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FIELD MEASUREMENTS ON RUNWAY FRICTION DECAY RELATED TO RUBBER DEPOSITS

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Abstract. Surfaces of airport pavements are subject to contamination that can be very dangerous for the movement of aircraft particularly on the runway. A recurrent problem is represented by the deposits of vulcanized rubber of aircraft tires in the touchdown area during landings and lesser during take-offs. This causes a loss of grip that compromises the safety of aircraft movements in take-off and landing operations. This study deals with the surface characteristics decay phenomenon related to contamination from rubber deposits. The experiment was conducted by correlating the pavement surface characteristics, as detected by Grip Tester, to air traffic before and after de-rubberizing operation and two models were constructed for the assessment of functional capacity of the runway before and after the operations de-rubberizing.

Keywords: airport; runway; rubber deposits; friction, decay curve; grip number; airport pavement management system.

Introduction

Monitoring the surface characteristics of the runway is a very complex problem for the airport agency. One of the most important and recurrent problem is the contamination phenomena due to rubber deposits. If not properly handled, these occurrences can have serious consequences on the landing and take-off operations, compromising significantly their safety (Čokorilo *et al.* 2014). In recent years, many researchers have proposed several solutions for the control and management of these particular phenomena that can compromise runway pavement friction (Yager 2009).

Chen *et al.* (2008) focused an important factor that affects the available friction on a runway: the amount of rubber deposits on the pavement surface. Rubber deposits occurring at the touchdown area on runways can be quite extensive. Heavy rubber deposits may completely cover the pavement surface texture and cause loss of aircraft braking capability and directional control when runways are wet.

Suh *et al.* (2002) developed mathematical prediction models for the deterioration of rigid airfield pavements in South Korea. To derive the models, an integrated database of pavement conditions, age, traffic volume, and other characteristics was assembled. From the validation plots, the pavement condition indexes (PCIs) predicted were in good agreement with the measured PCIs. Results from the independent data demonstrated an acceptable degree of accuracy of the models.

Wambold *et al.* (2003) report of the Joint Winter Runway Friction Measurement Program between the National Aeronautics and Space Administration (NASA), Transport Canada (TC), and the Federal Aviation Administration (FAA): the program performed instrumented aircraft and ground vehicle tests aimed at identifying a common number that all the different ground vehicle devices would report. This number, denoted as the International Runway Friction Index (IRFI), will be related to all types of aircraft stopping performance.

This paper describes an experimental study on runway pavement friction decay related to rubber deposits at the Lamezia Terme International Civil Airport located in Italy. The three years long experiment, from 2010 to 2012, was conducted by correlating the pavement surface characteristics, as detected by Grip Tester, to air traffic before and after de-rubberizing operation and two empirical friction decay models as function of aircraft loads were constructed for the assessment of functional capacity of the runway.

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1. Data Collection

1.1. Lamezia Terme Airport

The International Civil Airport of Lamezia Terme (Fig. 1) is equipped with a 4D class runway named RWY 10/28 of approximately 145000 m^2, built with flexible pavement whose structural characteristics are identified by the code: PCN 58/F/B/W/T.

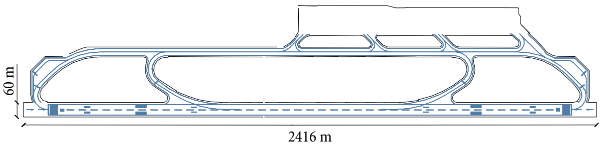

Fig. 1. Airside: runway, taxiway, and ramps

Runway has magnetic orientation 96–276°, length 2416 m and width 60 m.

Geographic coordinates and altitude on the average sea level are as follows:

- latitude: 38°54′30″ North;
- longitude: 16°14′30″ East;
- altitude: 12.31 m on the a.s.l.

The runway has a flexible pavement with a dense asphalt-wearing surface. The different layers and materials making up the pavement of the runway are as follows:

- first layer (surface): 4 cm in dense asphalt;
- second layer (binder): 4 cm in dense asphalt;
- third layer (base): 18 cm in dense asphalt;
- fourth layer (sub-base): 20 cm in concrete;
- fifth layer (subgrade): 40 cm in 'mixed crushed rock'.

The thickness data are the same, on average, for all the runway area.

