Coefficient of friction evaluation on Portuguese airports: The Lisbon airport

João Pedro Sousa Duarte
Instituto Superior Técnico, Lisbon, Portugal

Abstract: The adequate management and maintenance of an airport infrastructure is essential in order to assure its safe and economic operation. Pavements are responsible for the proper functioning of an airport, its deterioration is closely related to the occurrence of incidents and/or accidents which can be catastrophic and that is why several indicators were developed in order to assess the pavement condition and to define maintenance and rehabilitation actions. The introduction of Airport Pavement Management Systems allowed the airport authorities to maintain the safety conditions in a tight budget enabling the longer and economically sustainable preservation of a pavement. Together with ANA Aeroportos de Portugal and as a support to the implementation of a new pavement management system for the Lisbon international airport this research aimed to understand the skid resistance’s behavior for a specific runway. The analysis tried to understand the relation between skid resistance and its natural evolution, airplane traffic and any other problems reported and it was based on historical data from friction evaluation campaigns. Several unusual situations were found which led to trying to assess its causes and the way to mitigate them as well as to make some future recommendations on the best practices in managing future skid resistance issues.

Keywords: Coefficient of Friction; Texture; Airport Pavement Management Systems; Rubber Deposits.

1. INTRODUCTION

The air transportation sector is one of the main propellers of globalization providing individuals the possibility of getting together in a fast and easy way and by reaching virtually every corner of the globe. The peripheral localization of Portugal made it very dependent on air transportation and the Lisbon International Airport as the biggest airport infrastructure in the country has been the one which has required the most attention from everyone from air traffic related companies to politicians and economists.
The great development of aircraft technologies brought new challenges to the ones responsible for the airport management with stricter security regulations and tighter budgets. Big airports nowadays are more than a mere support for the transport of passengers and goods; they represent major areas for business, leisure and commerce with many employees and great economic revenues. However, the success of these activities is always closely related to the good performance of airplanes in their ground operations.

The costs of a disruption in the airport activity are huge and must be taken into account by the authorities responsible for the infrastructure. The runways are the most important area in an airport connected to the flights, allowing the take-off and landing of aircrafts, and any problem related to them can have catastrophic consequences not only from an economic point of view but also with loss of human lives. Airport and flight regulators have long been implementing Airport Pavement Management Systems (APMS) in order to allow the good operation at a reduced cost of every pavement in an airport including the runways.

Pavements suffer from the most diverse degradations which can be related to their natural evolution, to the deposition of pollutants like rubber or oil on their surface or to the adverse climatic conditions such as rain, snow or ice. Providing adequate friction conditions on a pavement surface is the aim of anyone responsible of its management.

At the Lisbon International Airport (ALS) under ANA aeroportos de Portugal (ANA Portuguese Airports) jurisdiction a new APMS is being implemented. As a support to this implementation the objective of this study is to understand and predict the behavior of the coefficient of friction on a runway at the ALS as well as trying to check for any serious problem affecting this coefficient or the pavement texture, two related factors. By doing this it can provide the responsible a tool to evaluate their system implementation and to easily understand the existing data and any problems that may occur.

The following sections deals with the pavements composition, main materials and the most common techniques used in today’s pavements whether it is for roads or airports. In order to be able to evaluate a pavement several factors are presented together with the equipments to collect the respective data and some reference values are exposed. After this theoretical introduction the next section presents the international regulations and recommendations followed by airport authorities worldwide in their pavement management activities. In this section, it is also presented a case-study with all the facts needed for a later analysis from the data recovery vehicle to the way the campaigns were made. In section 4 the results will be analyzed and discussed in order to assess the real conditions of the pavement and to predict any evolution based on historical data from the coefficient of friction and traffic. Finally a major conclusion is drawn on how the whole study was made and how the results were achieved and some suggestions for future actions are made.

