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Low environmental impact technologies for road construction
Tecnologie a basso impatto ambientale per le costruzioni stradali

The "*sustainability*" concept relates to the prolonging of human economic systems with as little detrimental impact on ecological systems as possible. Construction that exhibits good environmental stewardship and practices that conserve resources in a manner that allow growth and development to be sustained for the long-term without degrading the environment are indispensable in a developed society.
Past, current and future advancements in road construction as an environmentally sustainable paving material are especially important because the quantities of asphalt used annually in Europe as well as in the U.S. and all over the world are large. This research project is aimed to demonstrate the dual value of some new technologies in regards to the environmental and mechanical performance and to suggest a low environmental impact design procedure. In fact, the use of eco-friendly materials is the first phase towards an eco-compatible design but it cannot be the only step. The eco-compatible approach should be extended also to the design method and material characterization because only with these phases is it possible to exploit the maximum potential properties of the used materials.

Il concetto di "sostenibilità" si riferisce allo sviluppo dei sistemi di supporto per la vita umana che minimizzino l'impatto sul sistema ambientale. Le opere che si inseriscono bene nel contesto ambientale circostante e le pratiche che rispettano le risorse in maniera tale da permettere una crescita e uno sviluppo a lungo termine senza impattare sull'ambiente sono indispensabili in una società moderna.
I progressi passati, presenti e futuri che hanno reso i materiali stradali sostenibili dal punto di vista ambientale sono particolarmente importanti data la grande quantità di conglomerato usato annualmente in Europa, negli Stati Uniti ed in tutto il mondo.
L'obbiettivo principale di questo lavoro è quello di mostrare il duplice valore prestazionale-ambientale di alcune tecnologie innovative, sottolineando come il concetto di sostenibilità, applicato alla progettazione delle infrastrutture viarie, non dipenda esclusivamente dai materiali impiegati.
L'uso di materiali a basso impatto ambientale rappresenta solamente il punto di partenza della progettazione sostenibile. L'approccio ecocompatibile deve essere esteso anche ai metodi progettuali, costruttivi ed alla caratterizzazione in laboratorio dei materiali al fine di conoscerne il comportamento e conseguentemente sfruttarne le potenzialità.

Keywords*:* road construction; eco-friendly technologies; context sensitive design; pavement; recycling

Parole chiave*: costruzioni stradali; tecnologie ecocompatibili; progettazione sensibile al contesto; pavimentazioni; riciclaggio*

1. INTRODUCTION

The current environmental protection requirements have increasingly addressed the issue of the designers to the creation of works that can be built and coexist in harmony with the surrounding environment.
The efforts of designers and builders of roads are strongly oriented towards the identification of appropriate design criteria, construction technologies and their acceptance tests that can ensure mitigation of these phenomena unwanted and/or harmful.
The achievement of these objectives depends, in particular, by an appropriate use of materials both traditional and innovative, by a correct dimensioning of the pavement structures and a properly programmed maintenance to ensure its preservation.
The relationship between environment – pavement and road materials are numerous, complex and highly topical. You should also consider that the road construction materials in recent years have undergone a remarkable evolution to meet the demands for more performance, in addiction with new instances derived from new and more modern methods of "integrated design" of road infrastructures.
In this paper the environmental feasibility and the environmental impact assessment of the project documents viewed, not only in its own internal coherence, but built together with the design phase, have become the primary and most important instrument for minimizing the impacts both during construction and during the maintenance phase.
Environmental protection is no longer seen as some kind of document to be attached to the project but becomes an integral part, with its guiding principles.
With this in mind you can then immediately identify two different fields of study and research inter-connected with each other that exist between road construction and environmental protection : the first refers to the " micro-scale " typical of the environment crossed by the road infrastructure and , more generally, to the sustainability of the motion and the functional characteristics of the pavement, and the second refers to a larger scale (macro - scale) that directly impacts on the environment and available resources for the construction, management and maintenance the road pavement. We should try to predict, assess and minimize these in the design phase .
At the "micro- scale " level we do not have impacts in the absence of traffic, the eco-friendliness of the motion is directly related to the presence of vehicles on the road . At the " macro-scale " level instead the impacts of roads on the environment are independent by traffic.
In order to clarify the first of the two fields of study is appropriate to define the key performance parameters [1] required the asphalt surface and the top layers in particular.
You can identify and classify the functional characteristics that are directly related to the performance offered by the road pavement during exercise, they can be summarized as :

- Bearing Capacity, defined in terms of structural strength and adequate deformation response to traffic loads. It is closely linked to the service life of the pavement. With reference to the asphalt layers, the performance characteristic must be able to evaluate and assess the mechanical behavior - rheology of the mixture and the durability of the materials;
- Adherence, a fundamental parameter for achieving the objectives of road safety and connected directly to the compositional characteristics of the bituminous mixture and the surface texture;
- Evenness , with reference to the objectives of safety and ride comfort, together with the characteristics of the pavement bearing capacity and structural strength of the conglomerate described above ;
- Surface drainage, which is also linked to the needs of safety and dependent on the composition of mixtures of asphalt used;
- Visibility, function of color and light absorption characteristics of the material forming the top layers and also closely related to the objectives of safety.

