Performance of shotblasting as a pavement preservation technique

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ABSTRACT

Skid resistance is an important aspect of pavement preservation that enables road authorities to be proactive in efficient and effective pavement management. At present, multiple treatments are applied worldwide as part of preventive maintenance programs in order to restore and combat deficient skid resistance on asphalt pavement surfaces. Amongst these treatments, shotblasting has been introduced as an effective technique for the restoration of skid resistance. Its main characteristics include its simple structure, convenient operation, high working efficiency and it is environmentally friendly, in that it is a dust free process that recycles all materials used and generated by the process. The present study aims to evaluate the long term performance of shotblasting as a pavement preservation technique. Friction and macrotexture data were collected periodically after the application of the shotblasting in multiple site sections along a motorway under investigation. The collected data was comparatively analyzed with respect to the time after the application of the shotblasting treatment, while taking into consideration the effect of the seasonal variations on skid resistance levels. The analysis results demonstrated that the overall "*good effect*" of shotblasting has duration. However the crucial issue surrounding the effect of seasonal variations on skid resistance is not resolved by implementing the shotblasting technique and this is a matter of major concern. More findings and details are included in the paper.

BACKGROUND AND OBJECTIVES

Pavement skid resistance plays a significant role in road safety as it is a critical contributing factor in reducing potential accidents. Its importance has increased over the years due to increased demands for safer and comfortable roads. Pavement surfaces must ensure adequate levels of skid resistance for the vehicles in order to perform safe manoeuvres. As skid resistance of a pavement surface decreases, the accident rate increases *(1)*. This road safety issue is further amplified on wet pavements because the contact between the tires and the road is reduced and the water acts as a lubricant *(2)*. Numerous studies have demonstrated the significant safety benefits of a targeted approach to improving skid resistance in high risk areas where frequent braking takes place, rather than attempting to improve skid resistance to high levels over the whole network *(3)*. The resistance to skidding is therefore one of the fundamental requirements that road engineers must consider in pavement design to provide a safe travelled surface.

Skid resistance has long been recognized as the primary factor controlling vehicle direction and speed, as well as ensuring short braking distances. Lack of tire to road friction which leads to skidding is one of the most important factors of traffic accident potential *(4)*. Slippery pavements are the result of several causes, chief of which is the loss of both pavement surface micro and macrotexture. Therefore, pavements must provide an adequate level of skid resistance, and consequently microtexture and macrotexture, so that the users are able to avoid skidding and loss of control of their vehicle. With the passage of time due to traffic loads, weather conditions and ageing of materials, pavement maintenance or rehabilitation is required in order to restore pavement condition to its initial level or to newly acceptable functional level, in terms of skid resistance.

Skid resistance is an aspect of pavement preservation (*5*, *6*, *7*) that enables road authorities to be proactive in efficient and effective pavement management. Construction budgets cannot keep up with the demands of an aging infrastructure and as a result pavement preservation is very important. On this basis, multiple treatments are applied worldwide as part of a preventive maintenance program (*8*) to combat deficient skid resistance of asphalt pavement surfaces. Slurry sealing, chip sealing, microsurfacing, and resurfacing are all common treatments for improving surface properties and sometimes the pavement structural condition (9, *10*, *11*, *1*2, *13*, *14)*.

In addition, road authorities have been seeking innovative, low cost methods, without the need for road closure to maintain skid resistance at acceptable levels. With respect to these demands various methods are used in order to restore pavement skid resistance by retexturing the existing surface with either a surface treatment, chemical treatment or a mechanical process (*15*). Amongst these methods, shotblasting has been introduced as an effective process for the restoration of skid resistance. It has the advantages of a simple structure, convenient operation, high working efficiency, dust free and is environmentally sound.

Typically the performance of shotblasting has been reported as good *(16)*. However the service life of shotblasting applied to asphalt-surfaced pavements in the appropriate skid resistance condition appears to be dependent on the abrasion resistance of the aggregate in the pavement on which it is applied. This makes the task of assessing shotblasting performance in asphalt road pavements more complicated, thus it seems that the documentation of the related information in the international literature is insufficient. The later was the rationale of undertaking the present study, with the aim to evaluate the performance of shotblasting as a pavement preservation technique. Friction and macrotexture data were collected periodically after the application of shotblasting along different site sections of the Attica Tollway, which constitutes the ring road of the city of Athens in Greece. It is worthwhile mentioning that Attica Tollway is a 70 kilometer-long, fully access-controlled toll road, which was also the first Build-Operate-Transfer (BOT) road project in Greece.

