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A pin-on-disc study of airborne wear particle emissions from studded tyre on concrete road contacts

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ABSTRACT

Studded tyres wear surfaces of winter roads, generating inhalable airborne particles. In this study, four concrete road materials and two stud geometries were investigated in terms of wear, road material hardness and airborne particle concentration. The sliding contact between studded tyres and road materials was studied using a pin-on-disc machine in a clean chamber. The results show that the normal load and the stud size have a large influence on the wear and particle emission. It was found that the wear and particle concentration are inversely proportional to the hardness of the aggregate in the road material and proportional to the sliding distance. The particle size distribution has peaks at 0.2 µm, 1 µm and 2 µm.

1. Introduction

The use of studded tyres in winter can cause significant wear of road surfaces. Some fraction of this wear is released in the form of airborne particulates, affecting the air quality in urban areas [1]. In the EU, non-exhaust vehicle emissions (road and brake wear) equal exhaust emissions of PM10 particles (particles with aerodynamic diameters smaller than 10 µm) (Hak et al. [2]).

Several devices are available to measure the wear resistance of road materials. Two devices measuring how studs cause road wear are the Swedish Prall tester and the Tröger apparatus. Measurements using the Prall tester involve vibrations of bearing balls on the road surface while 4 °C water is injected over the surface to wash away loose particles (EN 12697–16:2004). The Tröger apparatus, which applies a vertical impact of bundles of needles to the road surface, is described by EN 1871:2000 Annex K. Another approach is to test unbound aggregates in abrasion-testing machines such as the Los Angeles abrasion machine and the Micro-Deval device [3]. These two methods, however, give no information on the properties of the composite road material.

Snilsberg et al. [4] compared the above four test methods with the VTI pavement-testing machine, in which a 6 m diameter test ring is brought into contact with four wheels at an adjustable rotation speed. The wear and concentration of airborne wear particles from the tyre-to-road interaction are measured under controlled environmental conditions around the machine (Gustafsson et al. [5]). Two other test set-ups, the internal drum test bench [6] and the overrun car test [7], use whole wheels as the contacting member on the road surface. In the overrun car test, a stone segment is overrun by a car 400 times at 100 km/h [7]. The mass loss of the stone segment is the criterion for acceptance of the studded tyre tested.

The contact between a car tyre and a road surface involves a combination of rolling and sliding [6]. The actual contact area of the tyre is about the size of an adult's hand. The interaction of a tyre stud with the road surface can be divided into two phases: first, an impact as the stud gets into contacts with the road surface, and then a sliding interaction until the stud leaves the road interface. The sliding velocity depends on the creep (the relative velocity difference between the tyre and the road surface in the contact). For free rolling at a velocity of 30 m/s (108 km/h), the sliding velocity in the contact zone is around 2 m/s [8].

The parameters and running conditions of the studs used in passenger car tyres are regulated by law. According to the legislation of the Nordic countries, the normal force on a single stud is limited to 120 N, the stud weight to 1.1 g, and the protrusion to 1.2 mm. In addition, the number of studs is limited to 50 pieces per metre of rolling circumference.

At high velocities, the wear of the road surface by studded tyres is caused mainly by dynamic forces. Here the damage mechanisms are crushing and impact. On the other hand, at low velocities abrasive wear is the dominant mechanism. A vehicle velocity of 50 km/h is used in [9] as the boundary between the domination of impact wear and the domination of abrasive wear. The purpose of the present study was to study abrasive wear and airborne wear particle emissions at studded tyre on concrete road contacts using a pin-on-disc set-up.

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Table 1
Mohs hardness table.

Mohs hardness	Mineral	Mineral type and formula	Scratch test: Scratch able using a …	Vickers hardness	Similar hardness
1	Talc	Silicate $Mg_3Si_4O_{10}(OH)_2$	Fingernail	2	
2	Gypsum	Sulphate $CaSO_4{\cdot}2H_2O$	Fingernail	40	0 °C ice
3	Calcite	Carbonate $CaCO_3$	Copper coin	110	
4	Fluorite	Calcium fluoride CaF2	Steel knife (easily)	190	− 44 °C ice
5	Apatite	Phosphate $Ca_5(PO_4)_3(F,Cl,OH)$	Steel knife (barely)	540	
6	Orthoclase (feldspar)	Silicate $KAlSi_3O_8$	Steel file	790	− 70 °C ice, hardened steel
7	Quartz (silica)	Oxide SiO_2	Topaz	1120	
8	Topaz	Silicate $Al_2SiO_4(F,OH)_2$	Corundum	1430	
9	Corundum	Oxide Al_2O_3	Diamond	2060	Tungsten carbide
10	Diamond	C		10,600	

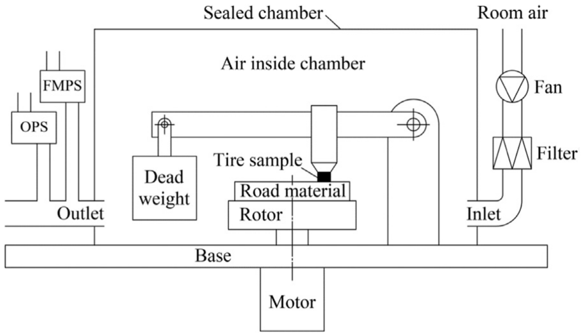


Fig. 1. Schematic of the experimental set-up.

