Assessing the Impact of Common Winter Contaminations on Runway Surface Condition

Jean-Denis Brassard[1], Marc Mario Tremblay[1] & Gelareh Momen[1]

[1] *Anti-Icing Materials International Laboratory, Université du Québec à Chicoutimi, Canada*
jean-denis1_brassard@uqac.ca

Abstract— **Heavy snowstorms and freezing precipitations impair northern airport operations every winter. A slight snow or ice deposit can disrupt aircraft operations (take-off, landing, and taxiing) and increase the danger for passengers and crew members by rendering the runway slippery and unsafe. Deficits in de-icing operations can also cause flight delays and even cancellations, which cost the business a lot of money, and in the worse cases runway overruns on landing that may cause fatalities. The International Civil Aviation Organization (ICAO) has been using the new Global Reporting Format (GRF) to evaluate Runway Surface Conditions from November 2021. The overarching goal is to reduce the risk of runway excursions by enabling standardized monitoring and reporting of runway surface conditions, as well as enhanced flight crew assessment of take-off and landing performances. Using the Runway Condition Assessment Matrix (RCAM), airport or aerodrome operators create a preliminary Runway Condition Code (RWYCC) for each runway third if its surface is covered in water, snow, slush, ice, or frost. The main descriptions of winter circumstances are directly obtained from this matrix, allowing them to be reproduced under controlled laboratory conditions. The goals of this work consist of: (i) to reproduce in the laboratory the above-mentioned winter conditions and (ii) to assess their impact on the runway surface conditions.**

To undertake this work, seven conditions were excerpted from the RCAM and reproduced in a cold room under controlled conditions, on 10 cm per 20 cm concrete paving stones. The conditions consisted of: dry, "as-is" condition, wet condition, removed snow, dry snow, wet snow, ice and snow on ice. All the conditions were reproduced six times and were evaluated using a British Pendulum Tester that meets the ASTM E303 Test Method. For each condition the measurements have been repeated five times. By fitting a linear function, it is evident that the trend obtained with the British Pendulum Number (BPN) correlates with the RWYCC. It is also relevant to know that a slight layer of snow or ice can increase the slipperiness up to 80% in the worst conditions. Being able to reproduce those conditions in the laboratory will help to assess the effectiveness of runway chemical products in de-icing or anti-icing modes and then allow to establish their minimal requirements.

Keywords— ***atmospheric ice, snow, runway de-icing products, winter maintenance, slipperiness, airport operation, global reporting format***

I. Introduction

Northern airports are annually disrupted by several heavy snowstorms and freezing precipitations which impair winter operations. Following a recent study, the most significant factors causing runway excursions are the poor braking performance with 15.5% of all the accidents that occurred between 2010 and 2019 [1]. A slight deposit of snow or a small coating of ice can interrupt aircraft operations (take-off, landing, and taxiing) and increase the danger for passengers and crew members by rendering the runway slippery and unsafe. In 2019, those accidents cost directly 4B$ to the industry with most of the accidents occurring during winter when contaminated by snow, slush, ice, brine or water [2]. These contaminants all have a negative effect on the braking performance significantly reducing the friction between the aircraft tires and the runway surface and then inhibit the manoeuvrability [1-7].

In order to monitor the state of the runway surfaces, several methods have been developed to evaluate the braking performance. Most of them are ASTM Test Methods to measure the surface friction characteristics. They can be divided in four classes: (i) fixed tests (ii) braking tests (iii) contact tests and (iv) Non-contact tests [8-14].

All those ASTM tests give relevant information on how the texture of the runway is, which is an important factor for the braking procedure of aircraft. Sometimes more information is needed to confirm the contaminant nature on the surface. Efforts have been made, over the past 20 years, to use weather and flight data to estimate surface conditions at landing using data analysis, machine learning and fusion and model correlation [15-17]. It exists a few sensors on the market that are mounted in the runway that could tell what kind of contaminant present [18-20].

More recently the International Civil Aviation Organization (ICAO) implemented the new Global Reporting Format (GRF) to evaluate Runway Surface Conditions. The principal goal is to decrease the risk of runway excursions by enabling standardized monitoring and reporting of runway surface conditions, as well as enhanced flight crew assessment of take-off and landing performances. Using the Runway Condition Assessment Matrix (RCAM), airport or aerodrome operators create a preliminary Runway Condition Code (RWYCC) for each runway third if its surface is covered in water, snow, slush, ice, or frost. Among the work carried out to implement this global standard, Transport Canada published the Advisory Circular (AC) No. 300-019 [21]. The GRF principle is that whenever water, snow, slush, ice, or frost are present on an operating runway, the airport operator evaluates the runway surface conditions. This evaluation yields a runway condition code (RWYCC) and a description of the runway surface, which the flight crew may use to calculate aircraft performance. The airport operator's best evaluation of the runway surface quality is based on this format, which is based on the type, depth, and coverage of contaminants. All other relevant facts should be considered as well. Changes in circumstances should be notified as soon as possible.