The collected data was comparatively analyzed with respect to the time after the application of the shotblasting treatment. For the analysis, the effect of the seasonal variations on skid resistance level was taken into consideration which is a major issue often investigated by researchers *(17, 18).*

SKID RESISTANCE AT A GLANCE

Skid resistance generates from pavement friction which is defined as the force that resists the relative motion between a vehicle tire and a pavement surface *(19)*. This resistive force (Figure 1) is generated when the tire rolls or slides over the pavement surface. A measure of the resistive force is the non-dimensional coefficient of friction, μ, which is the ratio of the tangential friction force (F) between the tire tread rubber and the horizontal traveled surface to the perpendicular force or vertical load (FW).

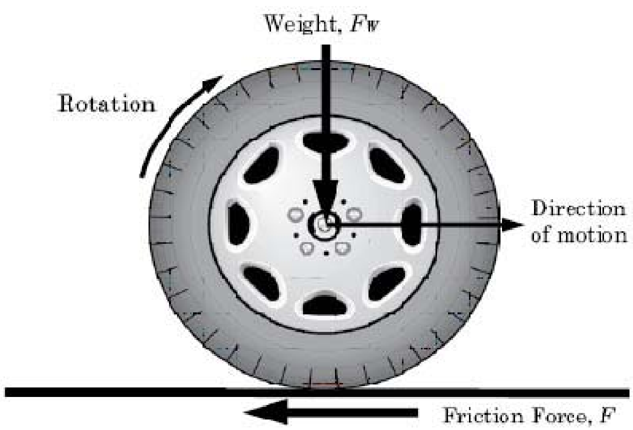

FIGURE 1 Force acting on a rotating wheel.

Tire pavement friction, which is also used in road geometric design to determine the adequate minimum stopping distance *(*20*)*, is not a property of the tire or the road surface individually, but the result of the interaction between the tire and the pavement. This interaction plays a critical role in road safety as it keeps the vehicles on the road by allowing drivers to make safe maneuvers. Although, there is typically a human error that makes emergency maneuvers necessary, loss of control through skidding can be a significant factor in many car accidents, especially when the road is wet. This is more pronounced when considering that in many cases the friction demanded by the individual driver for the maneuver being attempted is greater than that which the road surface in that location (whether wet or dry), and the tires on the particular vehicle acting together can provide, in the particular set of circumstances at the particular time, and if skidding or wheel slipping leads to a loss of control or to a collision *(21).*

Friction is mainly due to two sources of energy dissipations i.e. adhesion and hysteresis (Figure 2) (*3, 22)*. Adhesion results from the shearing of molecular bonds formed when the tire rubber is pressed into close contact with pavement surface particles. Hysteresis results from energy dissipation when the tire rubber is deformed when passing across the asperities of rough surface pavement. These two sources of energy that are characterized as skid resistance's components are related to the key properties of flexible pavement surfaces, which are the macrotexture and microtexture (Figure 3) *(23, 24)*.

Macrotexture is defined by wavelengths of 0.5mm to 50mm (0.02in to 0.2in). It is the coarse texture evidenced by the aggregate or by artificially applied texture such as grooving. Its primary purpose is to enhance bulk-water drainage, thereby reducing the tendency for vehicles tires to be subject to dynamic hydroplaning. Microtexture is defined by wavelengths of 1μm to 0.5mm (0.0004in to 0.02in). It is the texture of the individual stones and is hardly detectable by the eye. It can be felt, but cannot be directly measured, and it is one of the most important factors in reducing the onset of viscous hydroplaning.

