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Recycling Techniques and Environmental Issues Relating to the Widening of an High Traffic Volume Italian Motorway

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Abstract: On the last few decades, the use of recycled materials has become important because of the limited availability of good aggregates and the difficulties and excessive disposal costs for milled materials. This study provides an environmental evaluation of a specific rehabilitation project involving several recycling techniques on one of the main Italian motorways. Three rehabilitation options are evaluated and compared in terms of their environmental impact, with particular emphasis on the construction of the subbase course. In the end, the definitive design involved different recycling techniques, including cold in-place recycling (CIPR) with bituminous emulsion and cement for the subbase layer, stabilization of the soil with lime for the embankment, the use of reclaimed asphalt in the production of hot mix asphalt, and the use of crushed cement concrete for the cement treated layers. All of these recycling methods allow the saving of the virgin aggregates, and a reduction in materials transportation and pollutant emissions coming from both the production plant and the means of transport.

***Key words**: Air pollution reduction; Energy saving; Recycled materials.*

Introduction

Since the late 1970s, the increase in the price of asphalt and the development of milling machines and drum mix facilities have led to a new awareness of recycling. Nowadays, the growing importance of environmental and economic matters has led engineers to promote and improve techniques for reusing milled materials from the existing damaged road structures, rather than to open new quarries and import materials for upgrading or building of asphalt pavements. Therefore, the new trend in road construction and repair is to use the intrinsic and residual properties of the materials *in situ*, to provide environmentally sustainable and cost-effective road structures [1-4].

In particular, in hot mix asphalt (HMA) recycling, the reclaimed asphalt (RA) is basically treated as an aggregate. The aggregates are superheated prior to mixing with the RA, which is added directly to the weigh hopper. Since RA is not heated, the maximum percentage of RA used is approximately 30% of the total mixture. However, most applications contain significantly less than 30% RA. On the other hand, cold-mix recycling allows the use of up to 100% RA or reclaimed materials. The recovered materials are combined with stabilizing agents (bitumen and/or hydraulic binders) *in situ* or at a central plant for the production of cold mixtures. In particular, cold recycling by means of bitumen stabilized materials includes bituminous emulsion [5] or foamed bitumen [5-7] treated mixtures. The adding of the bituminous binder provides lower brittleness and lower water sensitivity than materials treated only with cement. Moreover, the use of a bituminous binder prevents shrinkage, which typically occurs in cement-treated materials.

Road structure recycling is a strategy that started in Italy in the 1970s, and in the year 2000, it reached 2,000,000*tons* of RA recycled. Currently, one of the main applications of recycling techniques has been used for the A14 motorway, which links the city of Bologna to the city of Taranto along the Italian Adriatic coast. The A14 is a four-lane dual carriageway facility, except for the northern 117*km*, which is already a six-lane dual carriageway facility. The old road structure consists of 300*mm* of asphalt concrete, 200*mm* of cement treated mixture, and 200*mm* of granular mixture. Over the last few years, the increase in heavy vehicle traffic (now about 5,000,000 of 8*tons* Equivalent Single Axle Load (ESAL) per year) has seen the need for the widening of each carriageway into a three-lane facility for a further 171*km*. In particular, the selected section is 42*km* long and is located between the toll booths of Ancona Sud and Civitanova Marche, in the Marche Region.

In this road section, the upgrading works started in March 2007, and it involves heavy earthworks for the widening of each carriageway, followed by the construction of new road layers, including a bituminous treated subbase. In this context, the evaluation of three rehabilitation options preceded the construction work, with particular emphasis on the construction of the subbase course. The definitive design has involved different recycling techniques, such as cold in-place recycling (CIPR) with bituminous emulsion and cement for the subbase layer, the stabilization of the soil with lime for the embankments, the use of RA in the production of HMA, and the use of crushed cement concrete for the cement layers.

Since recycling on such a large scale was new to the Italian motorway construction company, a complete investigation over a trial section was undertaken in 2007 [8, 9]. The results of that study indicate that the asphalt pavement achieves the required structural capacity in combination with huge environmental and economic advantages.