The upper pavement layer (surface) has been put in place in 2004 and the operations of de-rubberizing, in the area of touchdown, were performed in July 2007 and November 2011.

1.2. Survey of Surface Characteristic

The surface characteristic of the runway (Thenoux *et al.* 1996; Najafi *et al.* 2013) has been detected by the Grip Tester according to ICAO-Doc.9137-AN/898 (Fig. 2). For more information on pavement surface texture and how tire friction performance can be improved, see references (Horne *et al.* 1968; Yager 1983; De Luca, Dell'Acqua 2014; Leland *et al.* 1968). In both runway touchdown areas, the Grip Tester friction (Grip Number – GN) measurements (De Luca *et al.* 2015) were collected along six alignments as shown in Fig. 3 following the time line schedule given in Table 1.

Fig. 2. Grip Tester

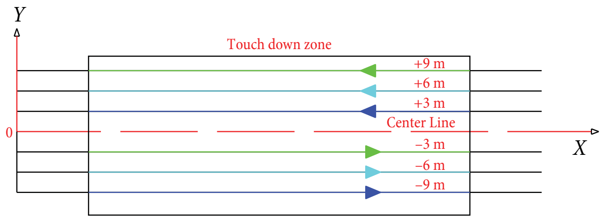

Fig. 3. Layout of GN survey

Table 1. GN surveys timetable before and after runway de-rubberizing

Surveys time	Runway status	Measured parameter	Number of surveys
From 1 January 2010 to 30 June 2011	Before de-rubberizing	GN	10
From 1 November 2011 to 31 December 2012	After de-rubberizing	GN	6

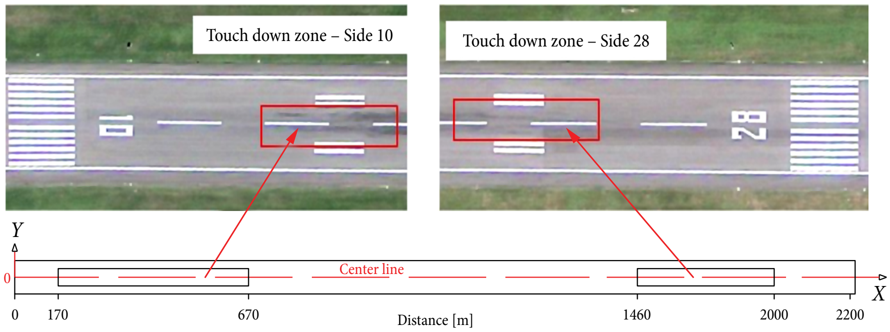

Fig. 4. Touchdown zones before de-rubberizing made in November 2011

In particular, the measurements were taken in the area with rubber deposits at the following distances from the side 10 of the runway (Fig. 4):

– from 170 m to 670 m;
– from 1460 m to 2000 m.

1.3. Air Traffic Data Providing and Organization

Traffic data relating to flights that occurred from 1 January 2010 to 31 December 2012 was provided by the Airport 'post-holder' office (Table 2).

The spectrum of aircrafts traffic is given in Fig. 5.

To define the loads acting on the runway due to the transit of aircraft, the following relationship was used:

$$L = \left(\left(\frac{TW}{A_{WGtake-off} \cdot N_{WG}} \right) + \left(\frac{LW}{A_{WGlanding} \cdot N_{WG}} \right) \right) \cdot A_{t,l}, \quad (1)$$

where: TW (Take-off Weight) – take-off aircraft weight [N], it was assumed to be equal to 70% of real weight (the load is reduced because there is the thrust due to the lift); LW (Landing Weight) – landing aircraft weight [N], it was assumed to be equal to 70% of real weight (the load is reduced because there is the thrust due to the lift); $A_{WGtake-off}$ – trace area of a main landing-gears wheel at take-off [m^2], defined as:

$$A_{WGtake-off} = \frac{L_{WGtake-off}}{P_{WG}};$$

$L_{WGtake-off}$ – load on a wheel at take-off [N]; P_{WG} – main landing-gears tires inflation pressure [N/m^2]; $A_{WGlanding}$ – trace area of a main landing-gears wheel at landing [m^2], defined as:

$$A_{WGlanding} = \frac{L_{WGlanding}}{P_{WG}};$$

$L_{WGlanding}$ – load on a wheel at landing [N]; P_{WG} – as above mentioned [N/m^2]; N_{WG} – total number of all main landing-gears wheels; $A_{t,l}$ – area where the 99% of aircraft has made the operation of touchdown or take-off [m^2]; it was considered a strip of 18 m (assuming the centreline as the axis) and a length of 1040 m.