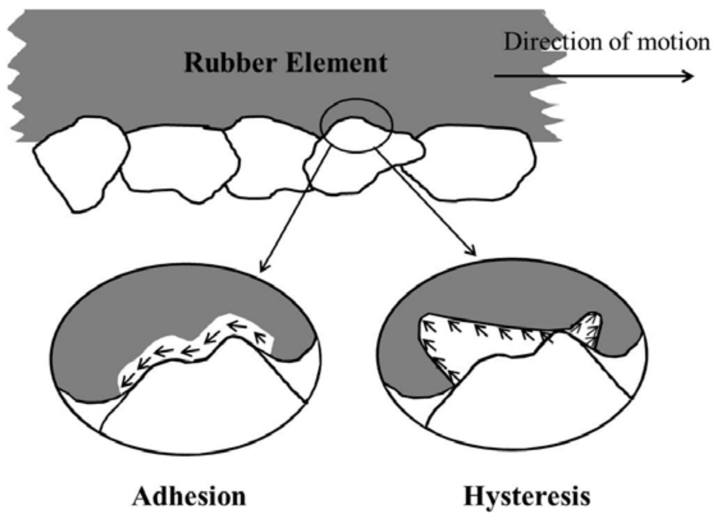

FIGURE 2 Pavement surface macro and microtexture *(22)*

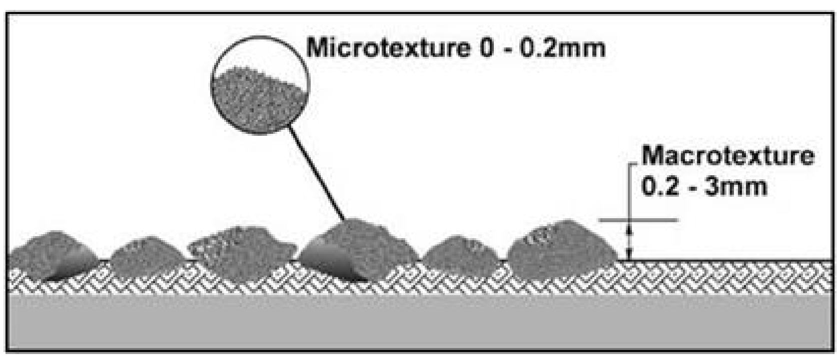

FIGURE 3 Pavement surface macro and microtexture *(24)*.

If both macrotexture and microtexture are maintained at high levels, they can provide adequate resistance to skidding on wet pavements. In addition, degradation of microtexture, caused by the effects of traffic, rubber deposits, and weathering, may occur within a comparatively short period compared with the time required for degradation of surface macrotexture.

SHOTBLASTING TECHNIQUE

The shotblasting technique can be applied on a structurally sound pavement that has become unsafe due to loss of skid resistance. It can be used to retexture both asphalt and concrete pavements. As an asphalt pavement preservation treatment, it has been proved *(25)* that the use of shotblasting to retexture a polished asphalt pavement's surface and restore skid resistance is both technically and financially feasible. Amongst authorized asphalt pavement preservation treatments, shotblasting is a minimal treatment that merely restores microtexture.

The shotblasting process relies on a machine that propels some form of abrasive particle onto the pavement surface and blasts away contaminants, such as excess bitumen, while restoring both micro and macrotexture. The process is fully controlled, safe and environmental sound. It uses no water, no chemicals or solvents, emits no pollutants or dust to the atmosphere and the removed material can often be fully recycled. A typical shotblasting system (Figure 4) essentially consists of the following components: shot propelling apparatus, vacuum system, magnetic separator, residue container and follow-on magnetic brush/broom to pick up any debris that might have been left by the shotblasting system *(26).*

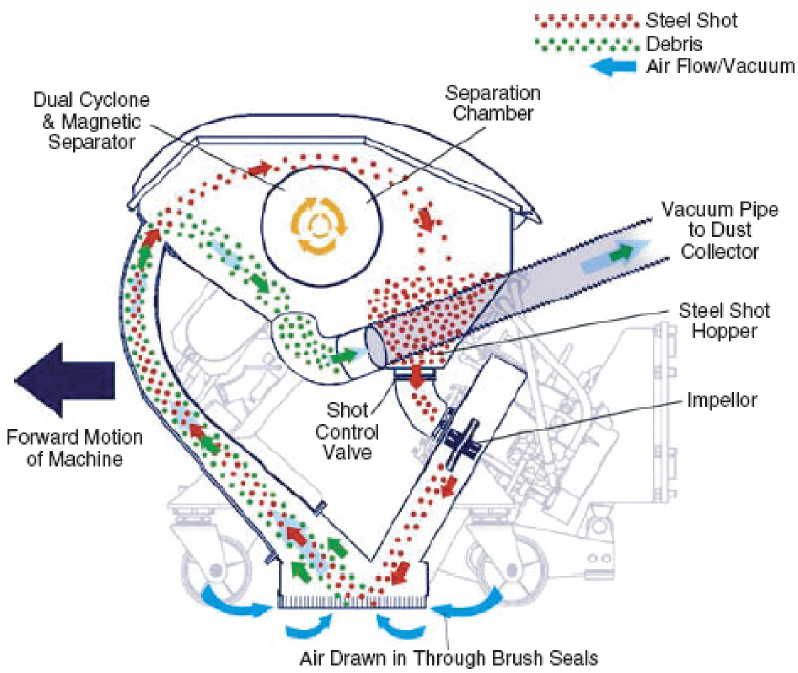

FIGURE 4 Shotblasting system *(26).*

As described in Figure 4, steel shot is fed by gravity through a control valve into an impellor. The impellor turning at high speed throws the steel shot through an adjustable opening at high velocity and at a specific angle on to the surface over which the self propelled machine is travelling. The steel shot impacts the surface and bounces off, as it does so material from the surface whether this is contaminants, coatings or the surface material itself is abraded and loose material together with the shot is drawn up into the machine by the airflow created by the vacuum unit. Brush seals enclose the blast head to the surface and air is drawn in through and under the brushes from the surface to ensure no shot or material from the blast head escapes into the atmosphere. The debris and shot is drawn up into the separation chamber and by a dual cyclone and magnetic separation process the debris is drawn off to the dust collector and the shot is recycled back to the blast head. The strength or degree of blasting required is infinitely variable. Accurate control of the blast pattern and the degree of removal or texture created is controlled using various machine setting and operational practices.

