A REAL SCALE ANALYSIS OF SURFACE CHARACTERISTICS OF A PHOTOCATALYTIC PAVEMENT

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ABSTRACT

Photocatalytic materials represent a new istrument supporting the preservation of air quality standards regarded as safe for health and environment. Titanium dioxide treated materials are applied on surfaces exposed to sunlight in order to favour the decay of air pollutants, particularly photocatalytic paints, plasters and cements are amply used.

The application of photocatalytic materials on the road surface allows to turn an usually inactive element, the road, into an active mean of pollutants demotion. The photocatalytic pavement has to guarantee the environmental effectivenss in the pollutant degradation as well the performace characteristics of a standard road pavement.

The Authors present the results of an experimental analysis concerning the functional characteristics of a photocatalytic pavement consisting in an open graded bituminous layer partly filled with a cementitious mortar added with titanium dioxide.

The experimental investigation aimed at defining the surface features of the examined pavement, to study their evolution under the action of traffic and to set up suitable techniques to increase Skid resistance.

The first experimetal phase consisted of a laboratory study concerning the definition of the most effective method of texture improvement. Afterwards a real scale test area was carried out in order to test the simply filled pavement as well as the superficial treatment for the macrotexture improvement. The test area, opened to traffic, was monitored for evaluating the evolving of surface features and the strength of the treatment under the action of both vehicles and atmospherical agents.

Keywords: photocatalytic pavement, macrotexture, skid resistance, surface treatment

1. INTRODUCTION

The maintenance of the pollutants concentration in atmosphere under safe levels is, nowadays, a problem not yet efficiently solvable according to traditional solutions. The control of air pollutants due to traffic has been so far faced with the emission reduction, pursued through the setting up of fuels and engines, together with a right traffic management.

Photocatalytic materials represent a new resource for air pollutant control, working not through the emission reduction but thanks to the acceleration of the natural chemical reactions of pollutants decay. Photocatalytic materials actually favour chemical oxidation reactions of pollutants thanks to the combined action of photo catalyst, sun radiation and substances normally present in the atmosphere.

It seems clear that the effectiveness of the photocatalytic action of pollutants degradation is proportional to the extent of the treated surface. In urban contexts there are lots of surfaces suitable for the application of photocatalytic materials: from building facades to concrete elements, from sidewalks to road pavements.

The setting up of a photocatalytic road pavement presents problems concerning the definition of the most effective application method of the photo catalyst on the surface as well as the guarantee of the performance usually required from a road pavement.

The Authors present the result of a test campaign aimed at analysing the surface features of a photocatalytic road pavement and at the setting up of suitable techniques of skid resistance and macrotexture improvement.

2. A PHOTOCATALYTIC ROAD PAVEMENT

The application of photocatalytic materials on the road surfaces represents one of the most interesting application of the technology connected to photo catalysis in urban context. The effectiveness of the photocatalytic activity is proportional to the width of the surfaces exposed to sunlight and air. The road pavement constitutes, into the urban tissue, a surface marked by a wide total extent and by a widespread and regular distribution in the urban area, ideal therefore to be treated to become photocatalytic and to be a useful instrument for the reduction of air pollution.

Various types of photocatalytic pavement are at present subject of analysis, the photocatalytic pavement considered in the present paper is formed by a bituminous open grade wearing course partly filled with a special cementitious photocatalytic mortar.

The effectiveness of the analysed photocatalytic pavement is due to the formula of the photocatalytic mortar: a mixture that combined the photocatalytic power of titanium dioxide with the chemical characteristics of cement. The cementitious substratum allowed actually a more effective action of air pollutants degradation and reduction to inert salts, easily removable by meteoric and washing water. The combined action of photo catalyst and alkaline substratum, represented by the cementitious mortar, in the pollutant degradation is especially evident in reactions concerning sulphur dioxide: the analysed chemical compound is in fact oxidised in sulphuric acid trough the chemical reaction bound to photo catalysis, the sulphuric acid in its turn is adsorbed by the alkaline substratum returning as result calcium sulphate, a chemical element weakly soluble in water and not toxic for the environment.

