Abstract

The pavement's wearing course has the function of assuring a safe, comfortable and economic travel to its users. To fulfill that purpose it is necessary that its functional properties, such as the coefficient of friction and texture depth, present good levels, especially in adverse weather and drivability conditions. In the last few years it has been given a greater importance to the pavement's surface characteristics, resulting in the improvement of asphaltic material's performance and in the arising of new techniques.

Two practical case studies are presented: one concerning the application of anti skid surfacing, where surveys were made to evaluate the functional properties of the wearing course, and another with the purpose of analyzing the coefficient of friction before and after the improvement with shot blasting. From the analysis of the results, it is clear the improvement of the functional properties (coefficient of friction and texture depth) in comparison with standard bituminous concrete pavement. Therefore it is possible to conclude that both solutions introduce gains in skidding resistance, allowing pavement to be safer.

1 – Initial Considerations

Asphalt mixtures applied in wearing course act as structural and functional prevailing the functional characteristics (coefficient of friction, texture depth, evenness and tire-pavement noise) when regarding a safe and comfortable travel. There has been a development in asphalt mixtures and new techniques of pavement's functional rehabilitation in recent years, with the aim of improving the pavement performance.

In Portugal the more common asphalt mixtures for flexible wearing courses are bituminous concrete, porous asphalt concrete, friction asphalt concrete and ultra-thin asphalt concrete layer, being the application of the bituminous concrete the most generalized.

With the intent of improving existing bitumen’s properties afterwards emerged the modified bitumen with polymers, most commonly used in porous and friction asphalt concrete. More recently it come up the modified bitumen with rubber (MRB), used mainly in friction asphalt concrete and open texture surfaces.
By comparing the coefficient of friction values of a bituminous concrete with other wearing courses (Table 1.1), these last often present minor results, with the consequence that nowadays, in new roads, bituminous concrete has been replaced by other techniques that provide better functional performance.

New techniques, like anti-skid surfacing and shot blasting, originate important benefits in tire/pavement adhesion, in decrease wear, followed by faster and less expensive applications, providing these way better results.

Traffic safety can be evaluated through the analysis of the coefficient of friction and the texture depth. During the road’s life, these parameters should be monitored frequently, in order to follow their evolution and asset the network performance. Consequently, new methods and properties standards were developed with respect to the pavement’s surface.

The functional properties of the pavement can be measured through a wide range of methods and equipments. Measurement can be made in continuous (dynamic methods) or in a specific point (static methods). Selecting the most appropriate technique depends on the survey’s objectives: the static method is recommend to evaluate a more confined area of the pavement, for example a zone more prone to accidents; whereas for pavement’s maintenance it is usual to choose dynamic methods.

Low skid resistance is not the only cause of accidents, but can have an important contribution. When the road is slippery the risk of losing control is higher than in a regular situation. However, the challenge is to relate accident risk with pavement’s properties, allowing references to be established regarding road maintenance and construction, to guarantee safety.

### 2 – Anti-skidding surfacing. Case study

Anti-skidding surfacing is a technique applied on pavement’s wearing course, not being necessary any structural intervention, if the structure is in good conditions. This is an easy application technique and when using alternated lanes, it results in minimum constrains of traffic.

In Portugal, the anti-skidding surfacing is a recent technique developed to improve tire/pavement adhesion. In other countries, such as the United Kingdom, this pavement is used to prevent accidents, and it is certified.

<table>
<thead>
<tr>
<th>Wearing course type</th>
<th>Conditions</th>
<th>GN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bituminous concrete</td>
<td>3 – 8 years in service</td>
<td>0.40 – 0.70</td>
</tr>
<tr>
<td>Porous asphalt concrete</td>
<td>New</td>
<td>0.80 – 0.90</td>
</tr>
<tr>
<td>Open textured mixtures with MRB</td>
<td>5 years in service</td>
<td>0.60 – 0.70</td>
</tr>
<tr>
<td>Friction asphalt concrete layer</td>
<td>3 – 8 years in service</td>
<td>0.50 – 0.65</td>
</tr>
</tbody>
</table>

Table 1.1 – Examples of coefficient of friction results on roads, measured with “Grip-Tester” (50 km/h; 0.5 mm film of water) [Antunes, 2006].
Due to the good results obtained when resisting skidding, the anti-skidding surfacing can be a good solution in areas prone to accidents or potentially dangerous in order to reduce accidents. Increasing the coefficient of friction, the tire-pavement adhesion improves, preventing loss of control and diminishing accidents.