Cold In-Situ Recycling for the Subbase Layer

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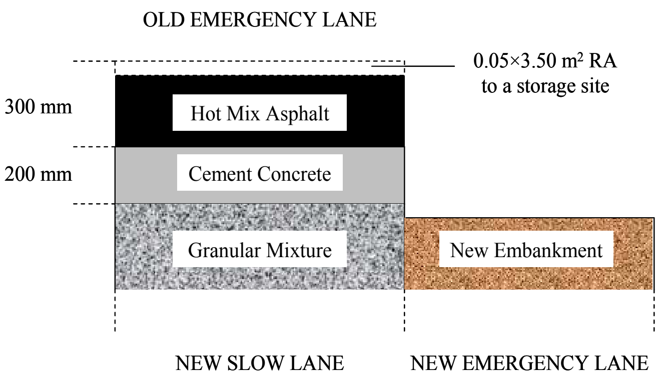

Fig. 1. Milling of the Old Asphalt Pavement - First Step.

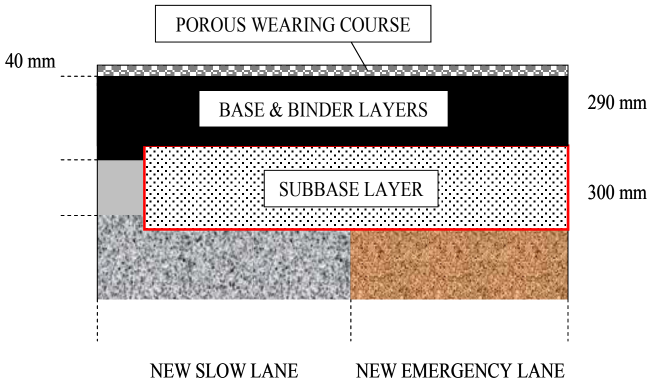

Fig. 2. Paving of the Asphalt Layers.

In this study, the authors present the technical and environmental benefits obtained from the adoption of CIPR for the widening of the Italian A14 motorway to a six-lane dual carriageway facility.

The first proposal provided CIPR stabilization with foamed bitumen of the subbase layer for the new slow lane, corresponding to the old emergency lane, and cement and/or lime treated soil for the new emergency lane subbase.

In more detail, the main construction phases are:

– widening of both carriageways;
– milling of 250*mm* of asphalt layers carrying materials to a storage site;
– soil stabilization with cement and/or lime for the new emergency lane subbase for a thickness of 300*mm*;
– stabilization of the new slow lane material by foamed bitumen, for a thickness of 300*mm* (50*mm* asphaltic material, 200*mm* cement concrete, and 50*mm* granular mixture); and
– surfacing with the asphalt layers (200*mm* base course, 50*mm* binder course, and 40*mm* porous wearing course).

Therefore, to guarantee the required structural capacity, the new road structure consists of 290*mm* asphalt concrete and 300*mm* stabilized subbase.

As an alternative, which was subsequently selected as the definitive solution, stabilization with bituminous emulsion and cement was adopted for both lanes (new slow lane and emergency lane) using the reclaimed materials coming from the old emergency lane. Indeed, the RA obtained from milling the old emergency lane was almost coincident with what was required for the construction of the subbase for the new emergency lane.

To obtain similar materials for the subbase of the new slow lane and the new emergency lane, the milling procedure was chosen so as to have a recycled blend of about 50% RA and 50% cement-treated and granular material from the old road structure.

To precisely obtain such a recycled blend, an “articulated” milling sequence was undertaken that involved the asphalt layers, the cement-treated layer, and the upper part of the foundation layer of the old emergency lane. This milling sequence and the successive construction phases are described as follows:

– widening and construction of the new embankment on which the new emergency lane is built. The top level of the embankment is 0.55*m* below the surface level of the old asphalt pavement. Indeed, the top of the new binder course corresponds to the old road-surface level;
– milling of asphalt concrete to a depth of 0.05*m* for the total width of the old emergency lane (3.50*m*) and carrying of materials to a storage site (Fig. 1);
– milling of the asphalt concrete for a further 0.20*m* (to a depth of 0.25*m*). Note that the depth of 0.25*m* corresponds to the top level of the new recycled stabilized layer. Moreover, this second milling operation generates a stair (0.25*m* wide and 0.05*m* thick) that is required for the joint stagger of the new binder layer. The recovered RA was placed on the new embankment by the side of the old emergency lane;
– milling of a further 0.20*m* (to a depth of 0.45*m*), involving the remaining 0.05*m* of the old asphalt concrete and 0.15*m* of the old cement treated mixture. Note, this milling operation generates another stair (0.40*m* wide and 0.20*m* thick) required as support for the wheel of the recycler. The milled materials were placed on the external side of the new embankment;
– mixing and leveling of the total milled materials using a grader, and compaction to the required level using a vibrating smooth-drum roller;
– spreading of cement (2% by aggregate weight) using the correct vehicle, equipped with volumetric batchers. Subsequently, the recycler coupled to a tank truck was used to stabilize a thickness of 0.30*m* of material with bituminous emulsion (3% by aggregate weight). Note that the stabilizing operation also recycles the remaining 0.05*m* of the cement treated mixture and about 0.05*m* of the granular foundation in the old emergency lane;
– the treated material was compacted by a 14-ton vibrating smooth drum roller and a 25-ton pneumatic tyre roller, before being shaped by a grader. Finally, the 25-ton pneumatic tyre roller was used to complete the compaction procedure of the stabilized subbase layer;
– application of a protective surface treatment consisting of cationic bituminous emulsion covered by 4/8*mm* crushed gravel. The emulsion contained 55% bitumen and was spread at a rate of 1.2kg/m^2 while the gravel was laid at an application rate of 6l/m^2; and
– surfacing of the asphalt layers. Note that the new binder level corresponds to the surface level of the old asphalt roadway. This implies a superelevation of 0.04*m* (wearing course) with respect to the old asphalt surface (Fig. 2).

From a technical point of view, this construction technique allows the realization of the whole subbase layer for both lanes with the same bound mixture, avoiding the formation of a longitudinal joint between the two lanes as considered for the original pavement design.

Moreover, there is no material moving, but rather a lateral displacement. From a logistic point of view, this aspect is a very important consideration in the case of narrow and long yards that are characterized by few accesses.

Bitumen emulsion offers several advantages with respect to foamed bitumen. Indeed, the bituminous emulsion does not have to be heated to 160-180°C, allowing improved safety for the workers. Foamed bitumen has to be rejected if its temperature is too low (generally below 160°C), and this is not the case for bitumen emulsion, which has a wider temperature range of application (5-80°C).

However, in using bitumen emulsion, particular attention has to be paid to the moisture content of the materials to be treated, to avoid any excess moisture due to water released by the emulsion. In this case, it is neither possible to lower the bituminous emulsion dosage nor to increase the cement content; it is necessary instead to leave the materials under natural aeration and wait until they reach the required water content.

Evaluation of Environmental Benefits

The construction of the third lane in the studied road section was developed by paying particular attention to the related environmental issues, involving the following main recycling techniques:

- CIPR with bituminous emulsion and cement for the subbase layer;
- stabilization of the soil with lime for the embankment;
- use of RA in the production of the HMA. In particular, the Italian specification provides for a maximum percentage of RA of 20% of the total mixture for the base courses, and 15% for the binder courses; and
- use of crushed cement concrete, coming from the demolition of old cement elements, for the cement treated layers, for depth adjustment in curved sections, or as the foundation for the New Jersey barriers.

In this section, the authors focus on the environmental issues related to the construction of the new lanes. The two above-mentioned construction proposals and the more common hot bituminous treated subbase are evaluated and compared.

In particular, the study mainly consisted of the assessment of:

1. the materials recycled;
2. the lorry movements for the transportation of materials involved in the construction process; and
3. the energy consumption and pollutant emission from a central plant during the production of the subbase layer.

Materials Recycled

According to the first proposal, the subbase construction would have involved treatment with foamed bitumen of about 80,000m^3 of reclaimed material for the new slow lane and the lime stabilization of about 70,000m^3 of supplied soil for the realization of the new emergency lane. On this basis, 15,000m^3 of RA would have been recycled into the subbase of the new slow lane, 35,000m^3 of RA would have been recycled into the base (20%) and binder (15%) courses, and 40,000m^3 would have been stored (Table 1).

On the other hand, the actual construction procedure adopted (the second proposal) allowed 150,000m^3 of the materials to be recycled for the realization of the subbase course for the new slow lane and the new emergency lane. In this case, 75,000m^3 of RA were cold recycled, while only 15,000m^3 were temporary stored prior to be re-used in HMAs (Table 1). Indeed 35,000m^3 of RA are used to produce HMA as for the previous proposal, so a further 20,000m^3 of RA was taken from other storage sites.

