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An infield study of road snow properties related to snow-car adhesion and snow smoke

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ABSTRACT

This article analyzes the properties of snow on the road related to the formation of snow smoke and contamination of the car. The increased usage of sensors for active safety in modern cars increases the importance of understanding contamination of the car body. The analysis characterizes snow in terms of shape, size, and adhesiveness. The data is related to changing weather conditions and experienced car contamination. Several different sampling positions were chosen both on the road and on the car. The temperatures during the days of measurements ranged from −4 °C to −12 °C, which gave cold and dry snow. Data on size and shape was obtained via microscope analysis. An infield adhesion tester for snow adhesion measurements was built.

The microscope analysis showed that the shape of the snow particles in the tire tracks and on the car body generally had a rounded structure. Even soon after a fresh snow fall, the rounded shapes remained in these positions. This structure was found to change to a more edgy hexagonal shape during hoar formation on the existing snow. The particle size distributions from tire tracks, from suspended snow smoke, and from different positions on the car were analyzed. It was found that smaller particles travel higher and are more prone to enter the wake behind the car to stick to the back parts of the vehicle. The adhesion test gave little distinction between the different snow types and samples. The adhesion force was found to range from 2 to 12 dyne.

1. Introduction

Snow road conditions have been studied with the purpose of accident analysis and prevention by several authors; Pisano et al. (2008), Jonsson et al. (2015), Khattak and Knapp (2001) and Qin et al. (2006), to name a few. Pisano et al. (2008) looked at the increased accident risk due to different weather conditions. Those authors found that a decrease in road-tire friction is the main factor contributing to an increase in accident numbers and severity. Snow and snow fall not only lead to decreased friction on the road but also decreased visibility during snow fall or due to snow smoke caused by wind or other vehicles. The hazards related to decreased visibility when driving have been evaluated by Konstantopoulos et al. (2010) and Abdel-Atya et al. (2011). These authors have found that decreased visibility due to fog, rain, or smoke leads to more accidents and more severe injuries. Head-on and rear-end crashes are the two most common crash types in terms of crash risk and severity for foggy, low visibility conditions.

The present study focuses on snow smoke formation and characterizes snow smoke in an infield study in northern Sweden. Driving through snow smoke not only affects the performance of a driver but may also cause complications for the car. Fine snow dust finds its way into ceiling and air in-takes and adheres to the panels and the outside of the car. The present study focuses on the outer parts of the car and snow adhesion to and buildup on the car body. New cars use more and more sensor technologies, such as radar and cameras, and dependence on this equipment working in all conditions is crucial for future autonomous driving cars. A better understanding of the properties and formation of snow smoke from vehicles would be useful for developing models that predict snow smoke formation and how snow smoke influences the driver and the vehicle. Such a model requires the input of snow properties on the road, information on the type of snow that forms snow smoke, and on the properties of the snow that adheres to the car body.

Snow properties have been characterized previously in for example avalanche research on the evolution of snow from flake to its different equilibrium forms and has been explained in ICSI-UCCS-IACS (2009). Snow morphs from a flake structure to a grain structure on the ground Colbeck (1982). The equilibrium grain shapes are either hexagonal or spherical grains for dry snow. The structural changes that take place in snow on the road in tire tracks have, to the authors' knowledge, not been previously studied.

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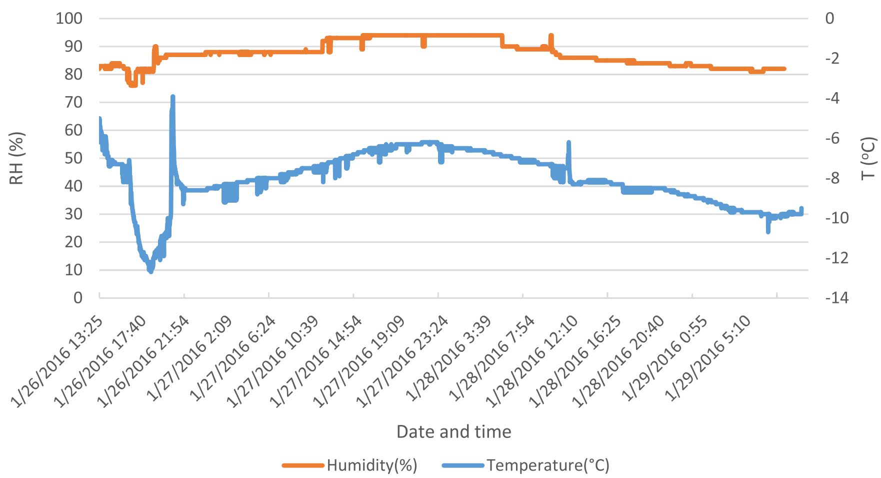

Fig. 1. Temperature and relative humidity measured during the test period.