Compounds washed away from the road surface present such chemical characteristics to not constitute a further criticality for first flush water softening and disposal, molecules resulting from an oxidation reaction present indeed, especially in the analyzed situation, a lower toxicity if compared with the starting polluting elements.

The photocatalytic road pavement semi-filled with cementitious mortar was subject of preliminary analysis directed to materials characterization and to the optimization of their combination, as well as the analysis of some real scale applications both in urban and rural context. The study of different applications allowed to indentify and solve problems concerning the application of the mortar as well as possible problem connected with the pavement working life.

Different real scale applications were considered each located in a different context characterized by high traffic. Each application was subjected to tests aimed at the determination of surface features in order to characterize this kind of photocatalytic pavement with regards to skid resistance and macrotexture.

Surface features of this kind of pavement are due to the condition of the most superficial stratum of photocatalytic mortar and to the variation of these characteristics in time, under the action of traffic and weathering.

In consideration of the examined case histories, referring to the pavement condition immediately after the application, and related to six and eighteen months after the opening to traffic it is possible to determine an average trend of surface features comparable to the one shown in Figures 1 and 2. The reported results sumed up the mesurement carried out by the Autohrs in different points located on a road pavement affected by high traffic volumes, the hatched line drowen in Figure 1 and 2 gave an indication of the average trend of the measured features.

