REINFORCED FLEXIBLE PAVEMENTS: COST-EFFECTIVE ANALYSIS

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ABSTRACT

Flexible pavements are a widespread method to build infrastructures in Europe and in Italy in particular. It is well known they are a multilayer system of Hot Mix Asphalt (HMA) and the lack of bearing capacity of this material can affect the service life. Therefore, in the last 10 years worldwide researches were involved in studies related to the use of different reinforcing systems, in order to build more efficient and cost-effective infrastructures, but taking into consideration the protection of the environment as well. Hence, the aim of this work is to analyze the benefits of the use of different kind of grids inserted in a multilayer flexible pavement. In fact, the consequent effects of this choice were studied in terms of service life of asphalt pavements.

As a result these advantages were translated not only in a saving of money, but also in an improvement of the quality of performances. Moreover, the reinforces were placed in the pavements in a "superficial position" and subsequently that means it would be possible to adopt this building technique in pre-existing infrastructures, in order to improve the performances and to extend the service life of weak asphalt pavements.

Furthermore, the objective of this work was reached arranging a laboratory survey using real scale samples. In fact, 3-point bending tests were carried out using different specimens with and without reinforces, in order to underline and analyze the dissimilarities between these two different scenarios.

1. INTRODUCION

In Italy the majority of the road pavements are built as multilayer structures and the materials involved in the superficial layers are asphalt concretes. In this case it is possible to define these infrastructures as flexible pavements and they are composed by several strata. Sub-base and base courses are not necessarily composed by asphalt mixtures and their main purpose is to sustain the vertical deflections caused by traffic load on the surface of the road.

In particular sub-base layers are basically built with stabilized natural soil, in order to obtain adequate mechanical properties (bearing capacity), as well as a satisfactory waterproofing capacity and a proper cohesion. Moreover, the superficial layers are usually created with two different Hot Mix Asphalt (HMA): the upper one (wearing course) have to support the shear stresses and the one below could be considered as link stratum (binder layer) between the deep part of a road pavement with the surface area. A different kind of road pavements is the semi-rigid ones. This is adopted in 90% of the Italian highway and it is common in the rest of the world. The superficial layers are realized as explained above including a base course, but the sub-base stratum is realized as a cement-modified granular material.

However, the ordinary maintenance work involves the superficial strata (wearing course and/or binder layers) that are compacted one upon the other using asphalt concretes with different particle size curve, amount of bitumen or filler. The thickness is usually around 10 to 15 cm and they are laid down on a base course with similar depth. In fact, the repairing works usually replace the surface layers milling the pre-existing strata every 10/20 years.

However, the restoration of the superficial layers, which is a common technique to increase the serviceability of the roadways, it is often connected to the use of reinforcing systems. In fact, in the last 10 years, the scientific publications worked on these new methods, which could be useful to extend the in-service life of the infrastructures and to delay a final reconstruction. Moreover, these interlayer systems could be inserted in flexible pavements as well as in rigid (or semi-rigid) pavements as a support when the traffic increase. In fact, the reinforcing systems could help the lack of support of the asphalt mixtures or absorb the deformations of the road pavement strata or even create a proper separation between layers.

The most common interlayer systems are steel nets, Reflective Crack Relief Interlayer (RCRI), Sand AntiFracture mix (SAF) or several kinds of geosynthetics, such as polypropylene, polyester, glass grid or geogrid. At the beginning of the XXI century, the University of Nottingham [1] started several investigations related to the performance of the reinforced flexible pavements, carrying out different tests in the laboratory, in order to underline the benefits of the reinforcing systems. This work was the basis of a recent work developed by Rowe et al. in 2009 [2], which could highlighted the advantage of the use of the interlayer systems. Moreover, studies related to this topic were carried out in-situ or using full-scale testing systems [3, 4, 5, 6, 7, 8], since these investigations could show the effects of the reinforcing systems in real conditions and make proper conclusions related to the use of these reinforcements.

In fact, test sections were realized in several research institutes and different tests could underline the benefits of different kinds of grids inserted in different positions and simulating the real traffic conditions. These research works were related to the performance of the flexible pavements with different kinds of reinforcing systems inserted at different depths. However, these investigations were also conducted on diverse typologies of roadways, such as rigid pavements where a jointed Portland Cement Concrete (PCC) layer is positioned on the bottom of an asphalt overlay. In fact, reinforcements could be inserted in the upper asphalt layers to rehabilitate an existing pavement or it could be considered an anti-reflective system. Several research works [9, 10, 11, 12, 13, 14] underlined the benefits and the versatility of the presence of a reinforcing systems in a road pavements.

