformity of interoperability constituents. Document ID number: IT/00002401890641/2021/000001, Regarding: Composite brake blocks in mix C810
https://eradis.era.europa.eu/

[Ref. 20] EC Declaration of conformity of interoperability constituents.
Document ID number: Regarding: Problock J822 1 x Bgu - Composite friction element for wheel tread brakes according to TSI WAG, in 1 x Bgu configuration, for nominal wheel diameter 920 mm

[Ref. 21] Official Journal of the European Union, L 222/88, COMMISSION IMPLEMENTING REGULATION (EU) 2023/1694 of 10 August 2023 amending Regulations (EU) No 321/2013, (EU) No 1299/2014, (EU) No 1300/2014, (EU) No 1301/2014, (EU) No 1302/2014, (EU) No 1304/2014 and Implementing Regulation (EU) 2019/777

[Ref. 22] JNS Normal Procedure, Consequences of unintended brake applications with LL blocks, Final report version 2.0, European Railway Agency, 29.02.2024

[Ref. 23] Design rules for composite brake blocks (K), 9th edition, *UIC*, 1 Aug 2013

[Ref. 24] Usage guidelines for composite (LL) brake blocks, 10th edition, *UIC*, 1 Aug 2013

[Ref. 25] ORE B 126, Report No. 7, Brake pads for disc brakes and composition brake blocks. The influence of winter conditions on the functioning of disc brakes and composition brake blocks. *ORE*, April 1983

[Ref. 26] UIC B 126/RP 33, BRAKING ISSUES - Use of composite brake blocks on wagons. Summary report - K blocks, *UIC*, January 2004

[Ref. 27] UIC B 126/RP 37, BRAKING - Winter properties of composite brake blocks, *UIC*, April 2010

[Ref. 28] UIC B 126/RP 43, BRAKING QUESTION - Winter properties of composite brake blocks, *UIC*, February 2013

[Ref. 29] UIC B 126/RP 46, BRAKING ISSUES - Bases of Leaflet 548 “Dynamometric test benches”, *UIC*, November 2015

[Ref. 30] ERRI B126 / DT 381, Fragen des bremswesens – Winterversuche in Schweden mit Verbundstoffbremssohlen des Typs K, *European Rail Research Institute*, May 2000

[Ref. 31] ERRI B126 / DT 381, Fragen des bremswesens - Bremsversuche in der Klimakammer von Wien-Arsenal zum Nachweis der Wintertauglichkeit von Verbundstoffbremssohlen (K und LL) sowie Graugußsohlen in Guterwagen, *European Rail Research Institute*, March 2002

[Ref. 32] ERRI B126 / DT 395, Fragen des bremswesens - Erprobung von K-Sohlen Jurid 816 und Cosid 810. Vereinfachte Bremsversuche unter Winterbedingungen in Schweden Feb.-Apr. 2002, *European Rail Research Institute,* January 2004

[Ref. 33] ERRI B126 / DT 396, Fragen des bremswesens - Bremsversuche in der Klimakammer von Wien-Arsenal zum Nachweis der Wintertauglichkeit von Verbundstoffbremsklotzsohlen in Güterwagen, *European Rail Research Institute,* January 2004

[Ref. 34] UIC B126 / DT 411, BRAKING QUESTIONS - Simplified brake tests with composite LL blocks under winter conditions in Sweden, February-April 2004, *UIC,* January 2005

[Ref. 35] UIC B126 / DT 412, BREMSWESEN - Zusammenfassende Beurteilung von Streckenversuchen unter Winterbedingungen, Versuchen in der Klimakammer von RTA und Prüfstandversuchen, *UIC*, November 2004

[Ref. 36] UIC B126 / DT 434, BRAKING ISSUES - Testing the K brake block Jurid J816M, simplified brake tests in winter conditions, Sweden December 2007 ,*UIC*, June 2008

[Ref. 37] UIC B126 / DT 435, BRAKING ISSUES - Testing the LL brake block ICER Becorit IB 116*, Simplified brake tests in winter conditions, Sweden February 2008,*UIC*, June 2008

[Ref. 38] UIC B126 / DT 444, BRAKING QUESTIONS - Approval of LL blocks in accordance with UIC Leaflet 541-4 in 2 x Bg configuration on vehicles with nominal wheel diameters of 840 mm and 760 / 730 mm, Sweden February 2008, *UIC*, December 2014

[Ref. 39] UIC B126 / DT 450, BRAKING ISSUES - Operational rule tests for composite brake blocks under harsh winter conditions in Finland 2019, Sweden February 2008, *UIC*, June 2019

[Ref. 40] Rail Transportation Safety Investigation Report R19C0015 (released 31 March 2022), *Transportation Safety Board of Canada*, Canada 2022.

[Ref. 41] CN Winter Plan 2024-2025, *Canadian National Railways*, 2024

[Ref. 42] H Heikkilä, Test report – Composite brake block winter tests at low speeds, Document ID VRTe/K 10/05/18/1215, *VR Group*, Finland 2018-11-07

[Ref. 43] D Larsson, Swedish Tests of Block Brake Performance in Winter Conditions Test period: 2018-03-14 – 2018-04-14, rev 1.0 2020-08-24, *Damill AB*, Luleå, Sweden

[Ref. 44] T Vernersson, A Ekberg and R Lundén, Swedish tests of block brake performance in winter conditions Winter 2017-2018 – Detailed analyses of experimental results, Chalmers Railway Mechanics, *Chalmers University of Technology*, Göteborg Sweden, 2019-06-13.