In some cases, the CIPR technique is used instead of the traditional HMA. On the basis of previous laboratory and *in-situ* experiences, the authors suggest the consideration of an equivalency coefficient between the thickness of the cold recycled material and the thickness of the HMA, of 0.75-0.85. This means that 300*mm* of cold recycled material corresponds to about 225*mm* of HMA. Thus, if this layer had been prepared with an HMA containing 4.5% bitumen and with 7% air voids, about 90,000m^3 of natural mineral aggregates and 11,000*tons* of bituminous binder would have been used, resulting in a relevant environmental issue. Moreover 55,000m^3 of RA would have been stored (Table 1).

Additionally, in all cases, 50,000m^3 of waste cement materials coming from the demolition of old cement elements were recycled to produce cement concrete used for depth adjustment for curved sections or as foundation for the New Jersey barriers. At the same time, 270,000m^3 of soil were recycled to build the embankments (Table 1).

Table 1. Comparison of Recyclable Materials.

	1st Proposal[a]	2nd Proposal[b]	HMA Subbase
Recycled Material (m^3)	80,000	150,000	0
Recycled RA in Subbase Course (m^3)	15,000	75,000	0
Recycled RA in Binder and Base Courses (m^3)	35,000	35,000	35,000
Stored RA (m^3)	40,000	15,000 (reused)	55,000
Soil Supply (m^3)	70,000	0	0
Mineral Aggregate Supply (m^3)	0	0	90,000
Bitumen Supply (*ton*)	0	0	11,000
Recycled Cement Materials (m^3)	50,000	50,000	50,000
Recycled Soil (m^3)	270,000	270,000	270,000

[a] New slow lane: foamed bitumen treatment; New emergency lane: cement and/or lime stabilized soil.

[b] New slow lane: bituminous emulsion treatment; New emergency lane: bituminous emulsion treatment.

Table 2. Environmental Footprint of Lorry Movements.

	1st Proposal[a]	2nd Proposal[b]	HMA Subbase
Lorry Trips	20,500	2,900	44,700
Gas Emission Due to Lorry Trips (*ton*)	285	80	1,700
Lifetime Decrease of the Secondary Roads (%)	3.2	0.46	10.0

[a] New slow lane: foamed bitumen treatment; New emergency lane: cement and/or lime stabilized soil.

[b] New slow lane: bituminous emulsion treatment; New emergency lane: bituminous emulsion treatment.

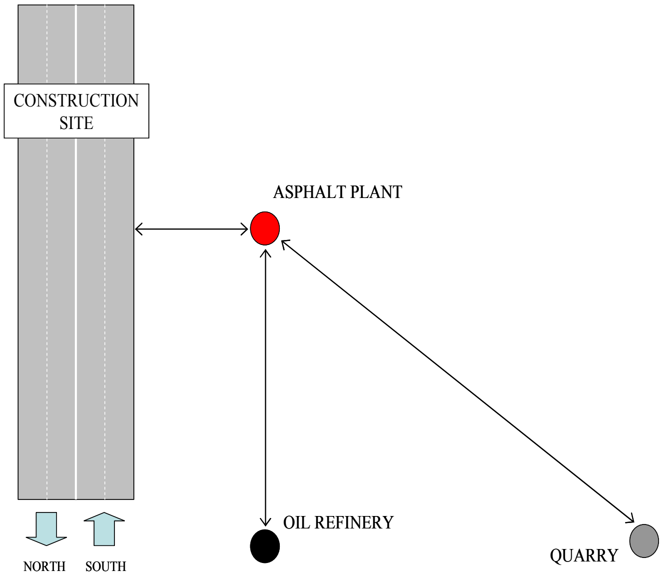

Fig. 3. Travelled Distances to Produce the Prospective Bituminous Treated Mixture.

Lorry Movements and Emissions

The first proposal would have asked for the required transportation of RA and soil to the storage site 10,000 trips of full lorries (15m^3 of materials) and 10,000 trips of empty lorries, while 350 and 150 lorry trips would have been necessary to carry the emulsion and cement to the construction site, respectively (Table 2).

In this sense, the air pollutant emissions due to these lorry trips can be estimated by referring to the mean emission factors of the vehicles circulating in the Italian roads provided by the Italian National Institute for Environmental Protection and Research. These factors are based on the COPERT version III software (COmputer Programme to calculate Emissions from Road Traffic) [10, 11]. COPERT aims at the calculation of air pollutant emissions from road transport and was developed within the European CORINAIR project (CORe INventory AIR) [12]. This project was financed and developed by the European Environment Agency (EEA), in the framework of the activities of the European Topic Centre on Air and Climate Change (ETC/AE), to provide instruments for the preparation of valid national inventories of air pollutant emissions. In particular, the estimated emissions depend on the type of vehicle (e.g. bus, car, heavy vehicle), vehicle category (e.g. weight), and vehicle technology (e.g. conventional, Euro I).