The presented bibliography review could emphasize the worldwide use of these devices as a rehabilitation method for pre-existent road pavements, as well as a suitable technique to postpone any maintenance works. Starting from these results, a laboratory investigation was set in order to underline the effects of two different kinds of reinforcing systems inserted in a typical Italian flexible road pavement, built as multilayer system.

2. LABORATORY INVESTIGATION

A laboratory investigation was set starting from the creation of suitable asphalt concretes, in order to create real scale samples able to reproduce a portion of a road pavements. In fact, the aim of this investigations were to test different kinds of specimens with different geometries and diverse reinforcing systems carrying out 3-point bending tests and collecting the data coming from the different scenarios.

A strict methodology was followed and in the first step three particle size curves were created to obtain three different kinds of Hot Mix Asphalt useful to build multilayer slabs. These asphalt materials were a typical base course (0÷30 cm), binder layer (0÷15 cm) and wearing course (0÷10 cm) mixtures. The aggregated used were limestone from Northern Italy, a natural bitumen (PG 64-28) was add to mix these concretes as well as a different amount of filler (Figure 1).

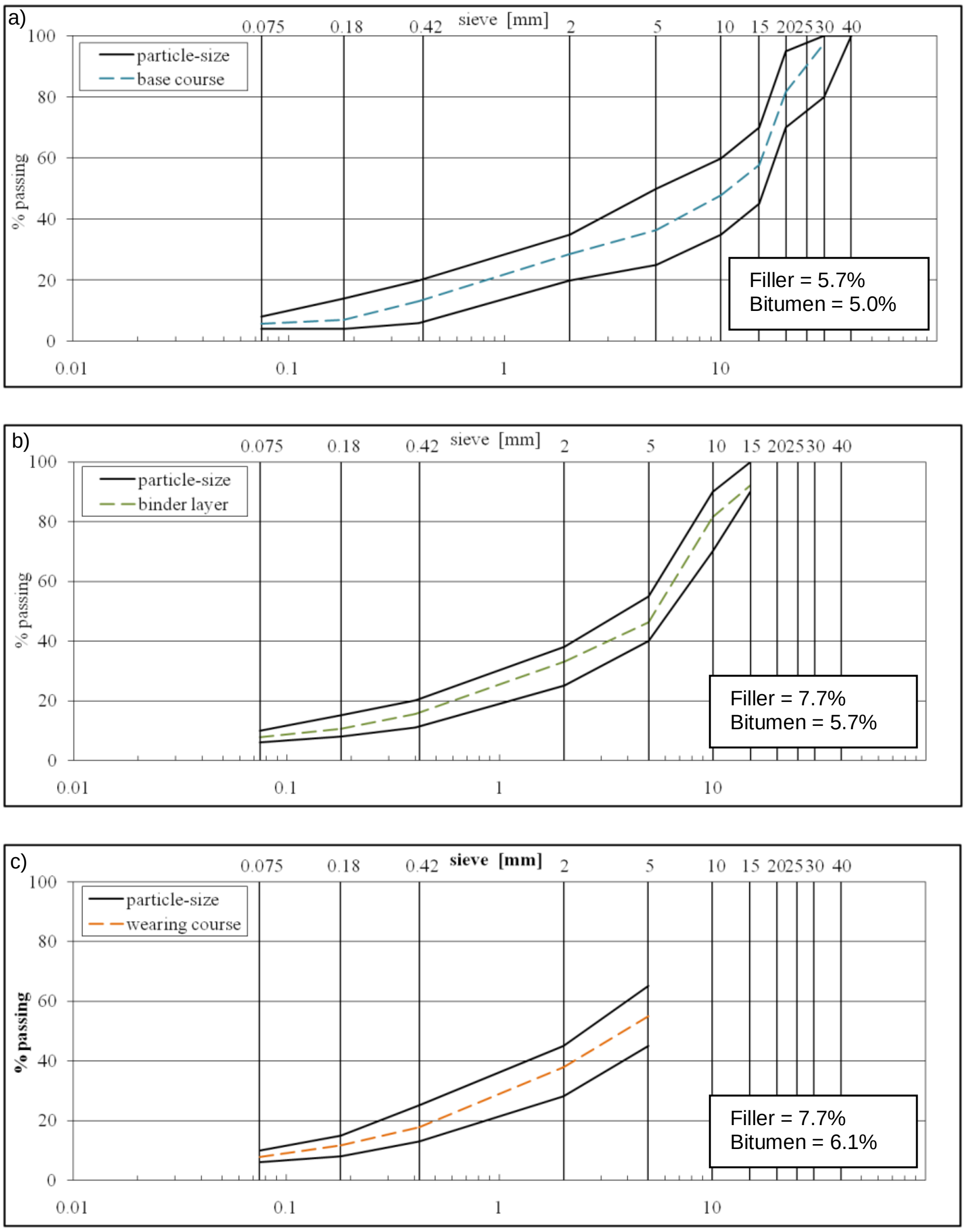

Figure 1 - Particle size curve of base course (a), binder layer (b), wearing course (c)