2. STATE-OF-THE-ART

A pavement is a multi-layer structure which has the main aim of providing adequate conditions for vehicle circulation under different traffic and climate conditions throughout its lifecycle. To do so a pavement must comply with certain structural and
functional requirements such as the ability to withstand and dissipate vehicle loads and at the same time to provide a smooth, comfortable and economical circulation for its users.

Among the several layers of a pavement, it is the one on top that matters for users because of its properties and especially because it is the only one seen and perceived through the wheels of a vehicle. This top layer also called wear layer usually consists of a blend composed of mineral aggregate glued together with a binder. The binder’s nature defines the type of pavement which can be a flexible pavement if it uses asphalt (bitumen) or a rigid pavement if the binder is Portland cement. There is also a third type of pavement combining both asphalt concrete and Portland cement concrete, the so called semi-flexible pavements (Branco et al, 2008).

Depending on the materials employed on a pavement the quality and the use of the structure will be defined in terms of loads, traffic and extreme weather conditions.

Mineral aggregates form the skeleton of the pavement and so they must be clean, hard, sound and durable. It should also respect the requirements of a particle shape, adhesiveness to the binder and should also respect the gradation based on standardized sieves. Aggregates should be free from any clay or organic debris which prevents its coating with the binder.

Asphalt is a derivative of petroleum distillation and it has thermoplastic properties. At atmospheric temperatures it is semi-solid and waterproof but when heated at high temperatures it becomes liquid and easy to work with which makes it suitable to use as a binder mixed with aggregate despite its degradation in the presence of oxygen and sunlight. Asphalt is usually tested for its viscosity and penetration being this last property the one that defines an asphalt cement. The most commonly used asphalt cements in roads and airports in Portugal are the 35/50 and 50/70. Apart from the common asphalt other solutions based on this material are used such as emulsified or cutback asphalts which have the main purpose of improving the working conditions on its application and to improve the final solution in terms of its functionality.

Portland cement is a hydraulic binder made from non-organic material. It is commonly used in construction due to its good mechanical resistance. Usually a cement is classified for its compressive strength after 28 days in Mpa being the ones used in pavement construction from the classes 32,5, 42,5 or 52,5.

Combining the different materials it is possible to reach different paving solutions for different uses and environments. Among the most commonly used pavements there are the HMA (hot mix asphalt), porous asphalt, rough asphalt and the rigid pavements (Kraemer et al, 2004).
HMA has been the most applied solution for decades in roads and airports thanks to its general qualities, low cost and long service life but new solutions have appeared in order to improve the safety and economy of the users. Porous and rough asphalt solutions brought great improvements in safety under adverse weather conditions, especially with rain by providing better surface drainability.

Among the different characteristics of a pavement it is the surface characteristics that will matter most to its users and that is why pavement managing responsible worldwide have been working in order to evaluate and maintain these characteristics for the longest time possible under controlled budgets. Several characteristics such as noise, drainability, rubber deposits were studied and are currently a target of numerous programs of pavement management but it is the texture and friction coefficient that have a greater influence in terms of safety for the users and the ones deserving more attention.

Pavement texture has a major importance in wet-weather conditions since it allows the water to drain providing a better adherence between the tire and pavement surface. There are two types of texture affecting wet pavement friction: microtexture which is provided by the roughness of the aggregates and macrotexture provided by the aggregate gradation as it possible to see in figure 1 (FHWA, 2005). Different travel speeds will require different types of textures, if on the one hand macrotexture is essential for vehicles travelling at high-speeds such as in freeways or airport runways by allowing the tire deformation on the other hand it is the microtexture that provides grip at lower speeds.

![Figure 1 – Macrotexture and Microtexture (PIARC, 2003).](image)

To evaluate a pavement texture there are several techniques available on the market but the ones mostly used are the Volumetric Patch Technique and the use of Surface Profiles. The first one uses a predefined amount of glass spheres to determine the average depth of pavement surface macrotexture while the second technique uses a laser mounted on a vehicle. Both techniques have drawbacks in terms of their use but these are the ones that have the most application worldwide (Gothié, 2008).