Rubber deposits produced from nose tire touchdown have been ignored.

For each aircraft, landing or in take-off, the load induced on the runway was calculated through Eq. (1). The cumulative load L_c [expressed in Gt = 10^{13} N] of the three years 2010, 2011 and 2012 was obtained as cumulative sum of all loads L [N] from 1 January 2010 to 31 December 2012. Fig. 6 shows the trend of the cumulative load in the three years.

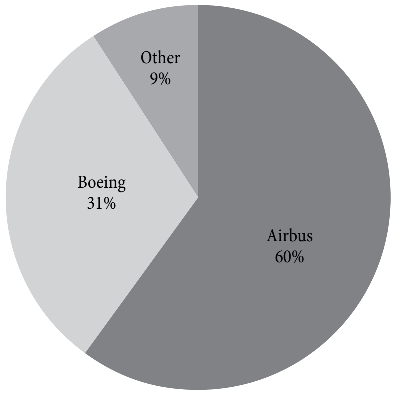

Fig. 5. Spectrum of aircrafts traffic

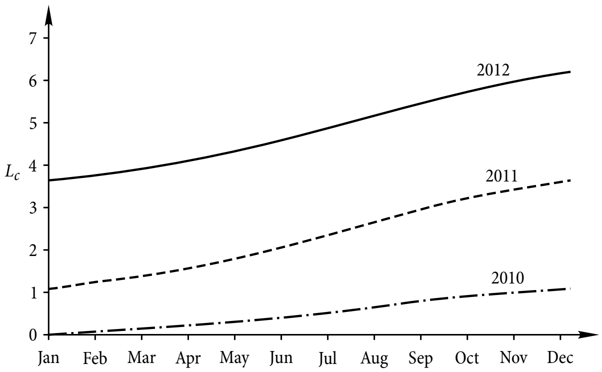

Fig. 6. Cumulative load L_c [Gt]

Table 2. Sample data excerpt from air traffic sequence on runway 10/28

Date	Aircraft type	TW [t]	LW [t]	$L_{WGtake-off}$ [t]	$L_{WGlanding}$ [t]	$A_{WGtake-off}$ [m^2]	$A_{WGlanding}$ [m^2]	Type gear	N_{WG}
….	….	….	….	….	….	….	….	….	….
24 June 2010	A 320	84.4	82.8	21.10	20.70	0.159	0.156	Tandem	4
	A 320	83.8	83.2	20.95	20.80	0.158	0.156	Tandem	4
	A 320	82.8	81.6	20.70	20.40	0.156	0.153	Tandem	4
	A 321	97.4	95.1	24.35	23.78	0.175	0.171	Tandem	4
	B 734	72.8	71.3	18.20	17.83	0.128	0.126	Tandem	4
	B 737	72.1	66	18.03	16.50	0.119	0.109	Tandem	4
	B 737	75.8	75.6	18.95	18.90	0.125	0.124	Tandem	4
	B 737	71.7	69.4	17.93	17.35	0.118	0.114	Tandem	4
	MD 82	69.5	68.3	17.38	17.08	0.138	0.136	Tandem	4
….	….	….	….	….	….	….	….	….	….

2. Data analysis

2.1. Data Analysis before De-Rubberizing Operations

The GN detected with the Grip Tester, according to the calendar shown in Table 1, before the de-rubberizing operations, was organized in 25 classes with the same width of 0.03 in ΔGN (Table 3). 25 is the number of classes that produced the best statistically model (i.e. the higher coefficient of determination ρ^2 and the significance at 95%).

Subsequently, through a multivariate regression analysis (*GN* as the dependent variable and L_c as the predictor), model (2) was obtained:

$$GN = b_1 + e^{b_2 \cdot L_c}. \tag{2}$$

$\rho^2 = 0.69$; coefficient and confidence interval of model (2) are shown in Table 4.