The asphalt materials were prepared using a proper asphalt mixture at the University of Parma. The aggregates were heated in an oven at the temperature of 150°C and mixed with the same asphalt binder at the same temperature. Once the mixture was homogeneous, the filler was added in the mixer and the material was put again in an oven at 150°C to make the temperature uniform. In the following step, these asphalt mixtures were compacted using a heavy compactor (Figure 2) specifically built up for the University of Parma [15]. Using this equipment, two different shapes of samples were created to carry out three-point bending tests: one was a typical beam [16] and the second one was a bi-layer slab.

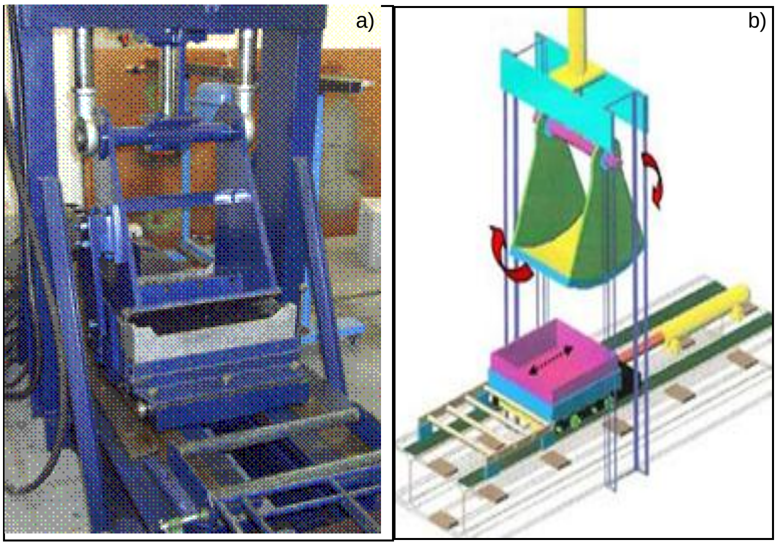

Figure 2 - Heavy compactor (a), the relative scheme (b)

The beams were cut from multilayer slabs composed by 30 mm of wearing course, 40 mm of binder layer and 100 mm of base course. The geometry of the samples is showed in Figure 3.

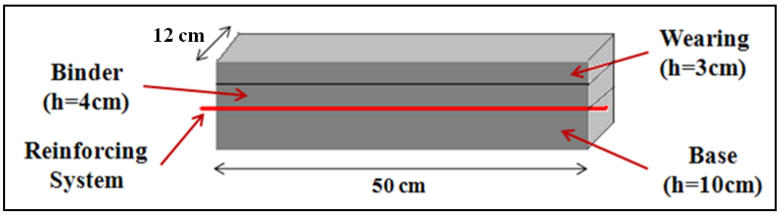

Figure 3 - The geometric features of the multilayer beams used for 3-point bending tests

The beams were divided into three different typologies: one with the steel net, one with the glass grid and the last one without any kind of reinforce, as control sample. The reinforcing system was positioned in a superficial position between binder layer and base course, since during the maintenance work, the superficial strata are the ones involved. In one of the typology of sample a hexagonal steel net with transversal reinforcing bars was inserted (Figure 4) and the characteristics are explained in Table 1.

Figure 4 - Steel net reinforcing system (a) and a detail of the double twisted grid (b)

Table 1 - Features of steel net reinforcing system

STEEL NET	
Steel Net Diameter	2.4 mm
Reinforcing Bar Diameter	4.4 mm
Longitudinal Stiffness	22.7 MN/m
Transversal Stiffness	19.5 MN/m
Longitudinal Nominal Stiffness	35.00 MN/m
Transversal Nominal Stiffness	50.00 MN/m
Elastic Modulus (E)	200000 MPa

A second typology of specimen was equipped with a different kind of reinforce: a glass grid composed by a squared mesh and with a thin bitumen film to guarantee a better adhesion with Hot Mix Asphalt (Figure 5). The characteristics of this second reinforcement are explained in Table 2.