Friction enables vehicles to accelerate, decelerate and change direction and therefore it is essential to allow vehicle maneuverability and for its safety. The contact between tire
and pavement it is essential to provide enough grip allowing tires to roll and at the same time not letting them slip under unusual circumstances and it depends on vehicle characteristics (vehicle load, tire conditions), surface characteristics (both macro and microtexture) and on weather conditions.

Friction can be divided into two different components: the longitudinal friction that allows vehicles to accelerate and decelerate in a straight line and the transversal friction that allows vehicles to change direction. If the second component is essential for roads and freeways it is the first one that matters for runways on airports due to the high circulation speeds.

Along the time, friction coefficient tends to vary as the surface suffers mechanical wear and tear from tires, or contaminants settling and filling the texture. During its lifecycle friction tends to reduce but annually there are some negative variations that need to be taken into account such as the accumulation of pollutants on dry weather and the presence of rain, snow or ice during winter (Pavestech, 2007).

Several test vehicles have been developed to assess friction conditions. These vehicles usually use a partially locked test wheel and all of them evaluate wet skid resistance. SCRIM and Griptester are the two equipments with most application worldwide. However for airport use some specific equipments were developed due to the particular characteristics of runways. Among those is the Airport Surface Friction Tester (ASFT) is one of the most used.

3. CASE STUDY DESCRIPTION

As a support for pavement assessment air transport regulators have established several guidelines to help pavement design and maintenance. Entities like the FAA (Federal Aviation Administration) or ICAO (International Civil Aviation Organization) developed reference documents such as the Annex 14 and Advisory Circular 150/5320-12C which serve as manuals for pavement maintenance.

The documents cited work as a reference in which it is recommended for an airport like the ALS that at least 4 friction evaluation campaigns should be taken every year (FAA, 1997). The test vehicle should have a locked test wheel with between 10% and 20% of slip and there must be an automatic water deployment device so wet skid resistance can be measured. It should also be able to conduct measurements at two different speeds (65km/h and 95km/h) in order to evaluate both macro and microtexture and finally it should record friction averages for at least 100m.

The way campaigns are taken is also relevant for the evaluation of pavement condition. To cover all the runway width measurements should be taken at longitudinal tracks
spaced 3m and 5m on both sides of the centre line. Test vehicle runs should be taken in both directions to avoid construction related problems and the runway should be divided into three equal length portions to differentiate the take-off and landing areas from the remaining areas. ICAO has also defined three friction levels: design level which is the minimum friction level for newly constructed/resurfaced runways; maintenance level which marks the minimum level before maintenance should be considered; minimum friction level shows which corrective measures should be taken as soon as possible (ICAO, 2009).

For this study the main runway of Lisbon International Airport, the 03-21, was chosen because it is the representative of the remaining runways in Portuguese airports. It is the one that receives the most traffic and since the ALS is the biggest airport in the country it is also the most likely to cause greater problems. The runway is 3805m long, 45m width and the pavement structure is composed of 3 layers of HMA. In terms of traffic for the study period the 03 direction received around 213,000 movements between landings and take-offs and the 21 direction received around 58,000 movements (landings and take-offs).

The test vehicle was an ASFT with 12% of the slip ratio provided by a suspended weight of 140kg that was calibrated previously to every campaign. The measurement speeds were 65lm/h and 95km/h and there was a 1mm layer of water. The vehicle was able to adjust the speed and the depth of the water layer automatically as well as process the data and reproduce wet friction averages for every 10m, 100m and a third of the runway length.

Friction evaluation campaigns took place on October 2008 and March, June and October 2009. Only in the last two campaigns both speeds were recorded. Given that ANA only has one test vehicle, it was not possible to run all the 4 campaigns predicted. In this campaigns the runway was split into 6 different parallel tracks (4 at the speed of 95km/h) spaced 1,5m and on both sides of the centre line.

4. RESULTS AND ANALYSIS

After the compilation of the wet friction data from the evaluation campaigns was taken, it needed to be analyzed in order to understand the behavior of this parameter and if there were any problems related to it.