[Ref. 45] T Vernersson, A Ekberg and R Lundén, Swedish tests of block brake performance in winter conditions Winter 2018-2019 – Detailed analyses of experimental results, Chalmers Railway Mechanics, *Chalmers University of Technology*, Göteborg Sweden, 2019-06-13.

[Ref. 46] T Vernersson, A Ekberg and R Lundén, Swedish tests of block brake performance in winter conditions Winter 2019-2020, Chalmers Railway Mechanics, *Chalmers University of Technology*, Göteborg Sweden, 2020-10-09.

[Ref. 47] T Vernersson, A Ekberg and R Lundén, Swedish tests of block brake performance in winter conditions Winter 2020-2021, Chalmers Railway Mechanics, *Chalmers University of Technology*, Göteborg Sweden, 2021-10-27.

[Ref. 48] T. Vernersson, A. Ekberg and R. Lundén, Railway freight braking and LL brake blocks −Three remaining challenges, International Wheelset Congress, Venice, Italy 2019.

[Ref. 49] Zhang Y, Liu Z, Stichel S. Study on the braking distance of composite brake blocks covered with ice for freight trains in winter. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit. 2023;237(8):1050-1059.

[Ref. 50] D.M. Cole, The microstructure of ice and its influence on mechanical properties, Engineering Fracture Mechanics, vol 68, Issue 17-18, pp 1797-1822.

[Ref. 51] Olofsson U, Sundh J, Bik U, Nilsson R. The influence of snow on the tread braking performance of a train: A pin-on-disc simulation performed in a climate chamber. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit. 2016;230(6):1521-1530.

[Ref. 52] Yezhe Lyu, Ellen Bergseth, Jens Wahlström, Ulf Olofsson, A pin-on-disc study on the tribology of cast iron, sinter and composite railway brake blocks at low temperatures, Wear, vol 424–425, 2019, 48-52

[Ref. 53] L. Pelcastre, L.-M. Weniger, J. Hardell, On the low temperature tribological behaviour of brake block materials for railway applications under dry and icy conditions, Wear, Volume 523, 2023, 204764

[Ref. 54] Prov och analys av motioneringsteknik för vagnar
Document no: BrBl-2018-001
Date/Edition: 2018-04-11/ 2
Issued by: Hector Rail AB
Translation: Test and analysis of exercising technique (regarding CBBs in winter condition
See: https://www.transportstyrelsen.se/sv/om-oss/publikationer-och-rapporter/rapporter/rapporter-inom-jarnvag/riskbedomning-avseende-bromsblock-av-komposit-under-svenska-vinterforhallanden/
Or alternatively: https://www.transportstyrelsen.se/globalassets/global/publikationer-och-rapporter/jarnvag/prov-analys-motioneringsteknik-vagnar-kompositblock-hectorrail.pdf

[Ref. 55] ERA Technical document. Friction elements for wheel tread brakes for freight wagons
Reference: ERA/TD/2013-02/INT. Version: 3.0. Date: 27/11/2015

[Ref. 56] ERA. Interoperability Unit. List of fully UIC approved composite brake blocks for international transport
Reference: ERA/TD/2009-02/INT. Version 15.0. Date 23/07/15

[Ref. 57] EC Declaration of conformity of interoperability constituents.
Document ID number: IT/00002401890641/2021/000002
Description: Sintered brake blocks in mix C333, 1 x Bgu configuration 920mm wheel
Issued by CoFren s.r.l.
With attached document: NoBo File. Doc. No: RVI_004 13693.01. Rev. 1. Issued by IIS Cert S.r.l.
Source: https://eradis.era.europa.eu/

[Ref. 58] EC Declaration of conformity of interoperability constituents.
Document ID number: DE/000DE811198586/2024/000008
Description: Friction element for wheel tread brakes – Jurid 822
Issued by Federal Mogul Bremsbelag GmbH
Source: https://eradis.era.europa.eu/

[Ref. 59] EC Declaration of conformity of interoperability constituents.
Document ID number: DE/00000129273865/2021/000009
Description: Problock J822 1 x Bgu - Composite friction element for wheel tread brakes according to TSI WAG, in 1 x Bgu configuration, for nominal wheel diameter 920 mm
Issued by Knorr-Bremse Systeme für Schienenfahrzeuge GmbH
Source: https://eradis.era.europa.eu/

[Ref. 60] IRS 40421:2025, Ed2: Rules for the consist and braking of international freight trains Issued by UIC.

[Ref. 61] IRS 50544-1:2025, Ed1: Brakes – Braking performance
Issued by UIC.