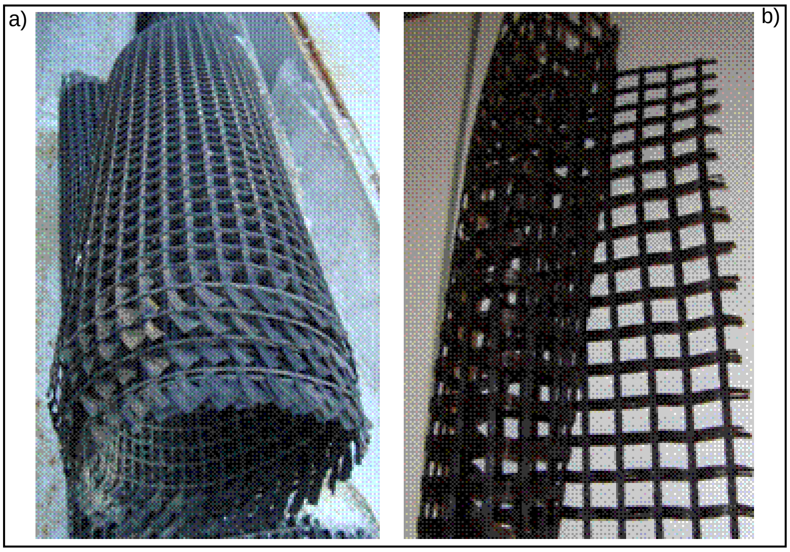

Figure 5 - Glass grid reinforcing system (a) and a detail of the squared net (b)

Table 2 - Features of glass grid reinforcing system

GLASS GRID	
Longitudinal Nominal Strength	100 KN/m
Typical Longitudinal Elongation (under max load)	<4%
Transversal Strength	100 KN/m
Typical Transversal Elongation (under max loading)	<4%
Elastic Modulus (E)	76 GPa

Moreover, the beams reinforced with the steel net were divided into two more typologies. In fact, the dimensions of the beams could not allow the insert of a whole mesh including the reinforcing bar. Therefore, there were beams with steel mesh and others with steel mesh plus bars (Figure 6).

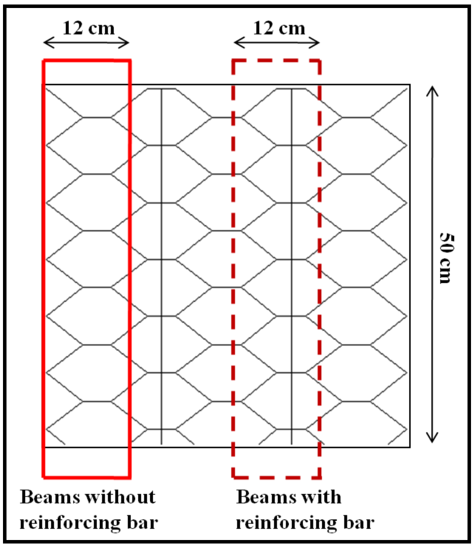

Figure 6 - The two typologies of multilayer beams reinforced with steel net: on the left the ones without bar and on the right the ones with bar

This issue was totally meaningless for those beams reinforced with glass grid. In fact, the smaller dimensions of this kind of mesh permitted to insert the whole geometry in each sample. In summary, the beams tested were divided into four categories: a control ones without any reinforcing system, the ones reinforced with glass grid, the ones with steel net and the last ones with steel net and reinforced with bar.

The second typology of samples used to carry out three-point bending tests was squared slabs 500 mm x 500 mm, but prepared with the same heavy compactor and using the same asphalt mixtures. These slabs were composed by 2 layers: 30 mm of the wearing course and 40 mm of the binder layer (Figure 7) and the reinforcement were positioned at the bottom of the slabs.