Together with these features can be added three more specifically related to the eco-friendliness of

the motion and the protection of the environment surrounding the infrastructure:

- Noise, in terms of definition and certification of the acoustic qualities of asphalt and study of compositional characteristics most suitable for the minimization of the noise in the generation process and of maximizing the absorption in the propagation phase;
- Vibration , in terms of minimization of the contribution of the surface of the materials and components of the pavement to the phenomenon of generation of vibrations and exaltation of the effects of damping in the process of propagation through the road platform;
- Rolling resistance, in terms of minimization of fuel consumption and tire to reach a reduction of costs for the user and the impacts on the environment.

All three parameters are directly related to the environment and its protection at the level of micro-scale, as defined previously.

With a proper and a careful study of the mixture leading to an assessment of surface texture and sound absorption properties of the material is already possible to give technical answers to new demands of environmental protection.

In addition to the requests for reduction of noise and vibration and minimizing impacts on the environment of vehicular traffic (micro - scale) we must also consider the higher level (macro - scale) connected to the needs of environmental protection and of an " integrated design " of road infrastructure as already mentioned earlier .

The construction , maintenance and upgrading of the road infrastructures determine, in addition to a high outlay of money, an also high demand for quality raw materials.

Over the last fifty years the transport infrastructures, especially the roads, have experienced an unprecedented development. Many of them have been in use for over twenty years and, having reached the end of their service life, requiring increasing maintenance works to maintain an acceptable levels of service. In addition, over the years, the number of vehicles is steadily increasing, the resulting increase in traffic and the stress caused by vehicles, the higher axle load and the pavement "old age" are all factors that contribute to the deterioration of road surfaces. To address the problems related to it is becoming increasingly widespread technique of recycling of flexible pavements.

The reasons that argue for the need to recycle are numerous and all equally important from the point of view of environmental protection, as well summarize the general lines of the OECD study [2] published in 1997:

- Reducing the use of raw materials;
- Reduction of the areas used as landfills;
- Reducing pollution of the soil and the atmosphere due to the transport of waste;
- Conservation of energy;
- Money saving;
- Technical advantages.

The recycling of asphalt becomes crucial for the correct policies for the protection of natural resources and for the design of new road constructions "integrated" in environmental terms .

For both fields of study described the technical experience and scientific innovations are manifold, the correlations between road materials in general and in particular asphalt and environment are indeed numerous [3]. For this reason, in this paper we will only describe the main and most recent experiences on the subject carried out by our research group at the University of Bologna.

2. MICRO-SCALE LEVEL: ROAD PAVEMENT AND ECO-COMPATIBILITY OF THE TRANSPORT

In recent years there have been developed many types of mixtures for low-noise top layers and new blends are still being studied, numerous studies have been conducted and are still in progress, to identify new types of bituminous mixtures, new materials requirements and surface evenness performance level, able to drastically reduce the generation and propagation of vibrations from

vehicular traffic.
In this short article I will describe two studies: the first relating to the design and implementation of an innovative formulation for thin overlays anti-skid draining and sound-absorbing, the second on the evaluation of the damping characteristics of the paving asphalt and possible technical mitigation.
In recent years it is becoming increasingly widespread in the field of functional maintenance of road surfaces the use of hot asphalt thin overlays. These mixtures are constituted by a discontinuous or semi- discontinuous aggregate grading curve and then are partially draining and sound absorbing in addition to being characterized by a high roughness.
The main reason of this diffusion is the possibility offered by this type of top layers to restore grip without the need to elevate the level of the road and being able to carry even a certain “draining“ and “acoustic“ function further enhancing the safety of circulation, the comfort of motion and the eco-friendliness of the transport.
At the DICAM Department of the University of Bologna we studied and developed both in the preliminary study phase of the mixture [4] that in the commissioning phase in work [5] a particular grading curve “discontinuous“ to use for the realization of a bituminous mixture for thin overlay draining anti-skid .
Considering the positive results obtained we was also considered the possibility of inserting in the conglomerate an amount of expanded clay in order to further improve the performance of the layer especially from the point of view of the adherence [6].
A mixture of this type , characterized by a binder matrix reinforced with glass fibers , by an high percentage of voids (12-15%) and by a semi- discontinuous grain size curve has been studied at the Laboratory of Roads of the DICAM Department and then layered on site as part of a regular maintenance program for the A21 Highway for an extension of about 13 km.
The testing of the new mixture for draining thin overlays compared to a traditional asphalt draining layer has provided very promising results.
It is therefore possible to realize, with thicknesses smaller and smaller (25 mm), surface layers for roads with high permeability and similar to those of a classical draining layer maintaining the advantages of a thin layer:

- Reduced costs, and hence the possibility to mill and repave more frequent;
- Reduced maintenance;
- Reduction of the spray effect and of the aquaplaning without the constraints of minimum thickness of the material put in place;
- Possibility of application on existing pavements with medium-low bearing capacity.

The tests performed in the laboratory and in situ by replacing part of the lytic skeleton with expanded clay has confirmed that its use has many advantages for the antiskid thin overlays.
These layers further improve their performance through the use of expanded clay and in particular we obtain a benefit in terms of grip.
We have, in some way, “integrated” the characteristics of macro-texture connected to the granulometric curve with those of micro-roughness due to the own grain of expanded clay , thus forming a conglomerate that ensures high safety over time.
These materials, as compared to thin overlay already described allow some further improvements including:

- The expanded clay, in part, has the function of absorption of the binder in excess and so we don’t need fibers as additive;
- The lightening of the mixture, significant for the application on bridges;
- A further increase in the coefficient of friction and sound absorption;
- A cost savings due to the lower amount of aggregates (basaltic type).

The second study concerns the analysis of the propagation of vibrations from traffic and possible

mitigation techniques [7] [8]. The vibrations generated by road traffic are a widespread problem in many cities, especially in historical town centers, for the long-term effects that you may have on the buildings and people.
At the base of the vibration generation there are many factors, including the characteristics and the road conditions, the weight, the speed and the suspension type of the vehicle, the properties and the stratification of the soil, the characteristics of the surrounding buildings .
Through the use of a calculation code (FLAC) it has been developed a numerical analysis addressed the evaluation of the mode of propagation of the vibrations generated by road traffic and the effectiveness of some possible attenuation systems of disorder resulting from these.
The mitigation methods examined are represented by structural changes to the pavement or insertion of "shielding" elements adjacent to it:

- Stiffening of the pavement by replacement of the asphalt layer with a layer of cement mix;
- Stiffening of the foundation by replacement of the aggregate layer with a cement bond layer;
- Improvement of the characteristics of the subgrade;
- Inclusion of a trench in concrete next to the pavement.

There has been a preponderance of the Rayleigh surface waves as the cause of the disturbance generated by the vibratory loads typical of road traffic, as already highlighted by the theory of the dynamics of the soil.
Following a parametric analysis we have analyzed the influence of the type of materials used and of the geometric characteristics of the interventions and the results confirmed the benefit of the use of such attenuation systems, they allow to obtain speed reductions between 50% and 80 %.
In particular, the results obtained with the free half-space model allow to argue that the rigid pavement and the wave barriers made of materials with high elastic modulus can reduce the accelerations in a similar manner if we refer to points situated at a certain distance (8-10 meters) from the source of disturbance.
From the study of a model with an adjacent building it has been observed instead that despite the positive effect for both interventions, the stiffening of the pavements reduces the intensity of the vibratory phenomenon, while retaining the amplitude of the load; the barriers instead act mainly on the trend in damping of the oscillation that goes more smoothly.
Overall, the results confirm the effectiveness of these types of interventions in order to shield from the vibrations particularly in sensitive areas.

3. MACRO-SCALE LEVEL: RECYCLING AND ENVIRONMENTAL PROTECTION

As already mentioned in the introduction the requirements of energy saving and environmental protection have meant that they were increasingly asserting "cold" production technologies.
The cold recycling provides many benefits, some of which are immediately apparent while others appear to be less tangible. It is especially important to emphasize the environmental benefits: by means of this process, it is used all the material of the existing pavement. There is no need, therefore, to find the appropriate storage areas, and the volume of new fill material from the quarries is minimized. In this way we will inevitably limit the disfigurement of the environment caused by the opening of quarries and borrow pits. Moreover the magnitude of transport operations is lower than in other processes. The overall energy consumption is therefore significantly reduced as well as the harmful effect on the road network due to the presence of heavy traffic.
In addition there is a further savings due to the low or even zero contribution of new high-quality material from the quarry.
To analyze the potential of the new "cold" technologies it has been developed a campaign of experimental investigations devoted to evaluate the possibility of use as a base layer "ternary" mixtures composed of 100% milled asphalt from old bituminous pavement surface mixed with

percentages varying between 0 and 2% of Portland cement and between 2.5 and 4.5% of bitumen emulsion; the joint use of these binders to the final product ensures a certain degree of elasticity and prevents the phenomenon of cracking that tends to occur when using only a hydraulic binder [9].
From the analysis of the experimental results it was possible to draw some final considerations:

- The mixing of cement, emulsion and recycled material allows to reuse up to 100% of reclaimed asphalt pavement (RAP) aggregate, obtaining a layer of foundation or base with good characteristics of bearing capacity and resistance to fatigue. The layer is flexible and does not crack at low temperatures despite the increase in stiffness due to the presence of the cement.
- The compaction typical of the Marshall test is not suitable for the design and the control in the execution phase of the recycled cold mixtures. The gyratory compactor for timing and mode of application of the loads is closest to the in situ situation through rollers and allows to express in a more objective way and meaningful judgements about the quality of the mixture. The volumetric design of the mixtures can also be applied to cold recycled asphalt.
- Just a small quantity of Portland cement (1.5%) is useful to obtain significant improvements in the compression test and indirect tensile and particularly in the susceptibility to water of the cold recycled mix.
- The cement influences in a positive manner also on the mechanism of reaction of the mixture aggregate-emulsion and allows to obtain conglomerates characterized by a better uniformity during the compaction.

There are still many unknowns to solve and evaluate in the process of cold recycling of the RAP but the use of cement has provided in any case always positive feedback from the point of view of mechanical strength of the mixtures, the fatigue strength of the pavement and the greater reliability and ease of installation of the mixtures.
Another field of research and investigation of the correlations between road construction and environmental protection is the problem of leaching of road surfaces by the rain.
Diffuse pollution is one of the most important environmental problems. This particularly interested in urban basins, where the volume of surface runoff and the concentration of pollutants are higher than in undisturbed basins.
The estimates of the pollutant load transported during a rainfall event are necessary for the following purposes:

- Assess the impact of surface runoff and the concentration of pollutants on the ecology of the watercourse;
- Investigate toxicity problems in the short term;
- Study the effectiveness of various pollution control measures;
- Design equipment storage / treatment.

The existing water quality models consider the contamination of water in two phases - accumulation of pollutants on the surface during periods of dry weather, build up, and the subsequent runoff during rainfall, wash off.
The wash-off is defined as the process of erosion or solution of the constituents accumulated on the surface during rainfall events. The apparent diversity of opinion in explaining the phenomenon of run-off is concentrated around four explanatory variables, rainfall intensity, volume of rain, trend and volume of surface runoff, and four processes, detachment of the pollutant due to the impact of the drops of rain, transport due to the 'splash' of the raindrops, detachment and transport due to surface runoff. It's difficult to distinguish between the explanatory variables because each of them is linked to the other.
The experimental research on the subject has been carried out in collaboration with the area of Hydraulic Structures [10].

4. CONCLUSIONS

At the end of the report is important to highlight the most topical and most relevant areas of research for the coming years in the field of environmental protection in relation to the road construction.
New potentials and consequently new areas of research open up for the correct use of asphalt in terms of reduction of impacts.
Among the most interesting topics we can remember:

- The use of foamed bitumen for recycling foundation layers in situ or for the realization of base layers;
- The actual applicability of the techniques of cold recycling with bitumen emulsion and cement with use of RAP up to 100% for the realization of base and foundation layers;
- The possibilities for use of the techniques of recycling asphalt also for draining layers;
- The study, the design and construction of new asphalt layers for anti -vibration base with part of the skeleton consists of granules of rubber;
- The possibilities for development of a new pavement with a sound-absorbing double drainage layer in urban areas;
- The potential from the point of view of the protection of the environment from new road pavement "perpetual" (perpetual pavements) or with zero maintenance;
- The study and evaluation of the transport of pollutants on the road surface and their relationship with the characteristics of the asphalt;
- The possibilities of use of titanium dioxide , already used in paving blocks of concrete as an anti-pollutant elimination of nitric oxide, even in the asphalt.

They are numerous and all equally interesting the challenges that lie ahead both in research and in the road construction techniques for the future, we must be ready to face them also to meet the current and increasingly stringent environmental protection requirements.

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