Table 3. GN classes before de-rubberizing

Class	GN	L_c [Gt]
1	0.94	1.00
2	0.91	1.00
3	0.88	1.00
4	0.85	1.04
5	0.82	1.27
6	0.79	1.41
7	0.76	1.46
8	0.73	2.02
9	0.70	3.07
10	0.67	3.34
11	0.63	3.54
12	0.60	3.57
13	0.57	3.35
14	0.55	2.29
15	0.51	2.61
16	0.48	2.91
17	0.45	3.10
18	0.42	3.10
19	0.39	3.02
20	0.36	3.23
21	0.33	3.31
22	0.29	3.37
23	0.26	3.39
24	0.24	3.48
25	0.20	3.71

Table 4. Coefficient and confidence interval of model (2)

Parameter	Estimate	Std. error	95% confidence interval	
			Lower bound	Upper bound
b_1	0.240	0.4\04	−0.595	1.076
b_2	−0.467	0.572	−1.651	0.717

2.2. Data Analysis after De-Rubberizing Operations

The GN detected with the Grip Tester, according to the calendar shown in Table 1, after the de-rubberizing operations, was organized into 17 classes with the same width of 0.03 in ΔGN (Table 5). 17 is the number of classes that produced the best statistically model (i.e. the higher coefficient of determination ρ^2 and the significance at 95%).

Through a multivariate regression analysis (*GN* as the dependent variable and L_c as the predictor), then model (3) was obtained:

$$GN = b_1 \cdot e^{b_2 \cdot L_c}. \tag{3}$$

$\rho^2 = 0.83$; coefficient and confidence interval of model (3) are shown in Table 6.

Table 5. GN classes after de-rubberizing

Class	GN	L_c [Gt]
1	0.75	3.89
2	0.72	3.75
3	0.69	3.93
4	0.66	3.86
5	0.63	3.84
6	0.60	3.83
7	0.57	3.91
8	0.54	4.44
9	0.51	4.25
10	0.48	4.30
11	0.44	4.05
12	0.41	4.23
13	0.38	4.58
14	0.35	4.68
15	0.32	5.01
16	0.29	4.93
17	0.26	4.97

Table 6. Coefficient and confidence interval of model (3)

Parameter	Estimate	Std. error	95% confidence interval	
			Lower bound	Upper bound
b_1	9.58	3.554	2.008	17.160
b_2	−0.698	0.091	−0.892	−0.504

2.3. Before-After De-Rubberizing Analysis

It is well known, that a good preventive maintenance allows the runway to have a good lifecycle. See for example a pavement decay curve with a proper preventive maintenance proposed in Fig. 7.

The rubberizing phenomenon in the areas of touchdown, if there are no periodic preventive maintenance actions, causes a sudden deterioration of the performance of the runway in terms of GN. In this regard, the Decay curve with preventive maintenance in Fig. 7 shows how a simple act of de-rubberizing in the touchdown zone, can bring the pavement surface to acceptable values of GN.

Specifically for this study, through the models (2) and (3) obtained in the previous paragraphs, it is possible to assess the degree of the benefit due to the action of de-rubberizing. Through Eq. (2), whose trend is shown in Fig. 8 (valid for values of cumulative load L_c belonging to the interval [1.00, 3.71]), it's possible to estimate the curve before de-rubberizing; through the Eq. (3), whose trend is shown in Fig. 9 (valid for values of cumulative load L_c belonging to the interval [3.75, 5.01]), it's possible to estimate the curve after de-rubberizing.