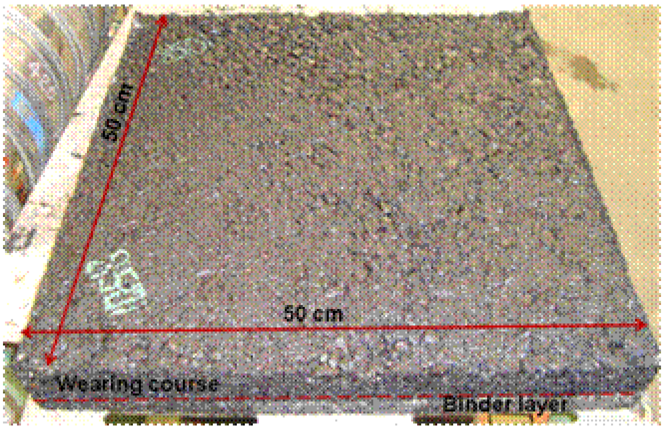

Figure 7 - The bi-layer slab 50 cm x 50 cm

Once more, these specimens were divided into three different types: one was the control specimens without any kind of reinforce and the others two were equipped with a reinforcing net (steel or glass grid) totally embedded at the bottom of the binder layer. In this case, the dimensions of these samples could include the whole geometry of the steel net, such as the entire mesh as well as the reinforcing bars (Figure 8). Hence, this second typology of specimens (thin slabs) could be only divided into three categories.

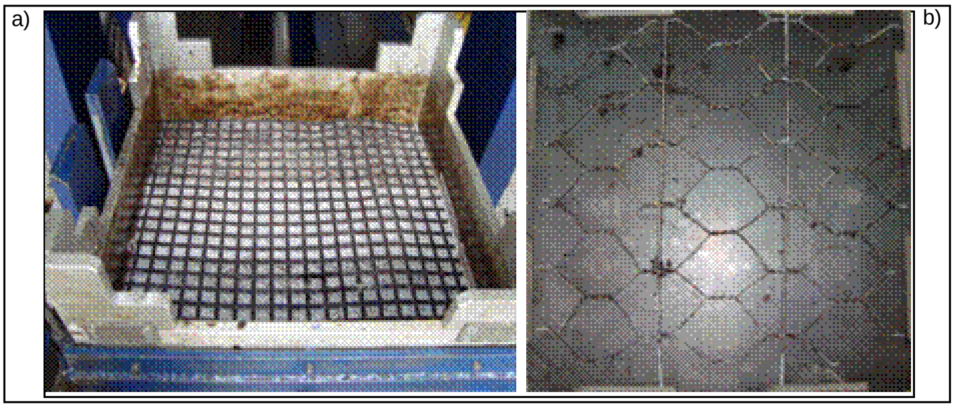

Figure 8 - Reinforcing systems positioned in the formwork used to prepare the : steel net (a) and glass grid (b)

However, the test set-up was the same in both cases (beams and thin slabs) and the data were collected using the Material Test System (MTS) machine available at the University of Parma. The tests were run adopting a three-point bending configuration and fixing a displacement rate of 0.084 mm/s (Figure 9). The investigations was totally conducted at 10°C, since this temperature could maintain the asphalt concretes in a visco-elastic domain [17] and avoid any plastic damages.

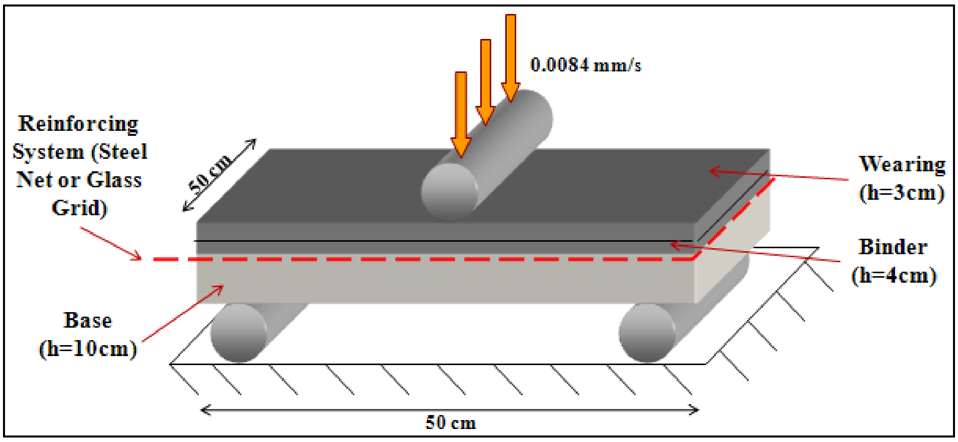

Figure 9 - The geometric features of the bi-layer slabs used for three-point bending tests and the test set-up

The graph in Figure 10 shows the results collected during the carrying out of the three-point bending tests and using the samples with beam shape. Four curves represent the different typologies of specimens. Furthermore, the investigation was implemented with an energetic analysis, in order to study the different levels of the stores of energy for each type of specimens (Figure 11).