The main descriptions of winter conditions are directly obtained from this matrix, allowing them to be reproduced under controlled laboratory conditions.

The goals of this work are: (i) to reproduce in the laboratory the above-mentioned winter conditions and (ii) to assess their impact on the runway surface conditions using the British Pendulum Tester.

II. Experimental

Experiments were carried out to evaluate the impact of the winter contaminants on the slip of the runway. All the measurements have been conducted in controlled cold conditions in a cold room. The substrates consisted of 10 cm per 20 cm concrete paving stones. Those paving stones were selected since their surface roughness and absorption characteristic correlated well with the actual concrete surfaces found in airports. Each stone has been cleaned using tap water and dry at room temperature. The pavements as well as the testing apparatus were placed in the cold room, at the test temperature, 24h prior testing. The skid measurements were undertaken using a British Pendulum Tester (BPT) that meets the ASTME303 using Tyre Slip Rubber (TSR) (CS-PEND-855/1060) [8]. The pendulum is presented on Figure 1. The BPT is a dynamic test that works on the principle of the Sharpy test, where the rubber slider in contact with the surface allows to evaluate the skid. The result is given in British Pendulum Number (BPN). The smaller is the BPN, the more the surface slide and is considered dangerous. Inversely, the higher is the BPN, the less the surface slide. Prior each testing day, the apparatus is levelled and the zero is verified. The contact surface is also verified using the ruler to ensure that the slider is in contact with 125.0 ± 1.6 mm.

Seven conditions were excerpted from the RCAM and reproduced in the laboratory. The first tested condition consisted of dry, "as-is" condition, which is equivalent to a RWYCC of 6, known as the reference value. The second condition consisted of the wet condition, where the concrete was fully wetted with water, at room temperature, with a RWYCC of 5. The two later conditions have been conducted at 20 °C. Following the RCAM, the next conditions were reproduced using harvested natural dry snow particles. The third condition was "removed snow"; where snow was sifted and compacted on the stone with a low pressure and then removed using a scraper. In this condition all the pores of the concrete were filled with snow and a thin layer of snow remained on the surface. This condition has been conducted at -15 °C. This allowed to reproduce compacted snow condition, having an equivalent RWYCC of 4. The fourth condition consisted of dry snow, which was obtained using a 1 mm sift to deposit approximately 4 mm of snow. The snow deposition is presented on Figure 2, the thickness of snow has been measured at five different positions using a metallic ruler. The snow is not compacted during the deposition process, so it is easily removed during the passage of the pendulum slider. The equivalent RWYCC is 3. The same methodology has been used to obtain the fifth condition, wet snow, except that the snow was submitted to a simulated freezing drizzle precipitation during six minutes at a targeted intensity of 8.5 g/dm². h. It also corresponds to a RWYCC of 3. The two latter conditions have been conducted at -10 °C. The sixth condition consisted of ice, obtained using a simulated freezing drizzle precipitation for 6 minutes at a targeted intensity of 8.5 g/dm². h at -5 °C. After the precipitation, a waiting time of 10 minutes was required to ensure completely frozen. In this case, the equivalent RWYCC is 1. Finally, the seventh condition consisted of snow on ice, obtained using the same ice condition and then by sifting 3 mm of snow. The equivalent RWYCC is 0. Each condition was reproduced six times and for each substrate the BPN has been measured five times, giving 30 data per conditions.

Figure 1 British pendulum measurement.

Figure 2: Snow deposition on the concrete pavement stone by using a 1 mm sieve.

III. Results and discussion

The first objective of this article is to reproduce in the laboratory the main winter conditions prescribed by the GRF and then correlate the obtained BPN values with the RWYCC ratings. Since the RWYCC has been established as a function of the state of the runway and by taking in consideration the Runway Friction Index (RFI), it is inherent that the results should correlate. The main results are presented in Table 1 below.

Table 1: BPN results obtained as a function of the RWYCC.