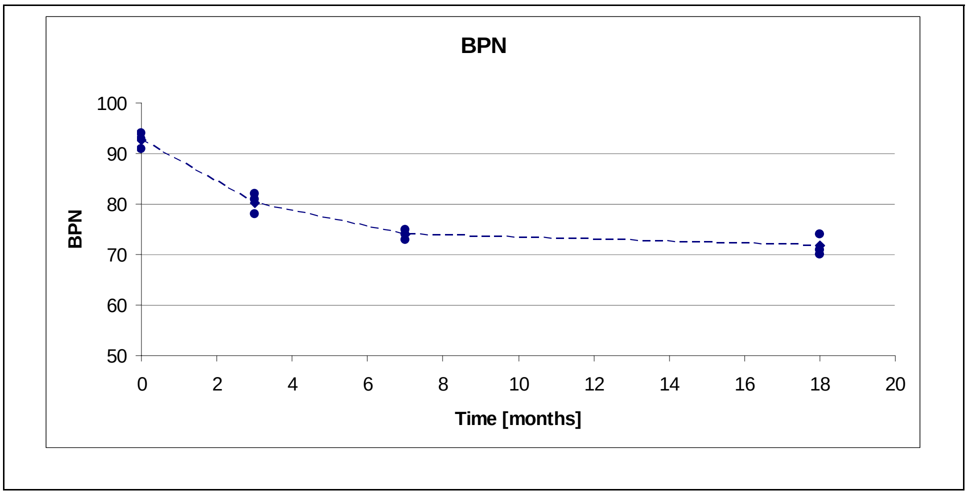

Figure 1 Evolution of BPN measured on a monitored full scale test site

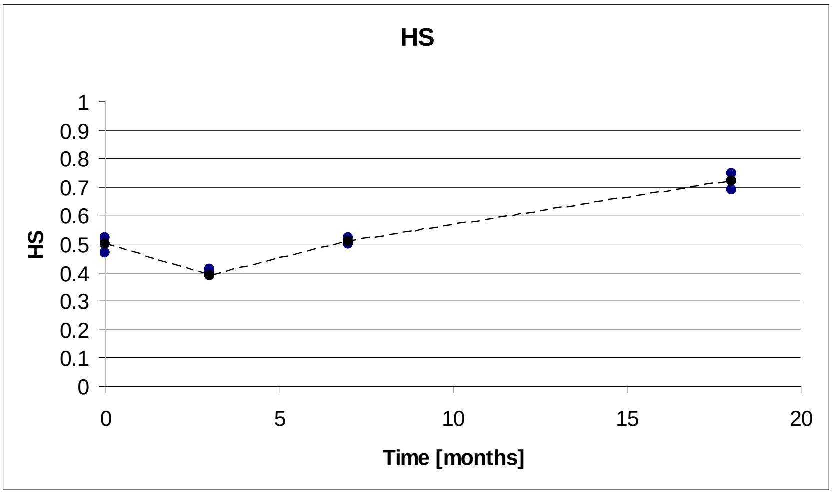

Figure 2 Evolution of HS measured on a monitored full scale test site

Surface features resulted to be, in the period immediately following the opening of the application to traffic, related to the superficial roughness due to the superficial treatment of the pavement. The tyre action led to a progressive smoothing of the surface and to a removal of the most superficial mortar stratum with the emerging of the asphalt concrete. The progressive mortar removal from the road surface is schematized in Fig. 3.

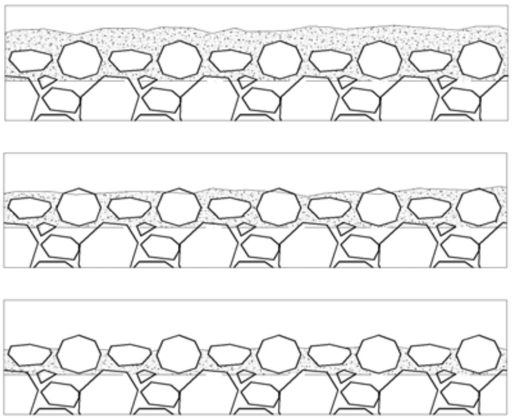

Figure 3: Photocatalytic mortar progressive removal

The analysis of measured data allowed to define as critical the phase of the pavement working life existing between the opening to traffic and the emerging of the bituminous substratum, particularly concerning macrotexture.

A skid resistance condition comparable with the one corresponding to a traditional bituminous wearing course is due, in the initial phase of the working life of the pavement, to the mortar granulometry and, in the following phase, to the emerging bituminous surface. The macrotexture instead is related, in the initial phase, to the harshness due to the superficial finishing treatments and, in the following phase, to the emerging of the asphalt concrete. In the period existing between the two described statuses the mortar granulometry is not able to guarantee an adequate macrotexture.

3. TECHNIQUES FOR SKID RESISTANCE AND MACROTEXTURE IMPROVEMENT

The analysis of surface features of examined real scale applications allowed to underline the need of an improvement of the macrotexture, particularly referring to the phase immediately preceding the emerging of the bituminous layer.

In the present section the Authors give a description of the experimentation regarding the setting up of suitable techniques of skid resistance and macrotexture improvement in order to offer an affective solution of the exposed problems.

3.1 Preliminary laboratory tests

The real scale experimentation was preceded by the setting up of suitable intervention methods through medium scale samples. Three open graded asphalt concrete samples were made up, with a superficial area of 1m x 1m and a thickness of 5 cm. The samples were compacted with suitable rolling. Each sample was obstructed with photocatalytic mortar and worked superficially according to different methods, in order to evaluate obtained surface features from each surface treatment.

The first sample represented the term of comparison for superficially treated samples in order to evaluate the amount of the skid resistance and macrotexture improvement. The sample 1 was partly filled with the photocatalytic mortar and worked superficially with scrapers for simulating the usual superficial treatment made on the photocatalytic pavement.

The sample 2 was partly filled with photocatalytic mortar as the previous one but it was also superficially treated with gravel in order to improve surface features. The gravel, presenting granulometry of 2-6 mm and Los Angeles of 20%, was scattered on the surface and worked with scrapers in order to favour the adhesion to the surface and the seizing with the mortar.