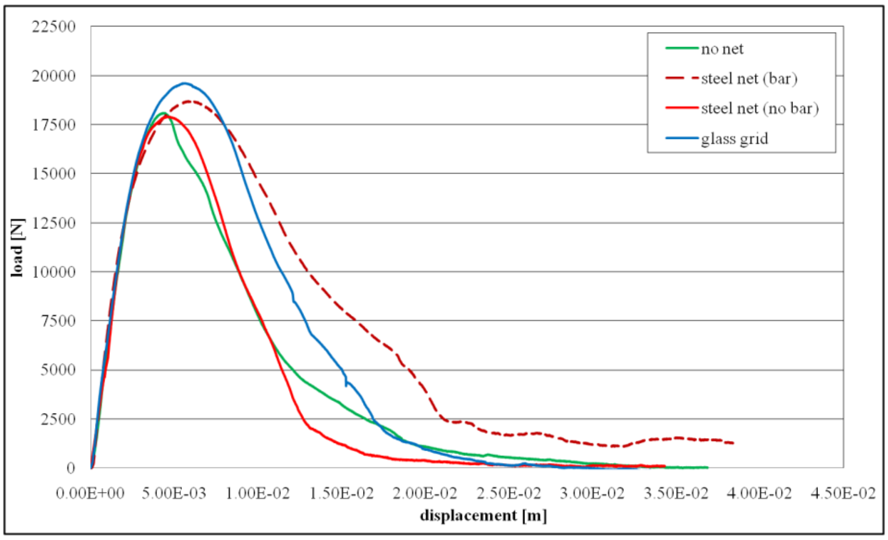

Figure 10 - The results collected running three-point bending tests on the four typologies of the multilayer beams

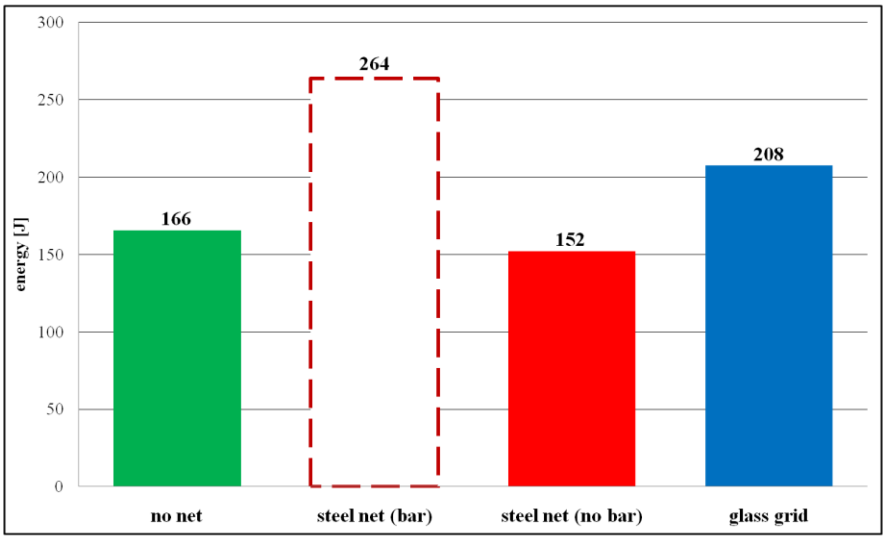

Figure 11 - The energetic analysis of the four typologies of the multilayer beams running three-point bending tests

However, the Figure 12 shows the output data collected during the analogous tests, but carried out using bi-layer slabs. Here there were only three curves: the green one represents the control slabs, the red one the slabs with steel net and the blue one the samples equipped with the glass grid. Moreover, in Figure 13 it is possible to observe the corresponding store of energy in this second kind of samples.