Heavy vehicles characterized by Euro I technology, with more than 32*tons* full weight and 7.5-16.0*tons* empty weight, were considered as the parameters for pollutant emission assessment. In this way, it was possible to estimate that about 28, 7, 3,300, 5, and 2.5*kg* of NO_x, CO, CO_2, VOC, and PM, respectively, are emitted for each kilometre of travel. Thus, taking into account that the closest site to carry RA to or to take cement is located 20*km* from the construction site, and that the production site of emulsion is located 60*km* from the construction site, about 250*tons* of noxious gases would have been estimated (Table 2).

Now, if the second proposal is considered, subsequently adopted as the actual application technique, 1,000 trips of full lorries and 1,000 trips of empty lorries were necessary to carry the RA, while 600 and 300 lorry trips were necessary to carry the emulsion and cement to the construction site, respectively. Thus, considering the same above-mentioned parameters, about 80*tons* of noxious gases are emitted (Table 2).

Finally, if the subbase construction through an HMA had been evaluated, the relevant environmental problems would have been provided. In particular, about 16,000 trips of full lorries and 16,000 trips of empty lorries would have been needed to carry the milled materials and asphalt treated mixture for a 20-km trip, resulting in 700*tons* of pollutant emission. Moreover, in this case, it must be taken into account that further lorry trips would have been necessary to carry the mineral aggregates and bitumen to the asphalt plant (Fig. 3).

In particular, 90,000m^3 of mineral aggregates would have arrived from an 80-km distant limestone quarry, while about 11,000 tons of bitumen would have been provided from a 45-km distant oil refinery. This would have provided 12,000 lorry trips to carry aggregates and 700 lorry trips to carry bitumen. Heavy vehicles carrying aggregates would have generated about 9, 2, 1,000, 1.5, and 0.8*tons* of NO_x, CO, CO_2, VOC, and PM, respectively. While the lorries carrying bitumen would have generated 300, 70, 35,000, 50, and 25*kg* of NO_x, CO, CO_2, VOC, and PM, respectively. Thus, preparing an HMA for the subbase layer would have provided more than 1,000*tons* of air pollutant emission due to lorry trips to carry the materials (Table 2).

In addition, lorry trips to carry materials results in more heavy traffic on the surrounding secondary roads and around the construction site, resulting in less comfort and safety for workers and citizens. More heavy loads on the secondary road network accelerate the deterioration process of the asphalt pavements. In particular, a full-weight lorry trip and an empty lorry trip correspond to about 8 trips of an ESAL (8*tons*). Thus, the construction of the subbase course according to the first proposal would have resulted in a traffic increase on secondary roads of about 80,000 ESALs. In contrast, the realization of the subbase layer following the second proposed construction technique provides an increase of about 11,500 ESALs. Finally, if the subbase had been prepared with an HMA, the traffic would have increased by 250,000 ESALs. This would have involved a 10% decrease in the lifetime of the secondary roads, on the basis that they are usually designed for 2.5×10^6 ESALs (Table 2).

Moreover, an increase in heavy vehicles on linking roads would have slowed the traffic down and caused traffic jams, thus lowering vehicle speeds and enhancing air pollution emission.

Table 3. Environmental Issues at the Asphalt Plant.

	1st Proposal[a]	2nd Proposal[b]	HMA Subbase
Fuel Consumption to the Asphalt Plant (*ton*)	Negligible	Negligible	1,750
Gas Emission to the Asphalt Plant (*ton*)	Negligible	Negligible	60

[a] New slow lane: foamed bitumen treatment; New emergency lane: cement and/or lime stabilized soil.

[b] New slow lane: bituminous emulsion treatment; New emergency lane: bituminous emulsion treatment.