The sample 3 instead was partly filled with photocatalytic mortar previously mixed with gravel presenting granulometry of 2-6 mm and Los Angeles of 20%. The gravel was added to the powder during the mixing of the mortar and the mixture was applied on the bituminous surface and suitably worked with spatulas for favouring the penetration into the bituminous substratum.

After 24 hours, the time required for the hardening of the mortar, measurements of skid resistance and macrotexture were carried out, according to BPN and Sand Patch Method tests, executed on three different points for each samples. Obtained valued were averaged out in order to obtain one representative value for each typology of surface treatment.

The results derived from the tests concerning surface features showed a significant increase of BPN and HS in all the examined solutions, as reported in Figure 4.

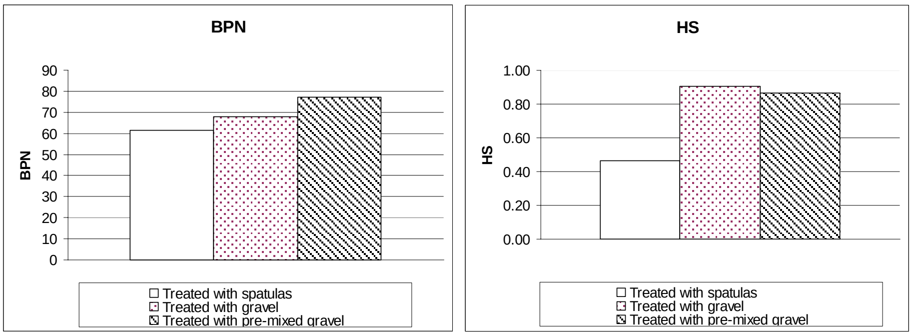

Figure 4 Comparison of surface features related to three different samples at time 0

The laboratory scale experimentation of different techniques for the application of gravel on the pavement surface showed some problems related to the partial obstruction of the bituminous layer with the photocatalytic mortar pre-mixed with gravel, the gravel in fact is an impediment to the achievement of the desired depth and regularity of penetration.

In the light of what emerged from the described experimentations it seemed to be appropriate to proceed with the real scale application of the technique for the improvement of skid resistance and macrotexture that implied the application of gravel on the pavement surface after the application of the photocatalytic mortar.

3.2 Full scale test

The full scale experimentation followed the preliminary analysis of techniques for skid resistance and macrotexture improvement described in the previous section. The construction of a real scale test area allowed to release the results from limitations implied by the laboratory scale, as well as to analyse the evolution of the photocatalytic pavement under the action of traffic.

The full scale test area was 12 metres in length and 4 metres in width, located lengthwise with regards to the traffic direction, including one of the road lanes for the whole width. The considered road pavement is located into an industrial area affected by high traffic flows, with a rate of heavy vehicles of about 30%. The test area was split into two longitudinal sections, the first was treated with the photocatalytic mortar simply treated with scrapers, the second instead was subjected to the treatment for surface features improvement. The area was subjected to the monitoring of skid resistance and macrotexture characteristics of each surface typology, constructive choices allowed to stress each section with the same traffic load.

Transversely the area was divided into three different parts, each one affected with a photocatalytic mortar mixed with different water contents in order to evaluate the influence of water content on the depth of penetration of the mortar into the bituminous layer. Three different water contents were tested, 28%, 32%, 38%, for verifying the mortar workability and its depth of penetration into the sub stratum.