Condition	RWYCC	BPN ± s.d.
Dry	6	50 ± 3
Wet with water	5	38 ± 1
Removed snow	4	33 ± 3
Snow	3	23 ± 2
Wet snow	3	19 ± 2
Ice	1	17 ± 1
Snow on ice	0	11 ± 2

The results are also presented in Figure 4. The first condition is the dry condition, with a RWYCC of 6. The evaluated BPN is of 50 ± 3, indicating that the surface skid is low. It is the safest condition on the runway. The selected concrete surface is uniform and basically not corrugated as a concrete surface would be. Canadian Runway Friction Index (CRFI) could be used as a reference regarding the data. The equivalent CRFI is higher than 0.40, excerpt from the GRF, indicating that the pilot does not need to adapt their braking action. The density of the concrete and its ability to absorb water has been evaluated in previous studies to be representative of an airport runway. On the wet condition (RWYCC of 5), the BPN reduced significantly to 38 ± 1. This condition remains secure on the runway. In that condition the equivalent CRFI is in the same range as the dry condition and the condition are considered good. The selected concrete allows a slight water absorption; however, some parts remain on the top when completely wet.

The removed snow condition matched to the compacted snow condition as described in the GRF, it corresponds to a RWYCC of 4. The obtained condition is presented on Figure 3.

Figure 3: Removed snow condition (RWYCC of 4).

It can be noted that the snow, when compressed and removed, fills the holes and then acts as a lubricant resulted in increasing slightly the slipperiness. The corresponding BPN is 33 ± 3. This condition is not clearly specified in the matrix; however, this is one of the most recurring conditions during the winter.

The dry snow and wet snow conditions are the next conditions to be presented. They correspond to a RWYCC of 3. Wet snow, with a BPN of 19 ± 2, is more slippery than snow only, with a BPN of 23 ± 2. The wet snow condition was close to the slush condition which corresponds to a RWYCC of 2. Slush corresponds to snow supersaturated with water that should be easily evacuated when compressed with the hand. In our case, the water cannot be removed from the snow, unless a high pressure was applied, so the condition was considered as wet snow.

The next condition corresponded to ice cover, with a RWYCC of 1. In that condition the BPN is 17 ± 1, indicating that the surface is slippery. The pilot braking action is greatly affected during this condition and the measurement is confirmed by BPN. The BPN is even more reduced when the snow is added to the ice layer. Corresponding to a RWYCC of 0; this is the worst condition to be encountered on the runway. It has been confirmed with a BPN of 11 ± 2, close to the lower limit of the pendulum. In that case, the dry snow acts as a lubricant on ice, rendering the surface more slippery and then more dangerous.

In order to validate the results, a linear fitting has been added to the graph of Figure 4. Most of the data were slightly over the curves except for the snow and wet snow conditions which are under. The obtained equation is

$$BPN = (5.5 \pm 0.7)RWYCC + (10.2 \pm 2.4)$$

The intercept was not forced to 0 since at the worst condition, a BPN of 11 was still obtainable. The Pearson's r of 0.96 indicates that the relation is strongly positive, thus validating the results. Finally, the R^2 of 0.93 also indicated that more than 90% of the data fits with this linear assumption.

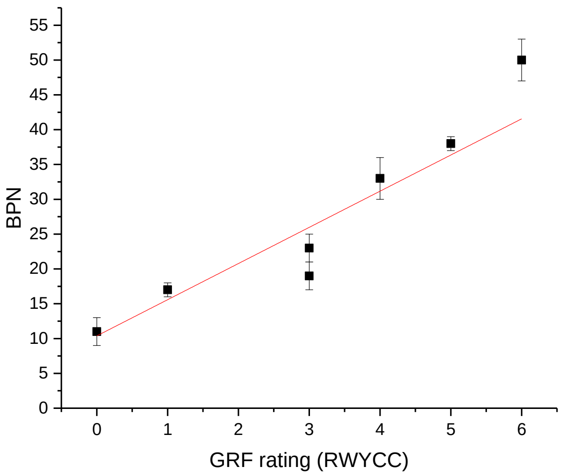

Figure 4: BPN as a function of the GRF RWYCC.

By this analysis, we can say that the reproduced conditions complied with the results given in BPN. The data correlate well with the RWYCC and then with the latter Runway Friction Index.

The obtained results correlated well with the literature on the subjects. It exists a few papers covering the British Pendulum versus real-life conditions, including wet and iced conditions [22-25].

IV. CONCLUSIONS

The reproduction of the GRF winter conditions were possible in the laboratory. The results obtained using the British Pendulum Tester correlated well with RWYCC ratings. The worst condition remained the snow on ice where the snow act as a lubricant and thus increasing the slipperiness. With the venue of the GRF which only requires visual inspection of the surface, having a laboratory methodology that reproduce the conditions will help the product manufacturer to develop more effective products by comparing them. The proposed testing conditions have then an enormous potential to evaluate the impact of the different winter chemical treated used during the winter operation, especially in airports. It will also help to establish minimal requirements following the needs of the airport's operators. The potential liquid, solid and pre-wetted runway de-icing products could be evaluated in different conditions, i.e. anti-icing and de-icing, and temperature in order to determine their effectiveness prior application in the real conditions, ensuring the product effectiveness in relevant winter conditions.

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