FIELD TESTING

Test Site and Conditions

The implementation of shotblasting along several sections of the Attica Tollway was decided by the relevant authority due to the warning level of skid resistance that deals with the increase of wet related accidents. There were 23 sections with deficient skid resistance with a length that ranged from 300m to 1000m. In the frame of a research project friction and macrotexture measurements were carried out periodically after the implementation of the shotblasting process along these sections. Table 1 describes the measurements conditions indicating two types of condition related to rain: a) "rain season" indicating that substantial precipitation occurred shortly before the period of measurements and b) "dry period" indicating that there was a drought period of at least two months before the measurements.

TABLE 1 Measurements condition

Time after treatment (months)	Rain season	Dry season	Average air temperature (^oC)
0		X	29
5	X		13
10	X		12
13		X	27
20	X		10
24		X	30

It is worthwhile mentioning that all sections consisted of an antiskid surface layer, representing open mixtures that correspond to Mix Designation O-5, as defined in the ASTM standards (D-3515). The aggregate type used in the mix design was steel slag and was produced using a 25-55/70 asphalt penetration modified with PmB and a binder content of 4.0% by mass of the mixture. Also the air void content of the asphalt mix was approximately 11.5% by mass of the mixture.

Data acquisition

Friction data was acquired, using a Grip Tester system *(27)* (Figure 5). The Grip Tester is a fixed slip system, with the measuring wheel fitted with a smooth ASTM standard tire *(28)* that is geared to rotate at a proportionally different rate, thereby producing a 14.5% slip relative to the drive wheels. This slip ratio is the critical slip and it is the point at which a peak friction occurs. Thus, the Grip Tester simulates vehicles with an anti-locking brake system (ABS) that are designed to apply brakes on and off repeatedly, such that the slip ratio is held near the pick coefficient of friction *(29)*.

The friction measurements were carried out continuously at a speed of 50km/h on the right wheel path over a wet surface along the 23 sections. Water was supplied by an automatic pump system that created a 0.25mm water film depth under the slipping wheel, according to the manufacturer standards. The data was recorded and averaged at 10m intervals in terms of the Grip Number (GN) index.

FIGURE 5 Grip Tester system.

On the right wheel path along the considered sections the macrotexture was also measured using a Laser Profiler system (Figure 6). This system is a vehicle mounted laser based instrumentation equipment capable to record data at vehicle speeds up to 100km/h (*30*).The collected macrotexture data was processed to determine the Mean Profile Depth (MPD) (*31*) with an interval of 10m.

FIGURE 6 Laser Profiler system.

It is worthwhile mentioning that in every case, field testing was performed under suitable climatic conditions so that the results are both accurate and valid. Moreover, for quality assurance purposes, the measuring systems were properly calibrated.

DATA ANALYSIS AND RESULTS

General analysis

The collected data was analyzed in order to evaluate the performance of shotblasting as a pavement preservation technique. For each test section the average GN value was considered to be representative since the Coefficient of Variation (CV) was less than 20% in all sections. This information is provided by the data box plots of Figure 7. Each box contains the middle 50% of the data with respect to the time after implementing the shotblasting treatment. The upper edge (hinge) of the box indicates the 75th percentile of the data set and the lower hinge indicates the 25th percentile. The range of the middle two quartiles is the inter-quartile range. The line in the box indicates the median value of the data. The ends of the vertical lines or whiskers indicate the minimum and maximum data values.

Based also on the descriptive statistics of Figure 7 (i.e. low CV values), an additional remark is that the friction of pavement surfaces remains homogenous in all sections through time.