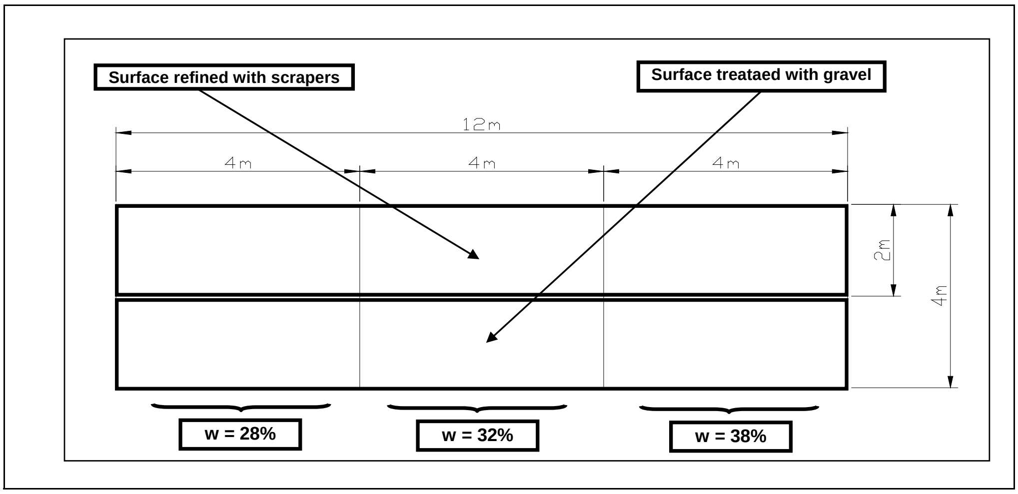

Figure 5 Full scale test area schematic plan

The real scale test area was closed to traffic, the existing wearing course was scarified for a thickness of 5 cm and the surface was suitably cleaned.

The construction of the photocatalytic pavement was made up of two following phases: the laying of the open graded asphalt concrete and, after a right cooling of the surface, the application of the photocatalytic mortar.

The asphalt concrete open graded layer, mixed with a modifying bitumen in the rate of 4,5%, was made up according to the granulometric curve reported in figure 6. The mixture granulometry was defined after suitable laboratory experimentation aimed to the achievement of a rate of Marshall Voids of about 20%, in order to guarantee a distribution and an average dimension of voids able to consent the obstruction of the bituminous layer for an adequate depth, fixed in about 1 cm.

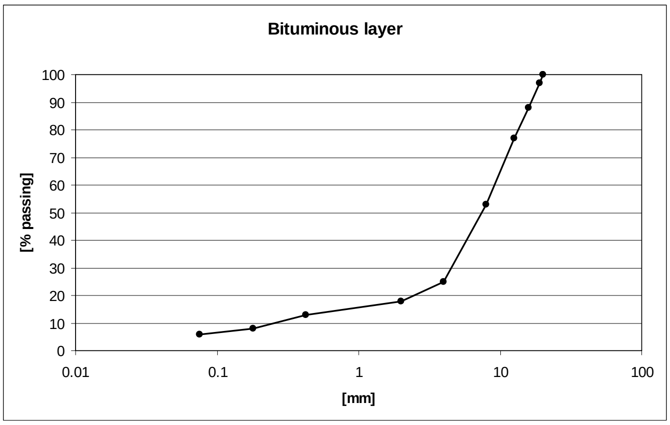

Figure 6 Granulometric curve of the bituminous layer

The compaction of the asphalt concrete was obtained trough one vibrating passage of a roller, followed by a smoothing static passage, in order to obtain an average rate of voids of about 20%. The temperature of the pavement was monitored till the achievement of a temperature suitable for the application of the mortar on the surface, fixed at about 30°C.

The mixing of the mortar was realised adding the photocatalytic powder with the previously defined water contents, proceeding with the mixing into a small concrete mixer for about 3-5 minutes.

The mortar was applied on the bituminous surface and worked superficially with scrapers in order to favour the correct penetration of the material into the asphalt concrete. The area to be treated with gravel was strewed with the aggregates, presenting a granulometry of 2-6 mm, and then refined superficially with brushes for favouring the adhesion and the integration between the gravel and the mortar layer, as illustrated in Figure 7.

Figure 7 Application of the mortar on the pavement and surface treatments

The amount of gravel applied on the surface was varied (0.1 kg/mq, 0.2 kg/mq, 0.3 kg/mq) in order to evaluate the most suitable solution for obtaining the desidered surface features.