Research on snow adhesion has focused on adhesion to structures and powerlines, which is a major factor of concern in the northern part of the world. The research has focused on fresh snow fall and on characterizing the hazardous weather conditions under which adhesive snow falls. The conditions are near zero degrees Celsius, and large patch-like flakes fall. Little effort has been made to study the dynamics and physics of the detailed process of the adhesion of individual snow particles. The modeling frameworks used for snow accretion are explained and evaluated in Nygaard et al. (2013). The models mainly use efficiency factors that are fitted to experimental data. The efficiency factor has a high dependency on the moisture content of the flake or particle and is zero or almost zero for a completely dry snow particle. This is in contrast to what has been seen in car tests in which dry snow smoke may stick to the car underbody and the back part of the vehicle. Snow smoke forms during cold and dry conditions, and the properties of the snow particles in the cloud have not been previously studied.

The dry snow adhesion force is certainly less than that of wet snow and is less studied. Hosler et al. (1957) have studied the adhesion of ice spheres in an astrophysical context. They found that ice – ice adhesion is strongly dependent on the relative humidity and temperature of the surrounding air. The size of the single particle force was found to range between hundreds of dyne close to zero degrees Celsius and down to zero dyne at − 25 °C at high humidity and − 5 °C at low humidity. The force dependence on temperature was found to have an Arrhenius-like logarithmic dependence with an activation energy and a rate constant that is dependent on the contact area. Temperature dependence is explained by Jellinek (1967), and depends on the existence of a liquid-like transition layer that governs adhesion. The existence and thickness of this layer is dependent on the ambient relative humidity and temperature. Landy and Freiberger (1967) have studied ice adhesion to plastic materials. They have explained different mechanisms of adhesion as liquid-like layer capillary forces, mechanical anchoring (water freezing on the surface), electro static, and van der Waals forces. The tangential force needed to remove ice that had frozen onto a material sample ranged from 40 N to 200 N. The force needed to remove ice that has formed on a plastic surface is many orders of magnitude larger than the force needed to separate ice that has just come into contact with the material, which is the context in which an ice particle collides with a car surface. Relevant for the snow adhesion on car surfaces due to snow smoke is also the restitution coefficient of the snow or ice particle as it hits the surface of the car. Higa et al. (1998) have studied the restitution coefficient in an ice – ice system. The findings of those authors showed the existence of, what they called, a quasi-elastic regime where the restitution coefficient was found to be 0.9 ± 0.05 for temperatures below − 4 °C. At high impact velocities, the quasi-elastic regime changed to an inelastic regime. The threshold for the regime change was found to be temperature dependent; around 15 cm/s at − 4 °C and 35 cm/s at − 12 °C. Temperature affects the behavior in a quasi-elastic regime as a whole. At temperatures higher than − 4 °C, the spread in the data in that study was large and coefficients ranging from 0.2 to 0.6 were found.

A number of devices have been used previously to study adhesion/cohesion. Haider et al. (2012) used a climate chamber with an apparatus able to attach particles to a plate and a piston. The force on the piston could then be measured while it was pushed onto the particle on the plate and when it was retracted, demonstrating the work of adhesion. Cameras were also attached to a microscope for a detailed study of the dynamics of the attachment. A simpler device was used in Malafronte et al. (2015), in the context of spray drying, where wet particles were glued onto thin steel strips that could then be manually pushed together to enable interaction among the particles and study the dynamics of the adhesion via a camera.

The aim of the present study is to investigate infield snow conditions, to characterize snow properties on the road, and obtain information on the adhesion properties of road snow and snow smoke. The adhesion tester was designed to study the adhesion force of snow particles that have just come into contact with a car surface, mimicking a particle - car collision. This is a type of contact adhesion measurements that have not been done previously and are necessary to understand car contamination from snow smoke. Samples of snow were collected during a field test in northern Sweden and were characterized in terms of size and adhesion properties. The collected data increases the understanding of snow on the road and will form a basis for the development of mathematical models of snow interactions with vehicles.

2. Snow sampling and experimental plan

The idea of the study was to analyze the properties of infield snow samples, ranging from snowflakes from the air to snow from tire tracks on the road, to study the changes in shapes, sizes, and adhesion properties of the snow at one location. The tests were performed in northern Sweden in January 2016. The temperature and relative humidity of the air under the entire measurement period is plotted in Fig. 1. The measurements were made on the ground by the side of the road from which the snow was collected.

The temperature and humidity values show stable conditions on the ground, with the exception of the first time period from 16-01-26 13:25 to 16-01-26 21:54 where larger fluctuations were measured due to snow fall and rapidly changing weather. The days in the following are numbered from one to four starting from the arrival day, 01–26 Day 1, 01–27 Day 2, 01–28 Day 3 and 01–29 Day 4. The measurements were done with two portable temperature and humidity sensors with an accuracy of + − 0.5 °C and 1% for the relative humidity.