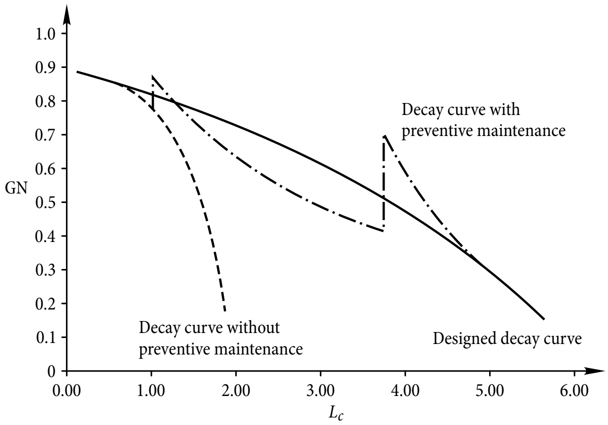

Fig. 7. Pavement decay curves

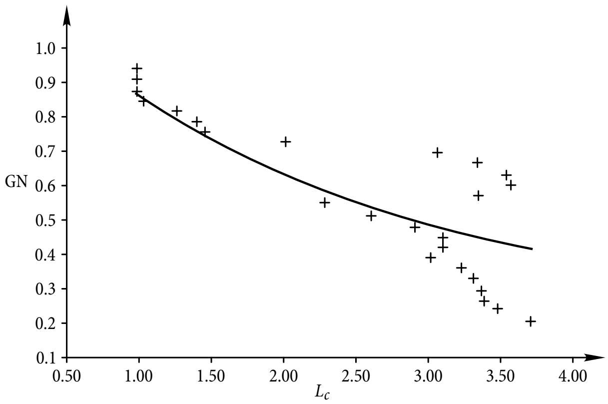

Fig. 8. GN versus L_c decay before de-rubberizing

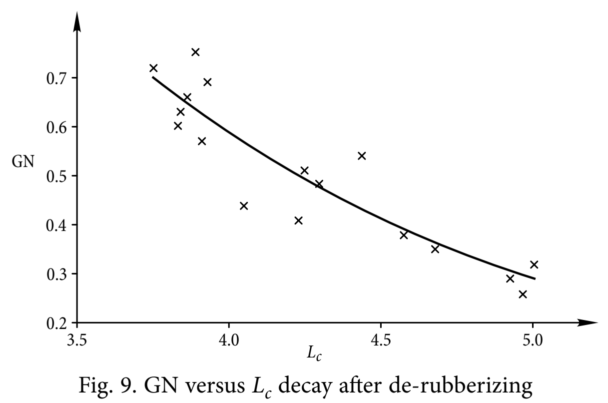

Fig. 9. GN versus L_c decay after de-rubberizing

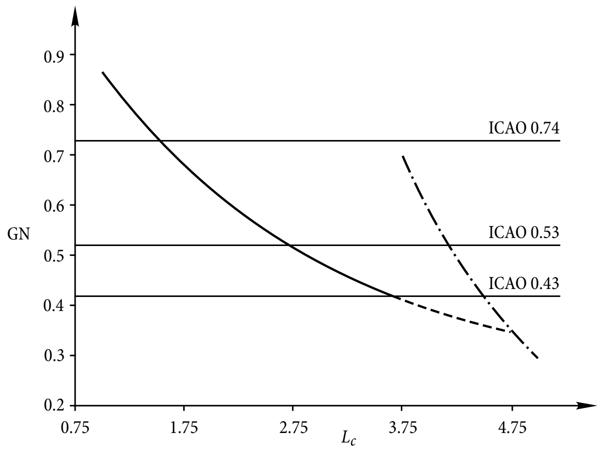

Fig. 10. GN: before–after decay

From the comparison of the two trends (Fig. 10) it can be evaluated as well as the benefit of degumming in terms of GN, also important information about the slope of the two curves; in fact, the second dashed curve GN after decreases faster than the first solid curve GN before. An explanation for this phenomenon of faster decrease of the curve GN After could be that the aggregates, even if the layers of rubber are cleaned up, are subjected to stress that compromises their structural and functional characteristics.

Conclusions

In this paper, a comparison was made between the functional characteristics of the runway before and after the operations of de-rubberizing.

In particular, in the touchdown areas, air traffic and GN (measured by Grip Tester) data were examined before de-rubberizing operations (from 1 January 2010 to 30 November 2011) and after de-rubberizing operations (from 1 November 2011 to December 31, 2012) and two models of decay as function of aircraft loads were obtained (Figs 8 and 9) characterized by good significance ($p < 0.05$) and by good coefficient of determination.

The comparison of the two models highlighted also that, even if the operations of de-rubberizing reported higher values of GN, the decay in the touchdown areas was characterized by greater speed than that before the de-rubberizing operation (Fig. 10).

The obtained models demonstrate that it is possible to predict with great accuracy the phenomenon of surface decay on the basis of air traffic and aircraft parameters, and how to do it. And therefore their usefulness as tools to design and update the Airport Pavement Management Systems, to plan maintenance operations, and to forecast the life cycle of runway pavement surface.

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