2.1 – Site work description

To study the anti-skidding surfacing experiments were conducted on two Sintra’s municipal roads where this technique was applied: EM 603 and EM 539-2.

EM 603 connects Várzea de Sintra and Magoito, has two lanes, one in each direction, low traffic flow and bituminous concrete wearing course. The application of the anti-skidding surfacing was made in September 2007, on an extension of about 300 m, mainly in curve (Picture 2.1). The occurrence of accidents led Sintra’s Municipal Council to intervene, deciding to apply this anti-skidding surfacing to reduce the number of accidents that happened in the curve. The main cause of the registered accidents was speed in excess, considering the type and the geometry of the road.

The second case study is about the EM 539-2, situated between Venda do Pinheiro and Negrais, and the application of the anti-skidding surfacing was made in May 2008. Like the previous case, the pavement on which this solution was applied was a bituminous concrete. This road has two lanes, one in each direction, again mainly curve (Picture 2.2). About 100 m after the curve in the Negrais direction there is a pedestrian’s crossroad. The new pavement was a request of Sintra’s Municipal Council to enhance vehicle adhesion to the pavement, increasing friction in the curve and near the pedestrian’s crossroad, to prevent accidents.

However, one considers that the application on the pavement should have been extended for some more meters, up to the pedestrian’s crossroad in the Negrais direction to increase friction, reducing the breaking distance, as well as in the opposite direction, where the anti skidding surfacing should start before the curve initiates, for a trajectory with better adhesion. By observation it was concluded that this road has a high traffic flow, of which a considerable percentage are heavy vehicles.
In both sites the application of the anti-skidding surfacing was made cold and by hand. The anti-skidding surfacing was applied on the asphalt pavement, using a two component polyurethane resin and a granite aggregate with an even size, both with red color, being the resulting thickness 4 mm (Picture 2.3).

![Picture 2.3 – Application of the anti-skidding surfacing: resin and aggregate dispersing](image)

### 2.2- Tests

This paper purpose is to evaluate the functional properties of the anti-skidding surfacing by measuring coefficient of friction and texture’s depth using standard methods. The equipment that was used was made available by the Laboratório de Vias de Comunicação of IST. To measure the coefficient of friction the British Pendulum was used and to determinate the texture depth was made the Sand Patch Test. In each section were made two tests with each equipment: in the right wheel path rut, where the friction has a tendency to be unfavorable due to the traffic, and in the middle of the lane for comparison.

The survey on EM 603 was made seven months after the application of the anti-skidding surfacing. Three segments were chosen for tests: the first one located on the old bituminous concrete, just before the anti-skidding surfacing, as a representation of existing conditions prior to the application of the new pavement; the other two were conducted on the anti-skidding surfacing in different road geometry conditions – one in a straight alignment and the other one in a curve. Both tests were conducted in Várzea de Sintra direction, which corresponds to the curve’s soffit (Picture 2.1).

<table>
<thead>
<tr>
<th></th>
<th>Friction (PTV)</th>
<th>Temperature (ºC)</th>
<th>Corrected Friction PTV</th>
<th>Texture (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old Pavement</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rut</td>
<td>0.60</td>
<td>18</td>
<td>0.59</td>
<td>0.75</td>
</tr>
<tr>
<td>1/2 of Lane</td>
<td>0.45</td>
<td>20</td>
<td>0.45</td>
<td>-</td>
</tr>
<tr>
<td>Anti Skid surf, Str. Line</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rut</td>
<td>0.69</td>
<td>17</td>
<td>0.68</td>
<td>1.50</td>
</tr>
<tr>
<td>1/2 of Lane</td>
<td>0.70</td>
<td>17</td>
<td>0.69</td>
<td>1.51</td>
</tr>
<tr>
<td>Anti Skid Curve</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rut</td>
<td>0.70</td>
<td>22</td>
<td>0.70</td>
<td>1.45</td>
</tr>
<tr>
<td>1/2 of Lane</td>
<td>0.68</td>
<td>20</td>
<td>0.68</td>
<td>1.30</td>
</tr>
</tbody>
</table>