[Ref. 62] EN 16834:2019. Railway applications - Braking - Brake performance

[Ref. 63] EN 15610:2019+A1:2025. Railway applications - Acoustics - Rail and wheel roughness measurement related to noise generation

[Ref. 64] EN 50126-1:2017/A1:2024. Railway Applications - The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS) - Part 1: Generic RAMS Process

[Ref. 65] TSFS 2022:36. Transportstyrelsens föreskrifter och allmänna råd om järnvägsfordon (nationella regler)[42]

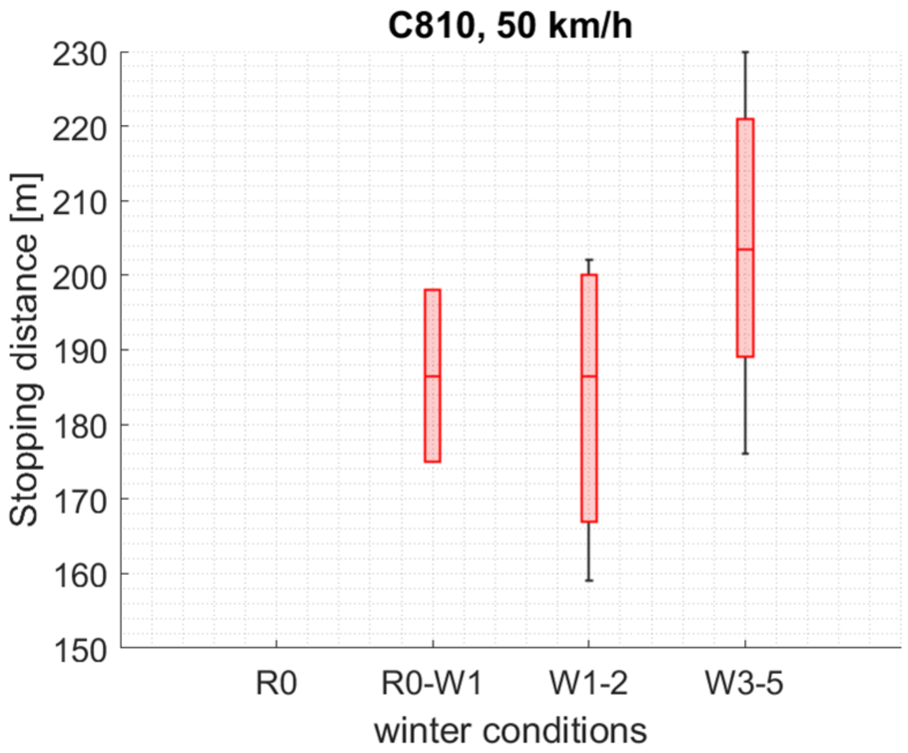
[Ref. 66] T. Vernersson, Temperatures at railway tread braking. Part 1: Modelling, Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit 2007 221: 167

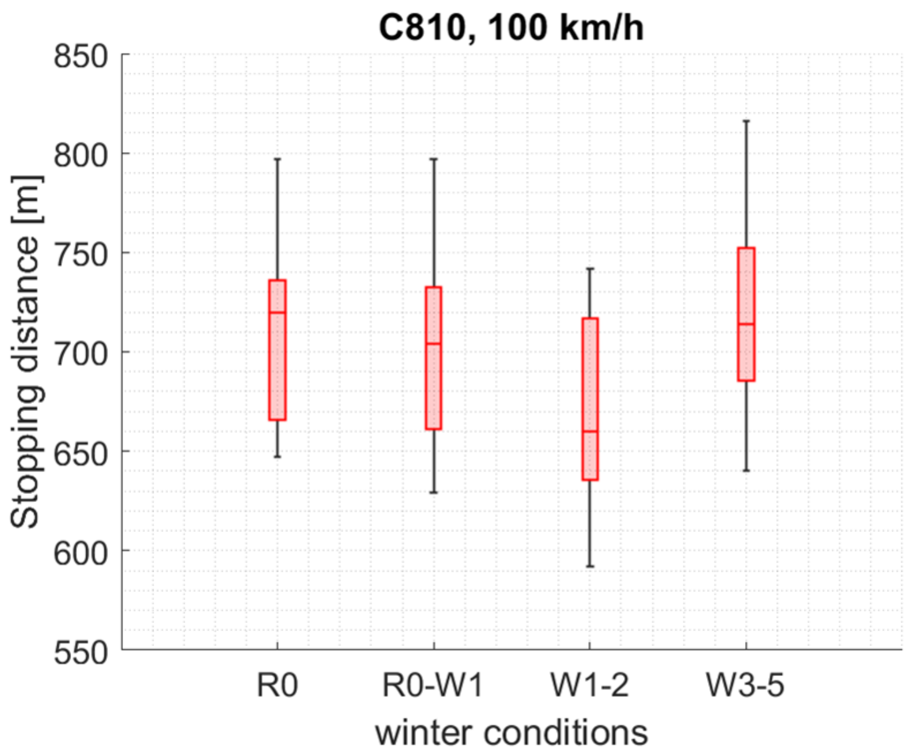
[Ref. 67] T. Vernersson, Temperatures at railway tread braking. Part 2: calibration and numerical examples, Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit 2007 221: 429