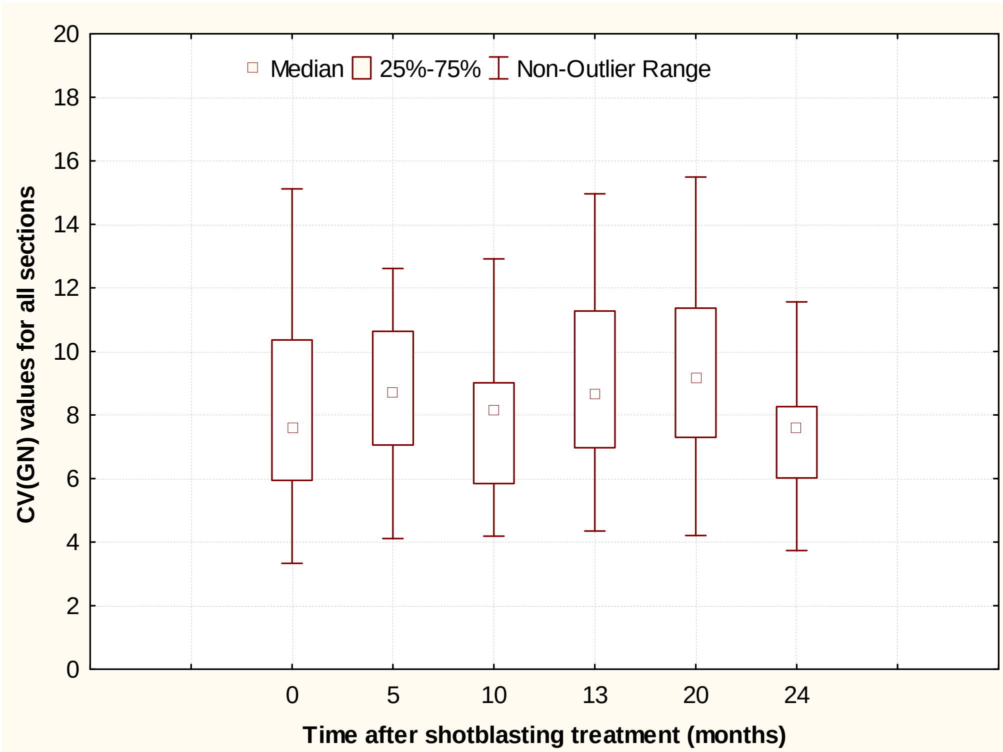

FIGURE 7 CV(GN) values.

As far as MDP data is considered, the maximum CV value appeared to be more than 20% for some cases but less than 30% in all sections (Figure 8). However, for the purpose of the analysis, the average MPD value was considered to be representative of each section.

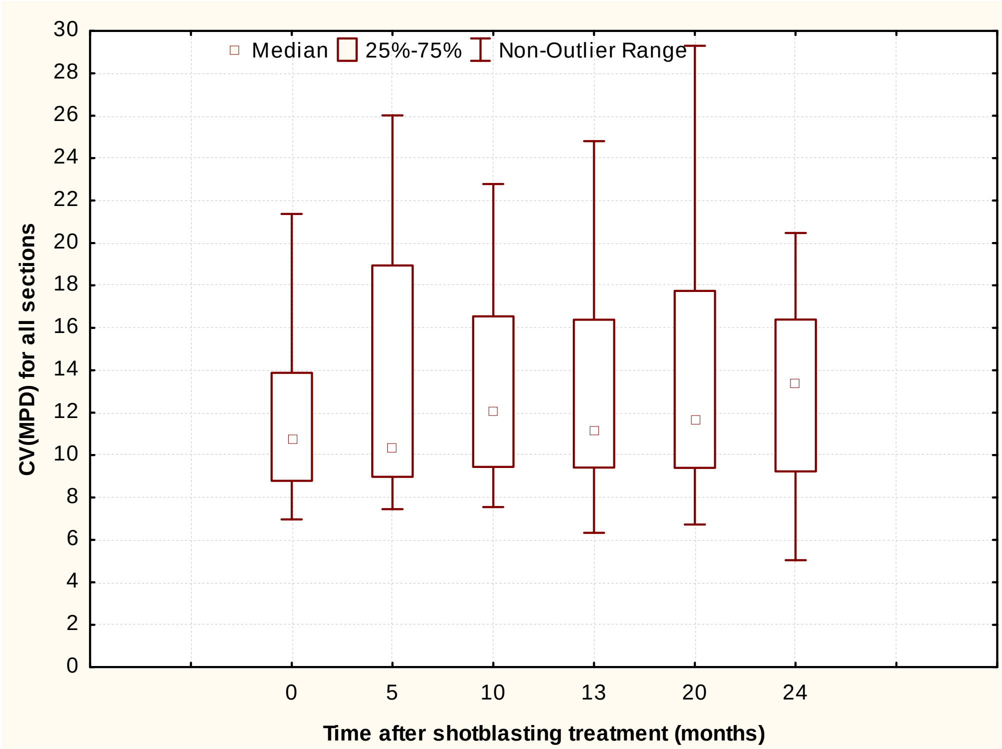

FIGURE 8 CV(MPD) values.

Considering the average values of GN and MPD for each section, two samples of a size equal to 23 were created, respectively.