In EM 539-2 were chosen three points for trials (5 m apart from each other) all of them in the portion of the road with the anti-skidding surfacing. It wasn’t possible to conduct any tests on the curve, due to high traffic flow and poor visibility. These tests were made two months after the application of the new pavement. The choice to perform three tests in zones with similar characteristics served to amplify the sample and produce more consistent conclusions. Picture 2.2 shows the results.
2.3 – Analysis of the results

From examining Picture 2.4 it is evident the coefficient of friction increment after the application of the anti skidding surfacing on the bituminous concrete. Contrary to what would be expected, one can see that friction on the wheel path rut area isn’t always lower than in the middle of the lane, which may be due to drivers trajectory. The same justification is adequate to the bituminous concrete because the tests were conducted near an intersection and the wheel path rut wasn’t well defined.

By comparing the tests results with the reference values for the coefficient of friction referred in the Portuguese Specifications Manual of Roads (0,55 PTV) [EP, 1998], one verifies that friction on the old pavement was below minimum recommended values. The application of the new pavement shows good results, with values 25% higher than the reference. If comparing with the old pavement, the anti skidding surfacing brought an improvement of approximately 15% in the wheel path rut section and 50% in the middle of the lane, which represents considerable results.

The surface properties of the EM 539-2 were evaluated in the beginning of its usage, when pavement was two months old, while on EM 603 trials were conducted seven months after opening to traffic. Picture 2.5 shows a 12% difference between the two situations, which can be explained by the five months period between the two applications. Despite the concern of choosing two road segments with similar geometry and identical surfacing, there are some significant differences between the two situations: traffic flow is clearly higher in EM 539-2 and the longitudinal gradient is also different. For a more thorough and realistic study the same

### Table 2.2 – British Pendulum and the Sand Patch tests results in EM 539-2.

<table>
<thead>
<tr>
<th></th>
<th>Friction (PTV)</th>
<th>Temperature (ºC)</th>
<th>Corrected Friction PTV</th>
<th>Texture (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anti Skid surf. Str. Line 1st point</td>
<td>Rut 0,77</td>
<td>43</td>
<td>0,80</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1/2 of Lane</td>
<td></td>
<td></td>
<td>1,70</td>
</tr>
<tr>
<td>Anti Skid surf. Str. Line 2nd point</td>
<td>Rut 0,67</td>
<td>42</td>
<td>0,70</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1/2 of Lane</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anti Skid surf. Str. Line 3rd point</td>
<td>Rut 0,75</td>
<td>41</td>
<td>0,78</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1/2 of Lane</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Picture 2.4 – Coefficient of friction in EM 603.

Picture 2.5 – Coefficient of friction in the straight alignment in the EM 603 and EM 539-2.
pavement should be monitored during its life, or using a similar situation in every aspect. Another concern might be the fact that tests must be conducted always in the same period of the year, to prevent seasonality’s influence in the pavement characteristics.

In EM 603, one verifies a clear texture increase when comparing the old bituminous concrete pavement with the anti skidding surfacing (Picture 2.6). On the wheel path rut, in the straight alignment, the increase was of 100% -1,5 mm depth, a very good result. The texture depth of the anti skidding surfacing in the middle of the lane is slightly different when in a curve or in a straight alignment, which can result from a higher pavement wear caused by the centrifugal force in the curve’s trajectory. Like friction, texture depth in the wheel path rut, in the curved section, presents higher values than in the middle of the lane, which can be explain by the location of the wheel path rut not being equal in a curve or in a straight alignment. As would be expected, one finds a relationship between friction and texture depth’s values: in the areas with higher friction, pavement’s texture presents higher values, and in the areas with lesser friction, texture depth is lower. This can be proven by examining Picture 2.4 and 2.6.