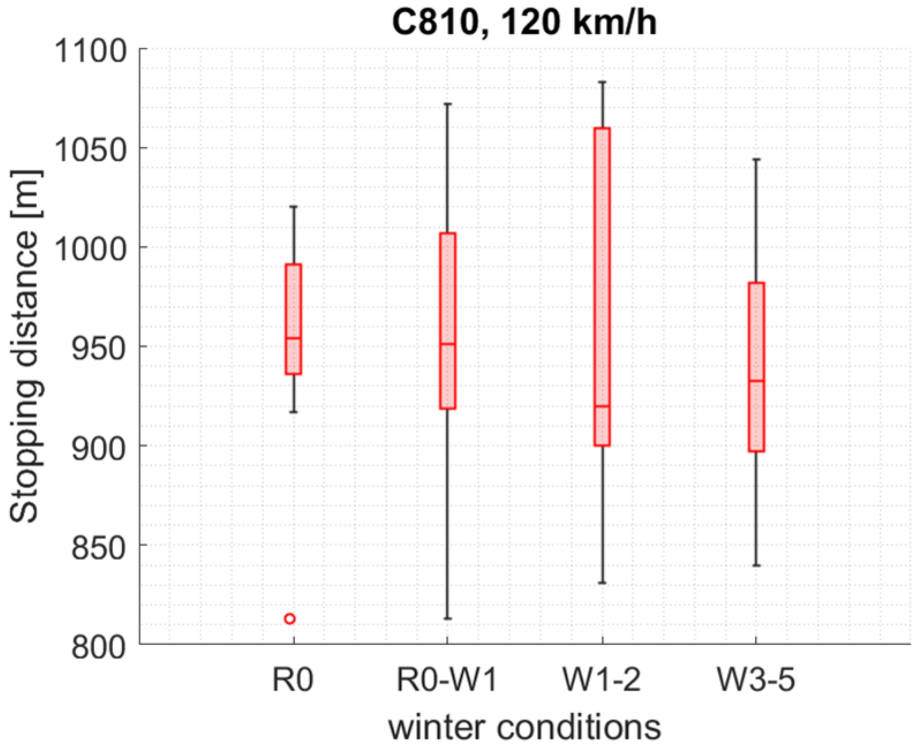
[42] SE NSAs, Transportstyrelsen's Transportstyrelsens regulations and general advice on railway vehicles (national rules)

13 Annex 1. Appendix A. Braking distances of C810

Data have been extracted from report B126 DT395. Note that snow conditions were report being between 0 (reference conditions) and 10. For the sake of comparison, these have been modified to fit the scale between 0 and 5 that is used in the rest of the present report.