A schematic image of the completed full scale test area is reported in Figure 8.

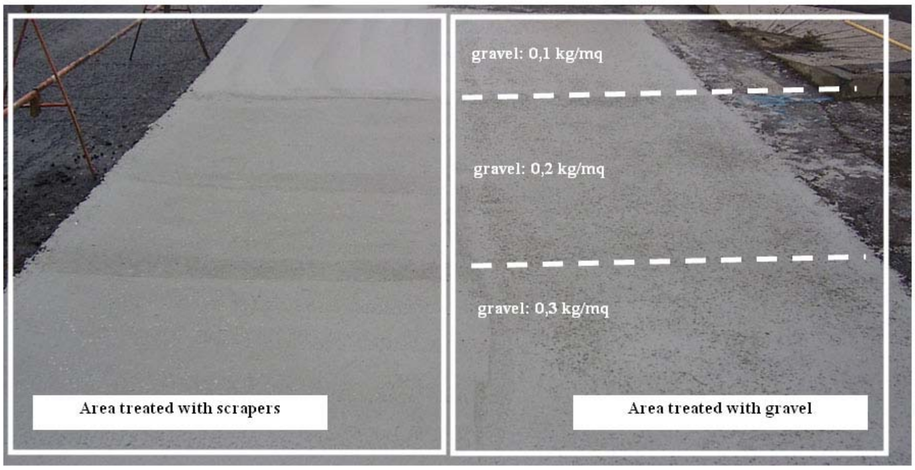

Figure 7 The completed full scale test area

3.3 Analysis of surface characteristics

The monitoring campaign of surface features was carried out on twelve different points of measure, two for each tested solution. Each point was located on the pavement surface according to the tyre path and marked with a nail in order to obtain the maximum possible accuracy during the positioning of the test apparatus.

The measurement was carried out considering both macrotexture, evaluated by The Sand Patch Method in accordance with the ASTM E965 standard, and skid resistance, tested with British Pendulum Tester according to the ASTM E303 standard. Each point of measure was subjected to skid resistance and macrotexture tests and an average value of the obtained results was calculated in order to represent each tested solution with a unique and representative value.

The first surface features test was carried out 24 hours after the application of the mortar, concerning the surface of each different tested solution, then the real scale test area was opened to traffic. Surface features tests were repeated afterwards the opening to traffic in order to analyse the evolution of macrotexture and skid resistance of the pavement exposed to vehicles flows.

The traffic affecting the test area was fairly intense. The traffic was variously constituted, with a rate of heavy traffic of about 30%.

The surface features monitoring was carried out according to intervals of about 15 – 20 days, for a period of three months after the pavement construction. Tests pointed out trends of evolution of macrotexture and skid resistance as represented in following graphs.

Results derived from BPN tests showed a level of skid resistance comparable, if not superior, to the one corresponding to a traditional bituminous wearing course: the increase of skid resistance given by the application of gravel, according to the method previously described, was measured as about 7% compared with the traditional solution.