In order to evaluate the performance of the shotblasting technique the collected data was further analyzed. The separation of data into different seasons based on the existence of adequate rain before the time of measurements was considered essential. This is due to the fact that prolonged periods of dry weather allow the fine particles that are polished off the pavement surface to accumulate resulting in a loss of both microtexture and macrotexture. This action together with the contamination from vehicles, (oil, grease etc) lead to lower skid resistance during dry periods. On the contrary, heavy precipitation allow for the fine material to be flushed out exposing a coarser aggregate surface. Rainfall also flushes out the drainage channels between aggregates and thus increases the macrotexture of the pavement. The parameter of air temperature, although a factor dealing with the seasonal variations in skid resistance, was not considered in the present study.

Below, friction as well as macrotexture data are analyzed and discussed with respect to the aforementioned seasons (Table 1) keeping as a reference the data gathered shortly after the implementation of shotblasting treatment in the 23 sections.

Rain season results

Focusing on the rain season’s data the boxpots of Figure 9 describes the way that GN data varies through time. Although a decreasing tendency of friction is observed, after a 20 month period it remains at satisfactory level.

The tendency of decreasing values is less evident in the case of MPD values (Figure 10). The variations in macrotexture through time could be considered as insignificant.

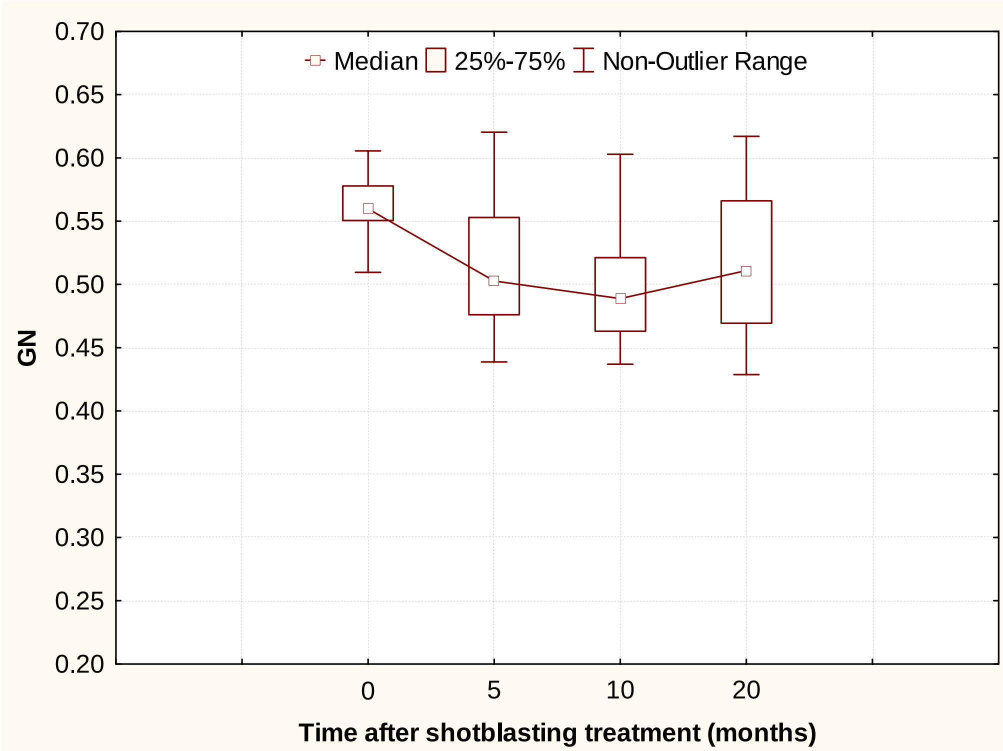

FIGURE 9 GN data variation for rain seasons.