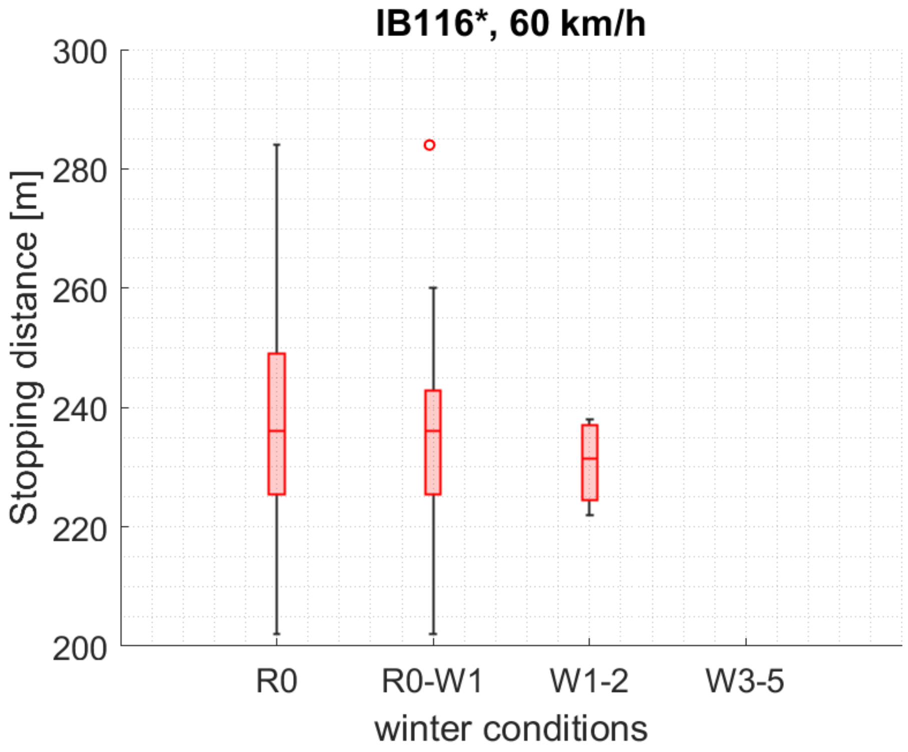


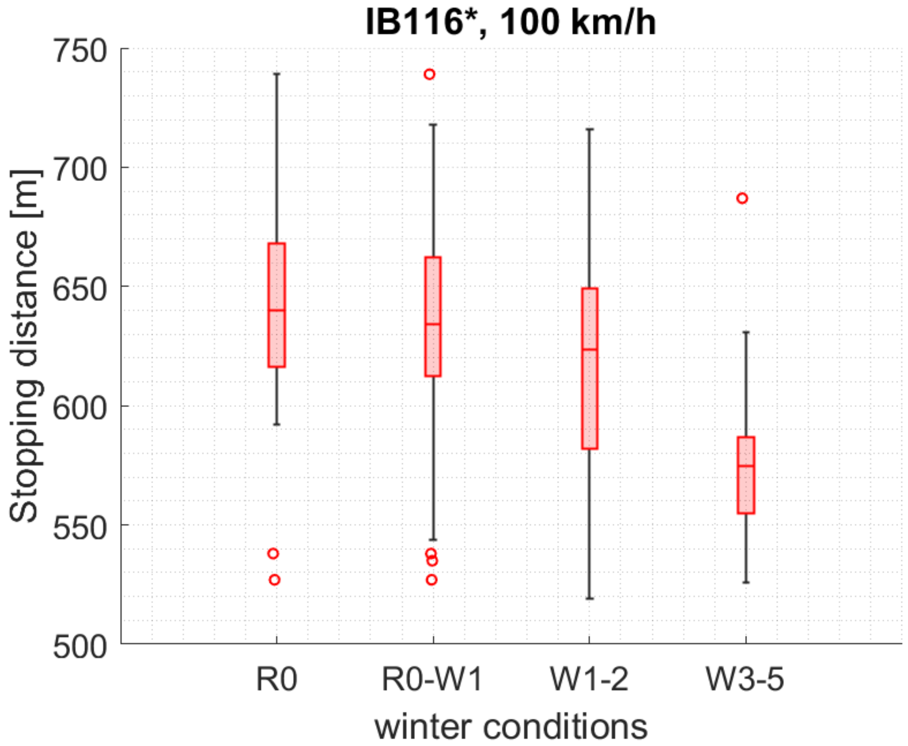


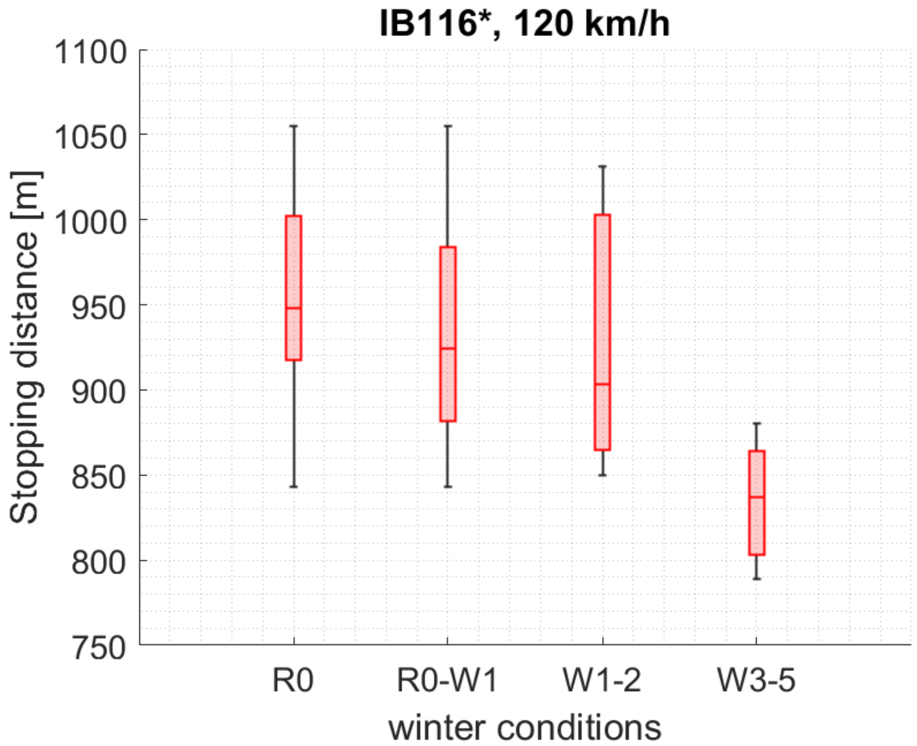

C810, 120 km/h
Stopping distance [m]
1100
1050
1000
950
900
850
800
R0
R0-W1
W1-2
W3-5
winter conditions

14 Annex 1. Appendix B. Braking distances of IB116*

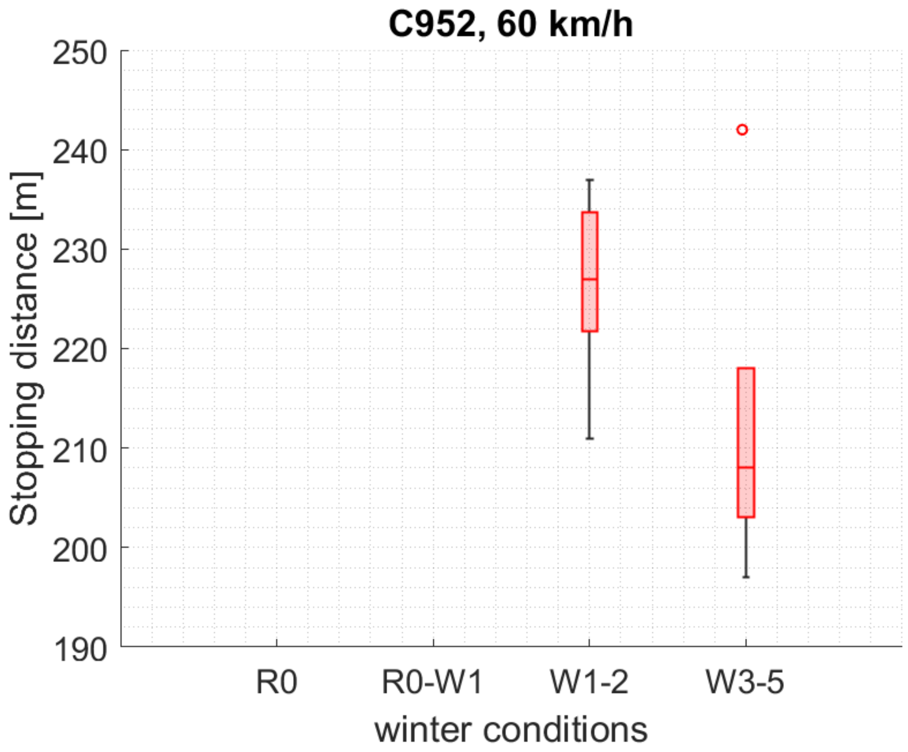
Data have been extracted from report B126 DT395.