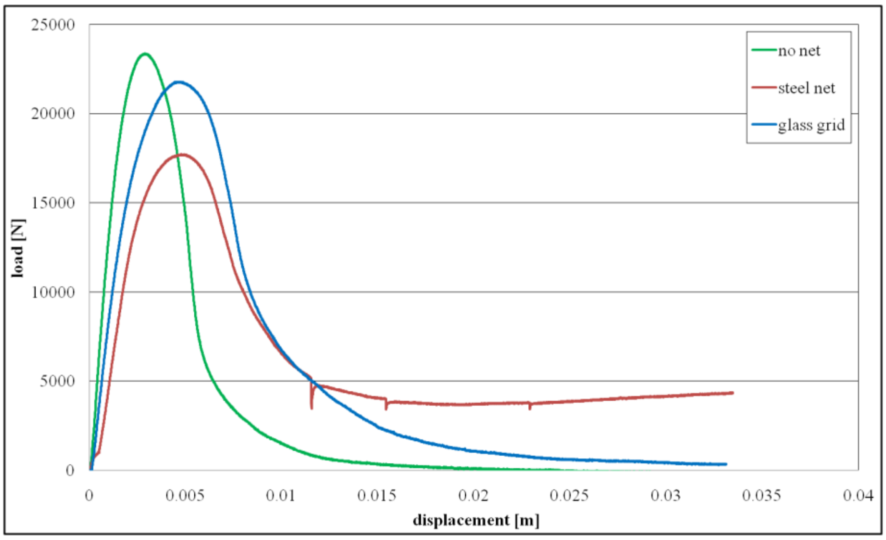

Figure 12 - The results collected running three-point bending tests on the three typologies of the bi-layer slabs

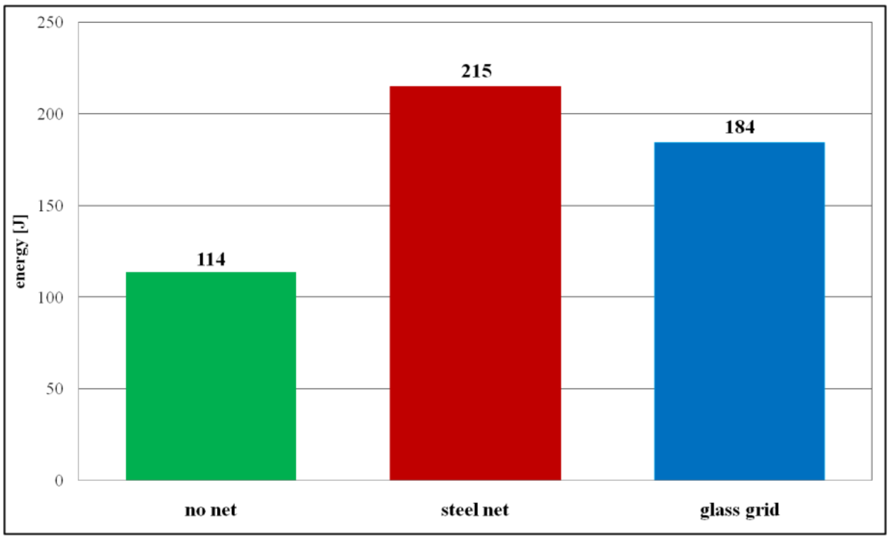

Figure 13 - The energetic analysis of the four typologies of the bi-layer slabs running three-point bending tests

The results presented in the Figures above show the different behaviours of the two typologies of samples. In fact the peak values of stress or the store of energy is not only different between reinforced and unreinforced specimens. But also slabs and multilayer beams provided with the same kind of reinforcing system exhibit different behaviours and this was expected since previous works showed analogous scenarios [16].

The study of the graphs in Figure 10, 11, 12, 13 has to consider the shape of the curves and not only the peak values of the stress. In fact, the area under those curves represented the energy. Table 3 shows that the beams with steel net plus bars or the bi-layer slabs with the same grid can store more energy than the other specimens. In fact, the unreinforced samples (both typologies) could store around 40÷50% more energy than the ones with a reinforcing system.

Table 3 - Energy stored by multilayer beams and bi-layer slabs during 3-point bending tests

Samples	***<u>Multilayer beams</u>* Energy stored [J]**	***<u>Bi-layer slabs</u>* Energy stored [J]**
No Net	166	114
Steel Net (with bar)	264	215
Steel Net (no bar)	152	-
Glass Grid	208	184

On the other hand, control samples are the ones that could reach the highest stress values. However, when the failure started they immediately collapsed and the specimens with reinforcing systems showed a better post-failure resistance. This behaviour is evident in both typologies of samples: in the multilayer beams (Figure 14) the crack arrived straight to the top of the samples and the bi-layer slabs (Figure 15) broke completely into two parts.

Figure 14 - Three-point bending test carried out of the multilayer beams at the beginning of the analysis (a) and the different failure of unreinforced samples (b) and the reinforced ones (c)