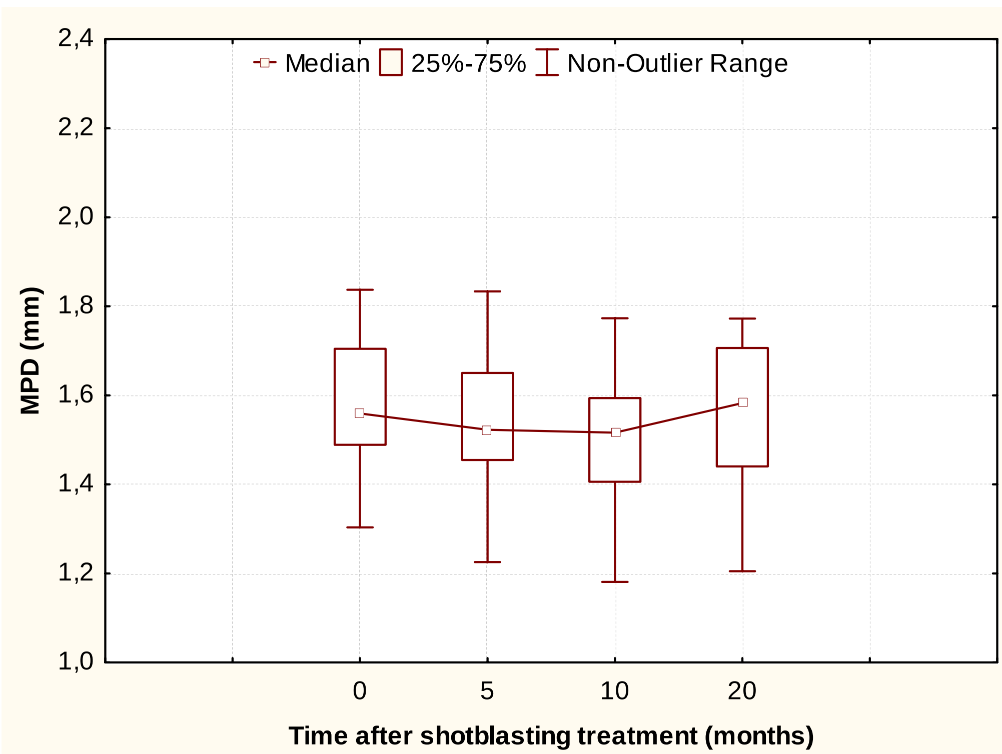

FIGURE 10 MPD data variation for rain seasons.

According to the results provided in Figure 9, it seems that the performance of shotblasting technique for the rain seasons is more than acceptable, especially when considering that this result is still valid 20 months after the implementation of the shotblasting. As far as the macrotexture is concerned, the variation range from time to time is rather narrow indicating that the shotblasting performance is less related to the macrotexture of the asphalt pavement surfaces.

Dry season results

The same procedure as for the rain seasons was followed for the study of the dry seasons' data. With reference to the skid resistance achieved after the treatment of pavement surfaces with the shotblasting technique, Figure 11 shows that friction significantly decreases after 13 months and reverts to warning levels 24 months after the implementation of shotblasting.

The above results are not connected with the way in which macrotexture data varies. According to the results presented in Figure 12, the MPD data do not seem to differ 13 months after the implementation of shotblasting, while 24 months after the level of macrotexture seems to be improved, something that is rather difficult to interpret.

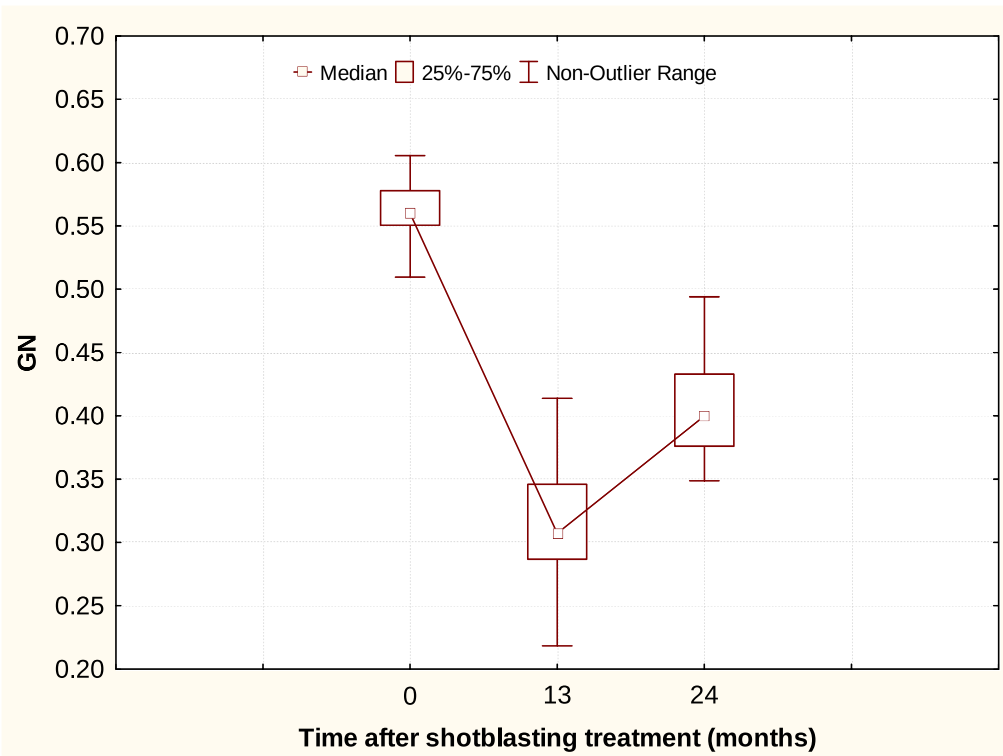

FIGURE 11 MPD data variation for dry seasons.