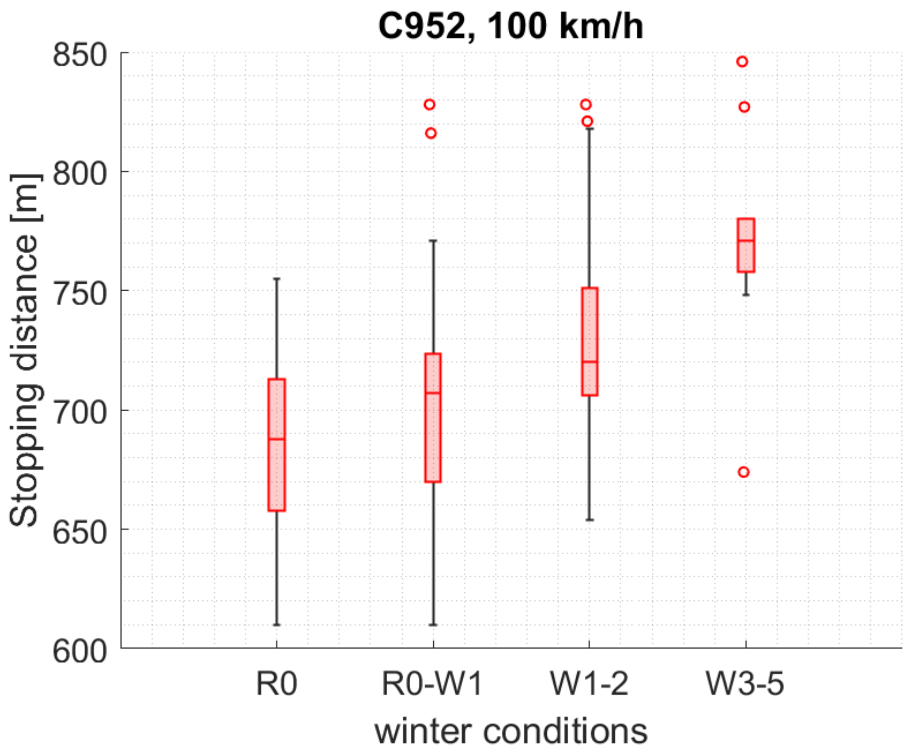


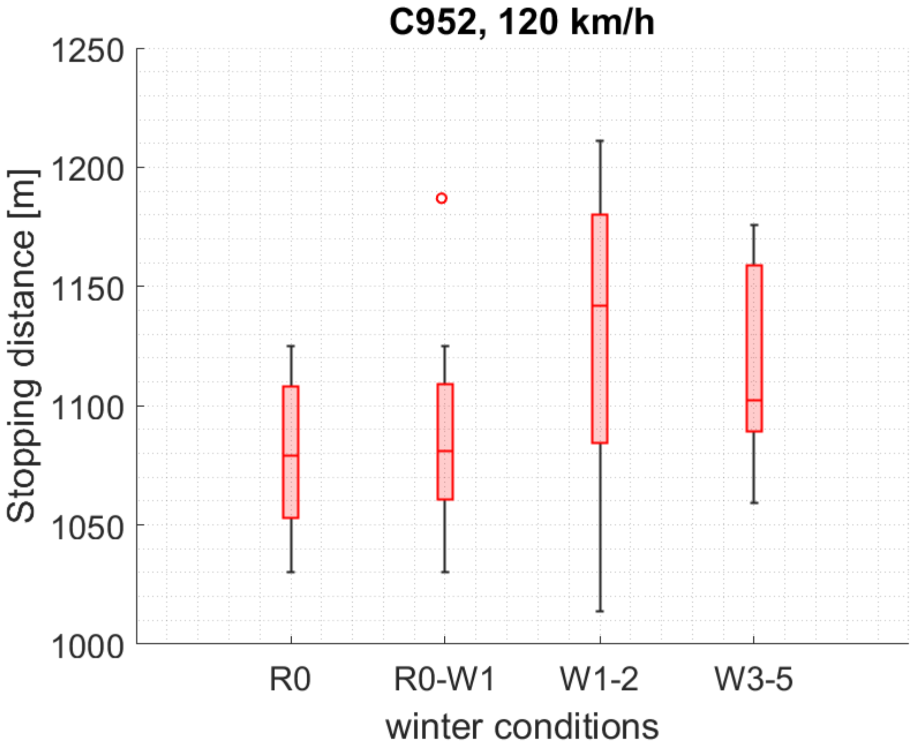

IB116*, 100 km/h
Stopping distance [m]
750
700
650
600
550
500
R0
R0-W1
W1-2
W3-5
winter conditions


IB116*, 120 km/h
Stopping distance [m]
1100
1050
1000
950
900
850
800
750
R0
R0-W1
W1-2
W3-5
winter conditions

15 Annex 1. Appendix C Braking distances of C952-1






C952, 120 km/h
Stopping distance [m]
1250
1200
1150
1100
1050
1000
R0
R0-W1
W1-2
W3-5
winter conditions