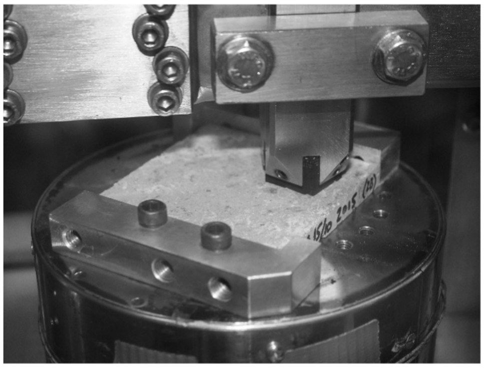
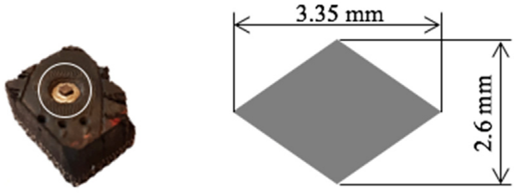
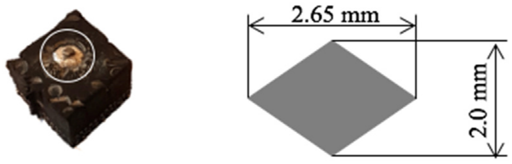


Fig. 2. Photograph of a tyre sample and a road material sample in contact.



(a) Hakkapeliitta 7



(b) Hakkapeliitta 8

Fig. 3. Stud geometry: (a) Nokian Hakkapeliitta 7 and (b) Nokian Hakkapeliitta 8. The sliding direction is perpendicular to the longer diagonal.

Table 2
Concrete road materials investigated.

Concrete specification	Code name
Road concrete with maximum aggregate size of 16 mm	Concrete 2
Road concrete with maximum aggregate size of 11 mm	Concrete 4
Concrete cut out from a road in use with aggregates Durasplit	Concrete 5
Concrete cut out from a road in use with aggregates Porfyr	Concrete 6

Table 3
Test plan.

Test No.	Road material	Tyre sample	Normal force, N	Sliding distance, m
1	Concrete 2	Nokian 7	120	10
2	Concrete 2	Nokian 7	120	5
3	Concrete 2	Nokian 7	120	3.75
4	Concrete 2	Nokian 7	120	2.5
5	Concrete 4	Nokian 7	120	10
6	Concrete 4	Nokian 7	120	5
7	Concrete 4	Nokian 7	120	3.75
8	Concrete 4	Nokian 7	120	2.5
9	Concrete 5	Nokian 7	120	10
10	Concrete 5	Nokian 7	120	5
11	Concrete 5	Nokian 7	120	3.75
12	Concrete 5	Nokian 7	120	2.5
13	Concrete 6	Nokian 7	120	10
14	Concrete 6	Nokian 7	120	5
15	Concrete 6	Nokian 7	120	3.75
16	Concrete 6	Nokian 7	120	2.5
17	Concrete 5	Nokian 7	60	10
18	Concrete 5	Nokian 7	60	5
19	Concrete 5	Nokian 7	60	3.75
20	Concrete 5	Nokian 7	60	2.5
21	Concrete 5	Nokian 8	60	10
22	Concrete 5	Nokian 8	60	5
23	Concrete 5	Nokian 8	60	3.75
24	Concrete 5	Nokian 8	60	2.5
25	Concrete 5	Nokian WR 4	120	10
26	Concrete 5	Nokian WR 4	120	5
27	Concrete 5	Nokian WR 4	120	3.75
28	Concrete 5	Nokian WR 4	120	2.5

2. Wear

To improve traction on icy roads, ice should be removed from road surfaces. This can be done by inserting studs in tyres. These studs, being harder than ice, wear away the ice layer. The problem is that it is not only the ice layer but also the road surface that is worn. As a rule of thumb, abrasive wear is the dominant wear mechanism when the hardness difference between the contacting surfaces is greater than 30% [10]. The mechanical properties of ice presented in [11] are