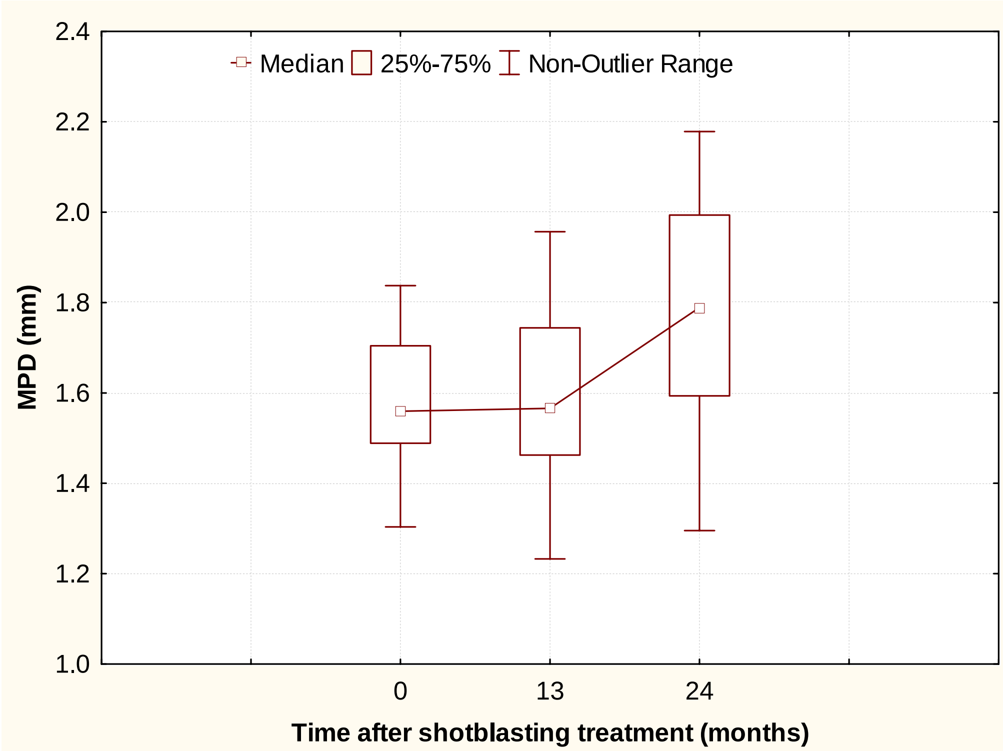

FIGURE 12 MPD data variation for dry seasons.

Concluding it could be stated that the performance of shotblasting during the dry seasons does not add value in its worth. It seems that the effect of the seasonal variation in skid resistance cannot be avoided due to the implementation of shotblasting and it remains significant. Furthermore, although it has been stated that "*shotblasting technology is very effective in reinstating both macro and microtexture*" *(22)*, the results provided in Figure 12 in conjunction with the ones provided in Figure 10, produce evidence in support of the statement that the shotblasting performance has a weak relationship with macrotexture.

CONCLUSIONS

The use of shotblasting to retexture asphalt pavement's surfaces and restore skid resistance is definitely both technically and financially feasible. In the present study, the analysis concerned the investigation of the performance of shotblasting in terms of friction and macrotexture indices, i.e. GN and MPD respectively. The application of the periodical data collection in two years period and the related analysis led to rather interesting remarks. For the rain season it seems that the performance of shot blasting technique in terms of friction was more than acceptable, and was standing even 20 months after the implementation of the shotblasting. However, this is not applicable for the dry seasons indicating that the effect of the seasonal variation in skid resistance remains significant.

In addition, although it has been stated that shotblasting restores both micro and macrotexture, the analysis showed that its performance has a weak relationship with macrotexture. This might be an indication that the level of skid resistance improvement due to shotblasting was related mainly to the improvement of the microtexture, at least for the pavement surfaces under investigation.

Concluding it could be said that shotblasting as a pavement preservation technique provides the road authorities with a tool to “do more with less” in maintaining the road, as they have to handle the critical factors of an aging infrastructure, increasing traffic demands, and shrinking budgets. However, the crucial issue of the effect of seasonal variations in skid resistance is not resolved by implementing shotblasting. Consequently, although the present research showed that the good effect of shotblasting has duration, it is recommended that shotblasting technique should not be considered more than a temporary solution that gives the road authorities the time to better develop their pavement maintenance management strategy.

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