By comparing texture depth values before the intervention with 0,6 mm, which is the minimum value recommended in specifications [EP, 1998], for bituminous concrete wearing course, one verifies that the existing texture’s depth of 0,75 mm is above the minimum. In regard to the anti skidding surfacing there aren’t any reference values yet, but it is possible to use the minimum value for the friction asphalt concrete as a reference, for their similarity. So, all texture depth measurements results in values higher than 1,0 mm, the stipulated value in specifications [EP, 1998]. Texture depth in the wheel path rut, for the straight alignment is 70% and 50% higher than the stipulated value, for EM 539-2 and EM 603 respectively. This difference can again be explained by the five months gap between applications.

3 – Study of a bituminous concrete pavement after the shot blasting application

Shot blasting is a superficial treatment consisting of shooting steel spheres with a certain speed onto the pavement’s surfacing, to cause its pickling. This method changes the surface micro texture property, and improves adhesion conditions (Picture 3.1).

Shot 3.1 – Shot blasting [Ferreira, 2007].
3.1- Data collection

For this work it was used data from two experiments made by LNEC: coefficient of friction measurements before and after the shot blasting application in a bituminous concrete surface, on a road in the Lisbon area. The shot blasting application was made in November 2006 and measures prior to this procedure were made in February of the same year, and the ones post application were made in February 2007.

For measuring tire/pavement coefficient of friction it was used the Grip Tester equipment from LNEC, which measures the coefficient of longitudinal friction, continuously, presenting the average GN results by sections of 10m. Two alignments that coincide with the right wheel path rut in the outer lanes in both directions were experimented, for a total extension of about 12740 m in each direction. The adopted survey conditions were: nominal speed of 50 km/h and to simulate a wet pavement surface it was used a water film of 0,50 mm.

3.2 – Analysis of the results

One can observe from tests results that speed values aren’t constant because it wasn’t possible to maintain 50 km/h during tests, due to traffic conditions and traffic lights. Since the friction is related to the test speed, for low speeds, friction is higher, so one chose to eliminate test results with speeds below 40 km/h. This 40 km/h speed was chosen because one thinks there are no significant differences between friction values in this speed range. By withdraw test results that were conducted at a lower speed makes the analysis more realistic.

In Pictures 3.2 and 3.3 are the charts that show average friction values and the respective test speeds, for 500 m segments, already without the low speeds. Results reveal that friction values after shot blasting are higher than the initial ones. It is still observed that the two curves (friction before and after) keep similar trajectories, and the increase or decrease of one, is followed by the other, for several sections except in specific situations. Even so, although there is an increase in friction after shot blasting application, it isn’t constant.

Picture 3.2 and 3.3 – Average coefficient of friction values and average speed values in 500 m segments before and after the shot blasting application; without lower speeds, in directions A/B and B/A
In the direction A/B the initial friction's curve is quite regular, with an average speed value of 0.61 and a standard deviation of 0.55, with the exception of the segment between 6000 and 8000 m, where it shows a slight coefficient of friction increase. Regarding the results curve after the shot blasting application, it was registered, as already mentioned, an increase in the friction values, being the average value of 0.77 and the standard deviation of 0.07, with a more irregular curve. In the B/A direction both curves are irregular, with a standard deviation of 0.07 and average friction values of 0.58 and 0.78, respectively before and after shot blasting.

Portuguese Specifications of the Roads [EP, 1998] indicate a friction value of 0.45 in tests conducted with the Grip Tester for a test speed of 50 km/h. Average friction value before shot blasting in the A/B direction was satisfactory, obeying the stipulated limit. In the B/A direction average friction value is lower, and yet above the stipulated value in the specifications. Although the limit values of the specifications are respected, after the site observation it was considered necessary to intervene and improve the tire/pavement adhesion conditions, so the stipulated value might be low demanding. With shot blasting application on the pavement, friction increase to values over 0.70, which is very good.