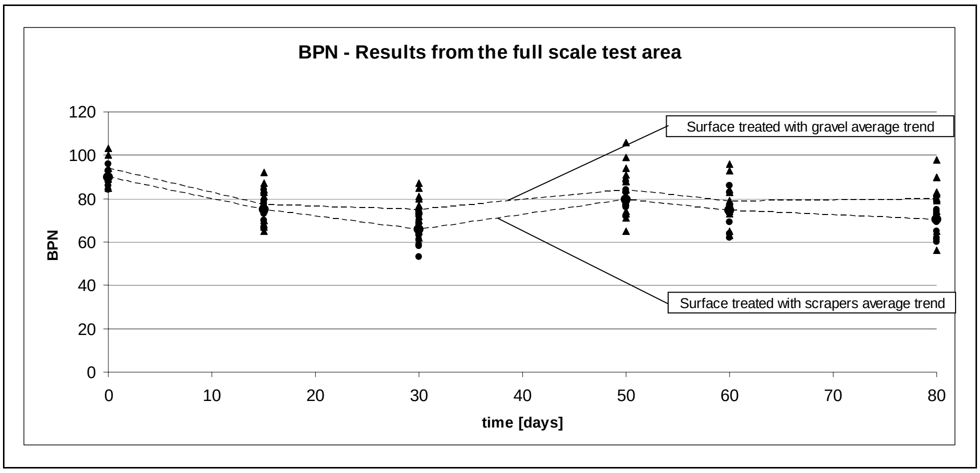

Figure 7 Results of BPN tests carried out on the full scale test area

The skid resistance is given, at time zero, by the micro harshness assured by the thin superficial layer of photocatalytic mortar. The tyre action, opened the test area to traffic, led to a quick removal of the most superficial layer of photocatalytic mortar with the consequent emerging of the asphalt concrete surface. It seems to be allowed to hypothesize that starting to the emerging of the bituminous layer the skid resistance will evolve with a trend quite comparable to the one defined for a traditional wearing course layer.

The macrotexture monitoring showed a significant improvement of values corresponding to the surface treated with gravel in comparison with values related to the surface simply well-finished with scrapers.

In figure 8 trends of macrotexture refered to surfaces treated with gravel in different quantities (0,1kg/mq, 0,2 kg/mq and 0,3 kg/mq), togheter with tha average trend, are represented.

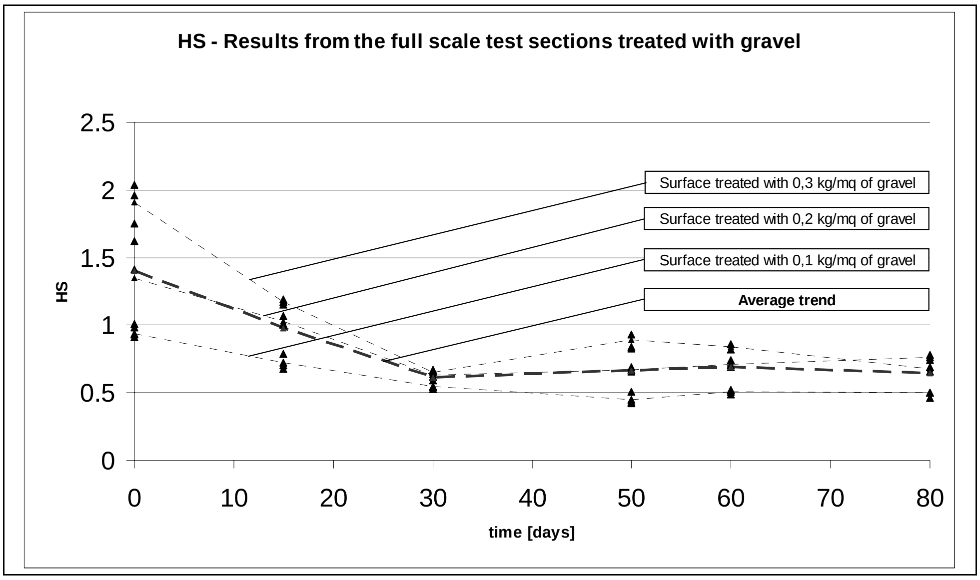

Figure 8 Results of HS tests carried out on the full scale test sections treated with gravel

The comparison of the three curves corresponding to gravel treated surfaces showed a convergence of values already after thirty days from the opening to traffic. The quantity of gravel applied on the surface affected macrotexture only in the period immediately subsequent the application.

The graph 9 showes the result of the comparison between the decay curve of macrotexure corresponding to the surface only treated with scrapers and the curve related to the surface treated with gravel. The two average curves derived from the measurement carried out on the full scale test area.