In the first analyze the runway was evaluated as divided into 3 equal distance parts and based on the 3 friction levels, as suggested in Annex 14 from ICAO. At this point the whole runway presented good values of friction for all the campaigns at both speeds, the only exception was the section near the threshold 03 and close to the centre line where values below the maintenance level were recorded in two campaigns at the
lowest speed (figure 2). Generally, it was possible to understand that the lowest friction values were taken on the left side near the centre line and closer to the threshold 03. The average for every longitudinal track, transversal section and for the whole runway was over maintenance level and sometimes even better than the design level. It was also analyzed the data dispersion of each section which pointed out to the fact that the tracks closer to the centre line presented less variation than the ones further away which can be related to its higher use.

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**Figure 2 – Average friction for each third of the runway at 65km/h on June 2009.**

From this point a more refined analysis needed to be taken since the results did not express what was really noticeable by the users (pilots). The Annex 14 claims that if it is needed sections with at least 100m long can also be analyzed and so it was done. At this point problems began to arise specially in sections where previously good average results were recorded. In most of the runway good friction values remained but for the area already pointed out near the threshold 03 more sections below the maintenance level began to appear not only on the left side track closer to the centre but also on each of the first 3 tracks on each side and for every campaign. Where previously there had been recorded values below the maintenance level now it was possible to see some sections presenting values below the minimum friction level and where prompt interventions should be scheduled. At this point no major differences were perceptible between the results of both measuring speeds.

Although 100m is the shortest distance recommended for the evaluation when looking at the results sheets it is possible to find some particular points usually at the same distance and on both sides of the runway where extreme low values of friction were recorded. By its symmetry is possible that such observations are related to the horizontal marking on the runway which may indicate problems with those markings especially with the paint employed.

Rubber deposition is a big concern at any big airport and so rubber removal works are regularly scheduled at least once per year. On this basis, during this study period 3 of
these actions took place promoted by ANA. The first one was made previously to the friction measuring campaign of June 2008. The other two took place on October 2008 and September 2009. The October 2008 campaign was an experimental action to test a new rubber removal product.

Following this first analyze in which several areas of the runway presented problems it was time to evaluate the evolution of the pavement’s wet friction. As such, variations between different campaigns for the longitudinal tracks were evaluated as well as variations between consecutive campaigns for the entire pavement of the runway. The last thing was trying to understand the relation between wet friction evolution and the traffic on the runway.

The comparison of the data for each track analyzed has allowed understanding friction behavior with time. Once again, it was possible to distinguish the behavior between the inside tracks and the outside ones. Closer to the centre line the friction tends to vary in a similar way from campaign to campaign even if an intervention was taken on the runway. The reproduction of low friction areas such as the ones on the threshold 03 is quiet perceptible and therefore it is possible to make forecasts on future evolutions of this parameter. As we move towards the edge of the runway the results become less predictable with different variations on the same track and even some unexpected values of friction. The differences observed and as mentioned on previous analyzes might be related to the fact that the inner areas of the runway are usually the one’s most used than the outer ones a factor that can make the pavement conditions more homogeneous and predictable.

In a pavement that has not been intervened the natural evolution of the wet friction is to decrease due to wear and tear of its materials. However, if a rubber removal action has been taken it is suppose to increase wet friction on the pavement. Analyzing between consecutive campaigns made it possible to find two different behaviors according to the test speed. At 65km/h friction tended to follow the expected behavior referred. Between campaigns when no intervention was taken friction values usually decrease but if a rubber removal action occurred then friction either increases or stays the same value.

Compared to the lower test speed values recorded at 95km/h it did not follow an expected variation. Between the first two campaigns when friction should have decreased it was possible to observe a general rise of this coefficient. For the following campaigns a mixed behavior was observed for the two different sides of the runway although the whole runway has seen its friction values increase which is in accordance to the intervention taken.
The distinct behaviors for the two different speeds may show problems with the pavement texture mainly the macrotexture since the unexpected values occurred for the highest speed but it may as well be related to the time of year when the campaigns were made. Rain fall previously to a campaign which has to do with the cleanliness of the pavement or the air temperature that influences the adhesiveness between tire and pavement are two factors that can influence the recorded values of wet friction but since no meteorological data was provided it was not possible to assess the exact cause of such variations.