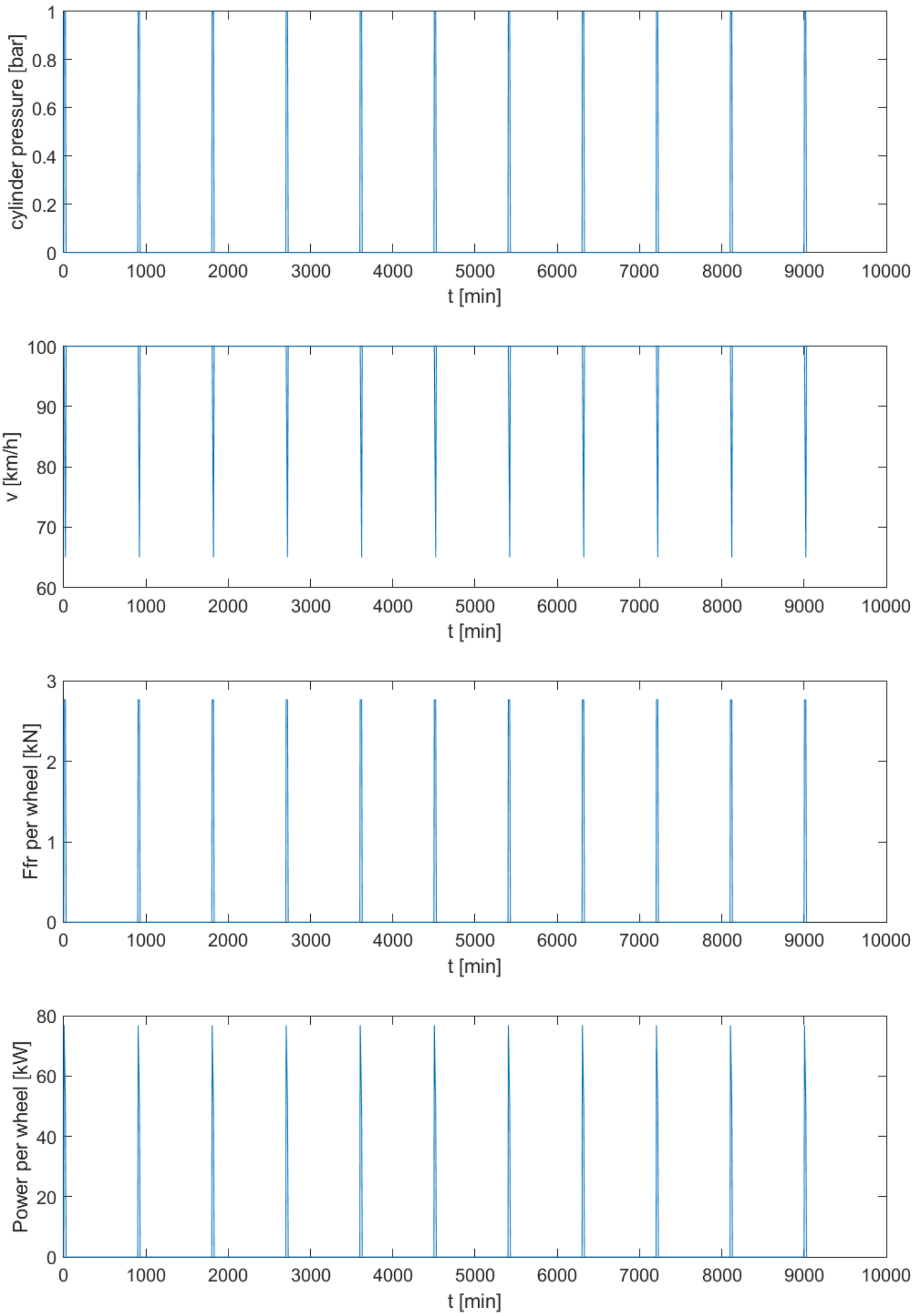
16 Annex 1. Appendix D. Thermal analysis of impact from brake applications of locomotive driver