From measured data emerged a macrotexture improvement of about 100% given by the superficial treatment as regards to the traditional solution,

The first part of the decay curve results to be descending because of the progressive levigation of the superficial roughness due by the progressive removal of the mortar carried out by tyres. The emerging of the bituminous layer led to a stabilization of macrotexture, concerning both the surface simply treated with scrapers and the surface treated with gravel.

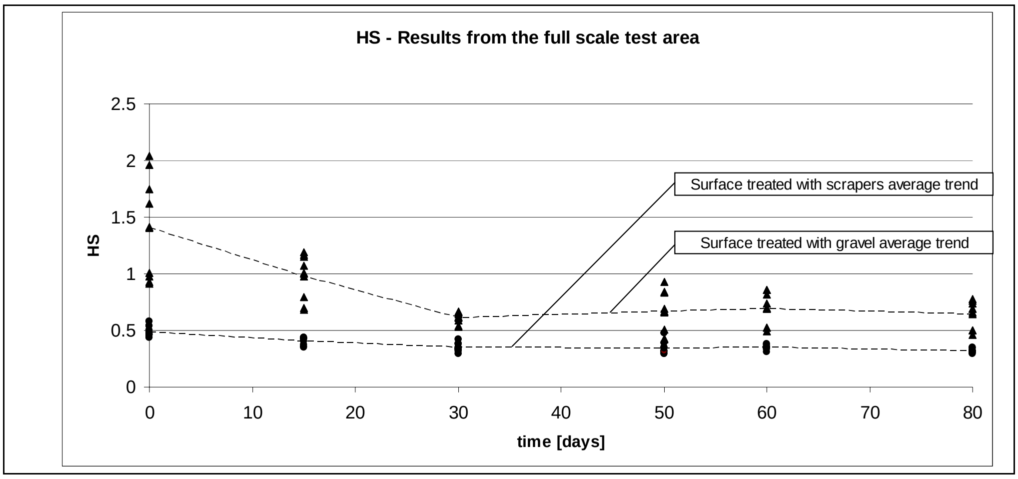

Figure 9 Results of HS tests carried out on the full scale test area

Samples were also taken out from the test area in order to measure the depth of penetration of each mixture. There was not a remarkable variation of the thickness of the mortar layer according to different water content. The average depth of penetration resulted to be about 1 cm, with a maximun measured value of 1,5 cm.

4. CONCLUSIONS

The carried out experimental analysis was aimed at setting up a suitable technique for improving surface features of a photocatalytic pavement made up of an open graded asphalt concrete layer partly filled with photocatalytic cementitious mortar. The Authors particularly focused on solving problems related to the quick decay of macrotexture characteristics due to the abrasive action of tyres and meteorical agents.

The first phase of the described analysis consisted in a laboratory experimentation aimed at finding the most suitable techniques to use. The phase of real scale experimentation allowed to evaluate the operating feasibility of the operation, to test the effectiveness of this technique through the monitoring of surface features under the action of traffic.

The skid resistance, monitored with BPN, already satisfying for photocatalytic surfaces only treated with scrapers, resulted to be further improved.

The macrotexture characteristics resulted to be improved of more than 100% compared with the solution taken as point of reference. The trend of macrotexture, tested with Sand Patch Method, resulted to be steady, after a first phase of quick decay of roughness due to the erosion of the peaks and to the removal of the most superficial mortar layer, assuming values noticeably higher than the solution taken as reference. Tests results showed also the independence of a good result in terms of surface features improvement from the tested quantity of gravel applied on the surface. Anyway the most suitable result is related to an average quantity of gravel (0,2 kg/mq).

The set up solution seems to be suitable to the aim, defined in consideration of results derived from in situ tests carried out on existing pavement.

The analysis of the evolution of surface features allowed to put forward some hypothesis concerning the life cycle of this kind of road pavement. The progressive removal of the most superficial mortar layers going to end with the complete emerging of the bituminous substratum.

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