The last analyze taken was to understand the traffic influence on the wet friction degradation. In this sense and based on the previous analyze it was chosen two consecutive campaigns at the speed of 65km/h where no interventions were made. To get a wider perspective of the pavement condition distinct points of the pavement were chosen. The touchdown area of the threshold 03 was the most degraded area but it soon became clear that the problems found for this section were due to the highest amount of landings and take-offs when compared to the remaining pavement (almost 3 times more compared to the threshold 21). As observed before, the pavement has a different behavior according to which side of the centre line is under analyze being the left one the most affected by traffic actions. One of the conclusions drawn was the fact that the threshold 21 was the area of pavement that most suffers with traffic. This might be related to pavement degradation provided by rubber removal actions since it is subjected to less traffic than the threshold 03 but some of the cleaning actions are made on a periodically basis and it can destroy part of the wear layer.

5. CONCLUSION AND RECOMMENDATIONS

In order to provide the best service quality at an international airport like the ALS it is essential to maintain all the sectors fully functioning from the flying operations to the shopping areas. With the increasing significance of air transportation in world development all the main actors must be involved in a search for trying to provide the best service at a reasonable price. Since pavements are one of the main infrastructures at an airport special management areas are responsible to maintain their quality and to ensure that they are always available to use. Similarly to what happened for road pavements, APMS’s have been designed and implemented. On that propose this work has been made as complementary to the introduction of a new APMS to the Portuguese airport network.

Following international recommendations several factors are regularly inspected and analyzed to assess pavement quality and to define any intervention. Being the wet friction one of the main factors that need to be evaluated in order to have a good quality accident free pavement it was the parameter analyzed for the main runway of the ALS, the case study.
On a first less refined approach the pavement seemed to have a good general quality in both test speeds, with only a few sections needing to have some considered maintenance actions. With a narrower analyze this perspective changed and the runway started to present several areas deeply degraded especially near the threshold 03 on both sides of the centre line but with more concern to the left side where the sections were in need of immediate corrective measures started to appear. The areas more affected by traffic, like the one already referred and the longitudinal section alongside the whole centre line were the ones that presented the lower friction values especially at the test speed of 65km/h.

Several sections with extreme low values of friction where detected on the outer tracks of the runway and usually with some symmetry to the centre line which may indicate problems with the horizontal pavement markings. Rubber removal actions have also taken place during the study period which indicates that this common phenomenon on runways is occurring on this pavement but at the same time actions like the ones referred can affect the final results here exposed.

In the course of time, the expected evolution of wet friction is its decrease due to natural and traffic related wear and tear as long as no improvement intervention had yet been taken. It was possible to observe two different behaviors for the two different test speeds which may indicate different evolutions for each one. The results for the lower speed tended to be more predictable and in accordance to the natural expectations as opposed to the ones for the higher speed. The comparison between the different pavement sections showed that the more used areas of the pavement despite being the most degraded are also the ones that presented the most homogeneous values with similar evolution from campaign to campaign. This fact might be due to the more intense use by the aircrafts and it was independent of the test speed. Finally it was found that there are some areas suffering a more intense degradation despite the lower traffic which may be related to an inadequate programming of pavement interventions that can affect its structure.

In future developments a wider data base including different parameters such as texture and other surface characteristics should be used in order to better assess the pavement friction conditions and to predict the evolution of this parameter. The continuous study of the pavement is essential for a better management of the infrastructure and unlike this study it should always include the economic factor because it can never be dissociated from any management action. Friction assessment campaigns should be done more regularly to better schedule any intervention and these should be made for the sections in need and not for the whole pavement so it does not affect the structure of the wear layer.
Bibliography