It was given special attention to the analysis of friction in zones of pedestrian crossroads and traffic lights, in order to understand if the available pavement conditions in these sensible areas, where is required frequent breaking, would be in the acceptable limits values. It was observed that average friction values in these areas, before the intervention, were clearly below registered average and near the limit value stipulated in the specifications. This situation might be the result of a higher wear in these areas due to countless daily stops; however it is precisely in these zones that one should be more demanding to prevent accidents by lacking friction mobilization.

As would be expected average friction variation after the shot blasting application varies depending on friction initial value. In Picture 3.4 there are represented the initial friction values sort by growing order and the respective average variations for each friction value, in the B/A direction. It shows that the friction variation is conversely proportional to the initial friction value, which means that, as long as the initial friction values increase, its variation values decrease. When pavement's initial friction has high values, the friction addition is relatively low, opposite when initial friction values are low, in which cases shot blasting application will increase friction significantly.

![Picture 3.4](image-url)
Some negative variations were observed when the initial friction is very high (above 0.70). These initial high values might be the situations where the pavement is degraded and the friction increases significantly, but by applying the shot blasting the degradations are well disguised making the friction lesser and consequently the variation is negative.

To evaluate friction evolution after the shot blasting application it is necessary to conduct more tests and so verify for how long this characteristic keeps high values, so it is competitive comparing with other techniques.

3.3 - Casualties in the study case

Road safety has been a constant concern of Road Agencies. Reducing casualties has led to several infrastructures interventions – signalization, road geometry, and pavement functional properties. Shot blasting application in this road segment is an example of an action made with the intention of increasing skidding resistance and consequently reducing the number of accidents.

After careful analysis of road accidents with fatal and serious casualties data obtained in the National Authority for Road Safety [ANSR, 2004-2007], occurred between 2004 and 2007, there is a general decrease in the number of fatalities; in 2007 (already after shot blasting application), there are no records of fatal accidents in this road segment. Records relative to accidents with serious injuries aren’t so positive, and although one can see a decrease between 2004 and 2005, there is a significant increase the following year, and once more a decrease in 2007.

By simple math it is possible to compare accidents average with fatal victims and serious injured registered before and after shot blasting application - approximately 19 accidents a year to 14. Though it is not possible to impute, for certain, the cause of this decrease to the improvement of the surfacing properties, one thinks that it had an important contribution to the increase of road safety.

From registered accidents (Picture 3.5) the ones that can be easily linked to the lack of skid resistance are loss of control, collisions with moving vehicles and running over pedestrians, coincidently the ones that occurred more often. One considers that some of these accidents might have been avoided if there were a higher skid resistance and one hopes that the new friction after the shot blasting application might contribute to that effect.
4 - Conclusions

From the analysis of the two study cases, one concludes that in both situations there was a substantial improvement of the pavement's functional properties (coefficient of friction and texture depth), when comparing with the existing bituminous concrete. This fact led to the consideration that anti skidding surfacing and shot blasting constitutes good solutions to improve tire/pavement adhesion conditions and in this way help pavement become safer.

Friction and texture depth values that were obtained in tests after the improvements are far superior to the Portuguese Specifications in Roads. It was possible to verify that in both cases coefficient of friction and texture depth prior to the interventions already respected stipulated limits, which can mean that reference values are low demanding in situations where risk of accident by skidding is higher (small radius curves, descendent gradient or approaching to pedestrian crossroads).

One verifies that texture depth increase usually corresponds to a friction increase, because it improves pavement’s macrotexture.

Comparing with the results of other wearing course solutions, these two techniques may achieve far superior skidding resistance results.

In Portugal there are other wearing course solutions that show good functional properties – porous asphalt concrete, mixtures with modified rubber bitumen and friction asphalt concrete mixtures. It is necessary, however, to monitor frequently the pavement to evaluate long term behavior, facing traffic and adverse weather conditions.

References