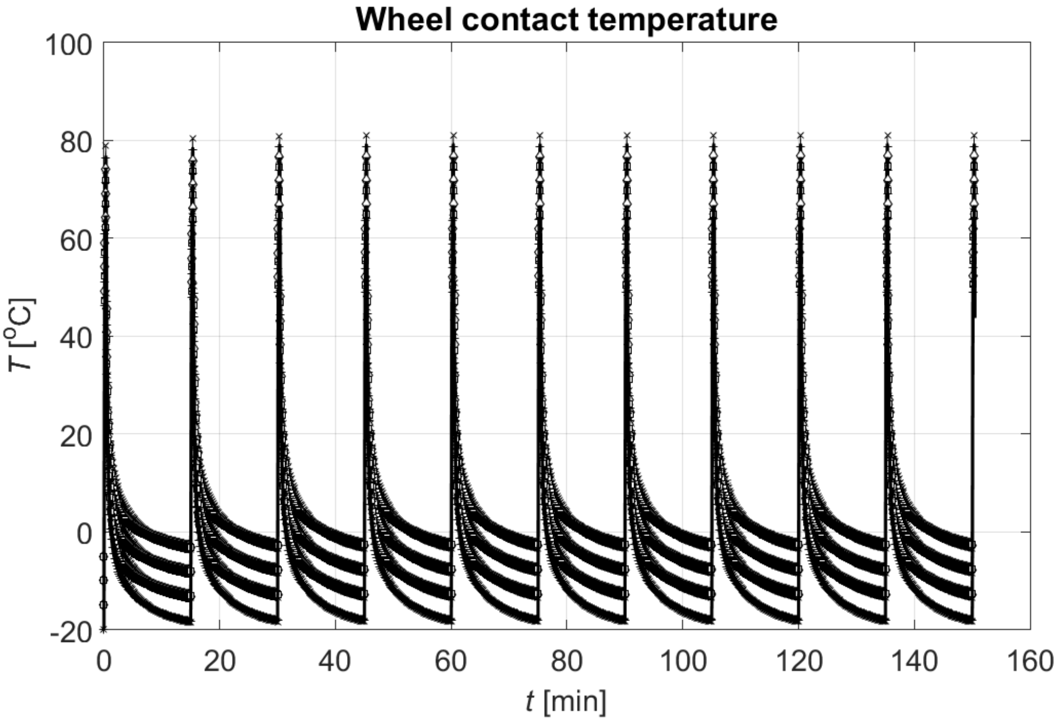
A thermal model, see [Ref. 66] in Chapter 12 References, developed at Chalmers railway mechanics is used to calculate braking temperatures for identified variations of brake power and train speed, employing data from the test campaign by Transportstyrelsen 2020-2021. The thermal model accounts for convection cooling pertaining to in-field conditions and the rail chill effect is considered. The behaviour of a generic organic composite brake block is here studied, with thermal properties of the organic material given in Table 3. Brake friction forces on blocks are calculated using data on wagon braking system and using a friction coefficient 0,2. It is based on a presumed increase of pneumatic pressure during 4,5 seconds, after which it is constant for another 16,5 seconds, upon which it decreases during 8 seconds. During the time that the pressure varies, the speed is assumed to decrease linearly from 100 km/h to 65 km/h.

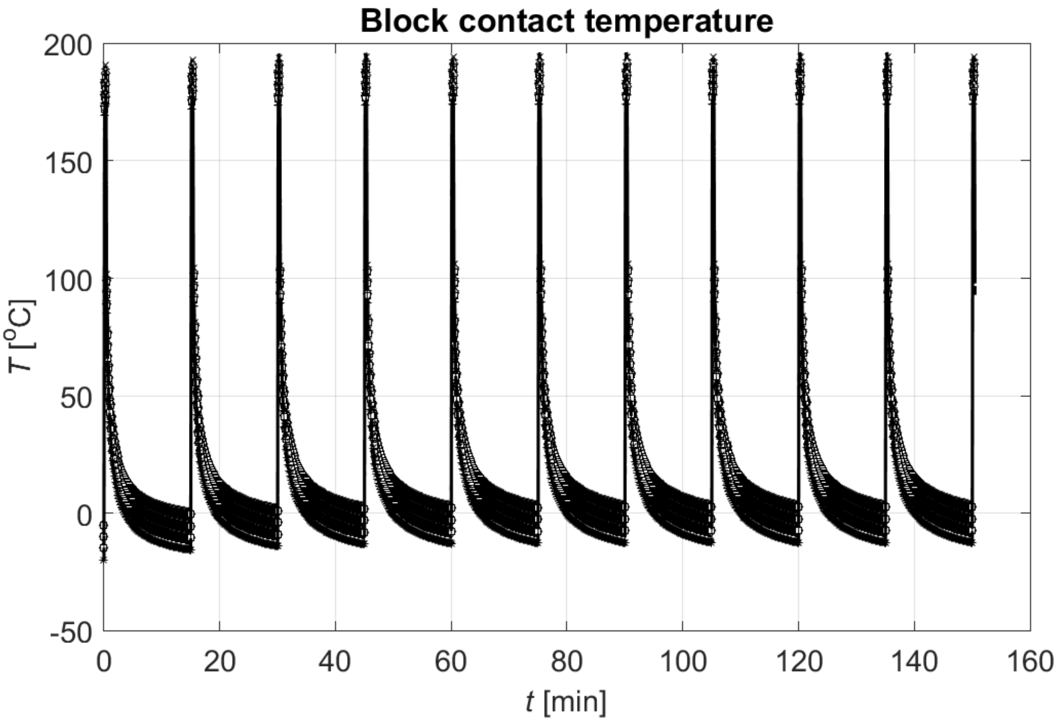
Variations of brake cylinder pressure, speed, friction force and brake power are first given and after that calculated wheel and brake block temperatures. The calculated temperatures are given for four presumed initial and ambient temperatures, -20 °C, -15 °C, -10 °C and -5 °C.

Table 3. Thermal properties of an organic composite brake block friction material [Ref. 67] in Chapter 12 References.

c [J/kg ◦C]	**λ [W/m°C]**	**ρ [kg/m3]**
1500	5.0	2670


cylinder pressure [bar]
t [min]
v [km/h]
t [min]
Ffr per wheel [kN]
t [min]
Power per wheel [kW]
t [min]


Wheel contact temperature
100
80
60
40
20
0
-20
T [°C]
0
20
40
60
80
100
120
140
160
t [min]


Block contact temperature
200
150
100
50
0
-50
T [°C]
0
20
40
60
80
100
120
140
160
t [min]