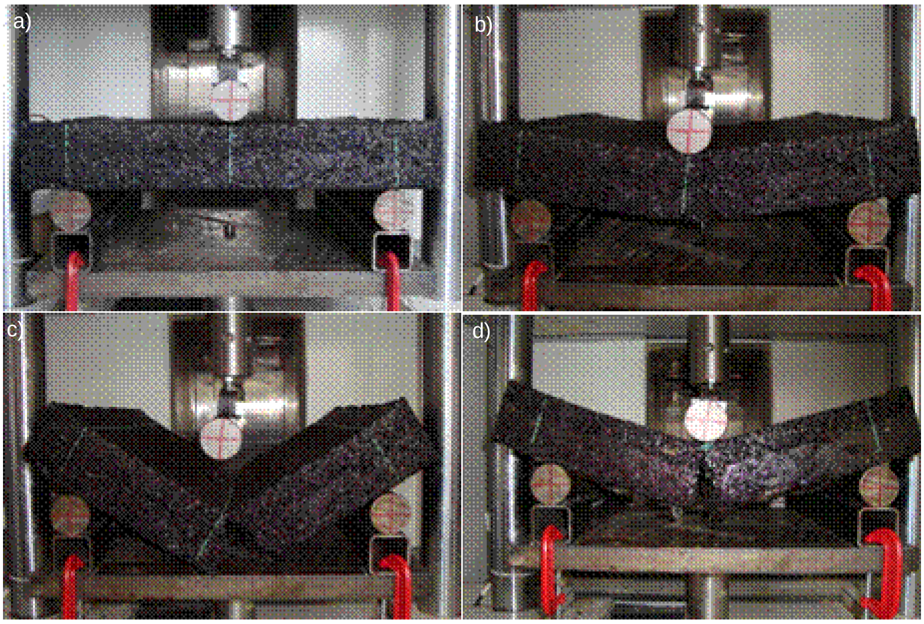

Figure 15 - Three-point bending test carried out of the bi-layer slabs at the beginning of the analysis (a) (b) and the different failure of unreinforced samples (c) and the reinforced ones (d)

In summary, the presence of the reinforcing systems could increase the amount of the stored energy and could avoid a brittle rupture, when the cracks occurred in the superficial layers. These results highlighted the possibility to consider these devices as a proper way to save money, since these interlayer systems permitted to postpone the maintenance work. In fact, the presence of these grids increase the performance of the infrastructures and the superficial position permitted to insert these net in pre-existent road pavements as well.

3. CONCLUSIONS

The results collected with the laboratory investigations allowed to draw conclusions related to the use of the reinforcements and their benefits. In fact, the tests underlined the possibility to improve the performance of the road pavements inserting an interlayer system in a superficial position. This choice permitted to use the reinforcing systems during a common maintenance work and to delay the final construction of a roadway. In this way, tonnes of asphalt materials could be saved and money as well.

The European Asphalt Pavement Association (EAPA) published in 2009 an overview referred to asphalt production and the application of binder among the European countries. The total production of Hot and Warm Mix Asphalt in Europe in 2009 was 326.9 million of tonnes, which is only 12.6% less than the analogous production in the United States (374.0 million tonnes). Table 4 summarizes the ten greater producers in Europe of asphalt mixtures and Italy is in fourth position.

Table 4 - Total production of Hot and Warm Mix Asphalt of the European countries

Country	***Total production of Hot & Warm mix Asphalt (million tonnes)***
Germany	55.0
France	40.1
Spain	39.0
Italy	***34.9***
Turkey	23.1
Great Britain	20.5
Poland	18.0
Netherlands	9.8
Austria	9.0
Portugal	9.0

The previous Table highlighted that Italy produced the 10.7% of the total asphalt production of the entire Europe. It is well known that these industries produce polluting substances and a restriction of consumption in asphalt mixtures would be an eco-friendly choice. Moreover, the production of Hot and Warm mix Asphalt could be related to the consumption of bitumen and Italy is the fourth country in Europe, right after France, Germany and Turkey. In fact, in 2009 the Italian road industries consumed 1.8 million of tonnes of bitumen, which is the 9.6% of the total European use during the same year. This consumption is not only a direct consequence of an increasing pollution, but it is directly connected with the lack of companies which product binder. In fact, in Italy more than 3500 companies among the road industries are just involved in laying the asphalt materials, which is 100 times more than those ones that are involved in the production (30 companies). Only 570 companies are occupied both in production and in laying the asphalt mixtures. However, these data highlighted the necessity of the Italian road industries to import binder, which implied an extra cost in the production of the asphalt mixtures. Hence, this analysis underlined the need to cut the use and production of asphalt materials, in order to save money and to preserve the environment.

The use of reinforcing system placed in the superficial layers of a road pavement permitted to extend the in-service life. Consequently, these devices would consent to save asphalt materials, delaying the maintenance works. In fact, the milling of the superficial layers could be postponed and it would be possible to decrease the production of the asphalt materials as well as the amount of the wasting materials.

4. ACKNOWLEDGEMENT

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