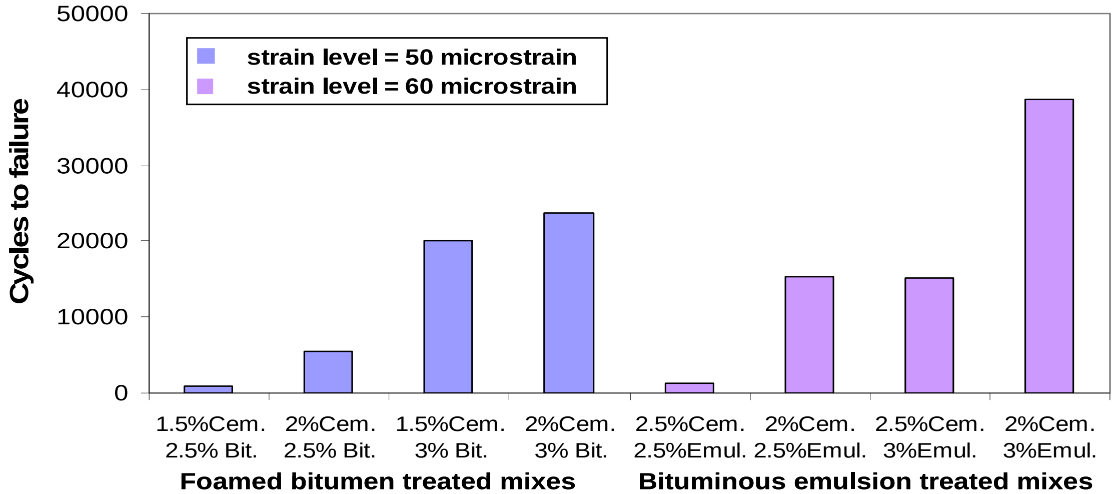

Fig. 4. Main Results of Subbase Mix Design [9].

Energy Consumption and Pollutant Emission to the Asphalt Plant

The proposal 1 and 2 provided cold construction techniques for subbase course. Thus, for this layer the mix plant has to heat only the binder (bitumen or emulsion). Considering that the amount of binder used for both proposal is about 3% of the whole mixture, energy and emissions to heat bitumen or to prepare bitumen emulsion are negligible with respect to those necessary at the central plant to produce HMA. In fact, for HMA production the larger amount of energy is needed for heating mineral aggregates at the mixing temperature.

In particular, according to recent data provided by the Environmental Protection Agency of the United States of America [13], it can be estimated that 10, 1.5, 37.5, and 12.5*tons* of PM_{10}, VOC, CO, and NO_x, respectively, would have been emitted by a batch mix HMA facility for the production of the HMA for the subbase layer (about 250,000*tons*). Moreover, according to Jenkins et al. [14], 50×10^9 J would have been necessary to prepare hot mix asphalt for the subbase layer. On the basis of another study [15], this amount of energy corresponds to 1,750*tons* of fuel (Table 3).

Mechanical Performance of Bituminous Emulsion Treated Materials

The optimum mix design (3% bituminous emulsion and 2% cement) of the cold recycled material and of the working procedures were selected after full laboratory and *in-situ* studies [8, 9]. As an example, Fig. 4 shows the comparison between laboratory fatigue performance of foamed bitumen treated samples and bituminous emulsion treated samples.

To validate the choice of this CIPR technique and to verify the road structure construction procedure, the bearing capacity of the material laid down was monitored by means of non-destructive *in-situ* measurements with a Falling Weight Deflectometer (FWD) apparatus.

FWD measurements were carried out on both lanes every 100*m* on materials laid down in different periods, allowing the evaluation of the increase in modulus due to the curing time.

The elastic modulus of the subbase layer was calculated taking into account the temperature-dependency law introduced previously [9], with the selected reference temperature of 20°C.

Figs. 5 and 6 show the elastic modulus values from back-calculation analyses as a function of the different curing times and the number of measurements "N" for the new emergency lane and slow lane, respectively.

It can be noted that the selected materials provided satisfactory results at all of the considered curing times, as they reached high values of elastic modulus (≈5,000*MPa* after 28 days of curing period). These values were greater than those required by the technical specifications after 90 days from construction (3,000*MPa*), indicating a very good bearing capacity provided by the stabilized layer. Furthermore, the treated subbase reached elastic modulus values greater than 7,000*MPa* after 94 days of curing time, achieving an increase of about 40% in two months.

In general, the standard deviations depicted great variability of the results due to the heterogeneity of the mixture obtained from the cold *in-situ* recycling of milled asphaltic and cementinous materials. However, the results obtained were greater than the technical specifications requirement in all sections.

The results obtained demonstrate that the material investigated is adequate as a subbase layer of a heavy loaded motorway.

Conclusions

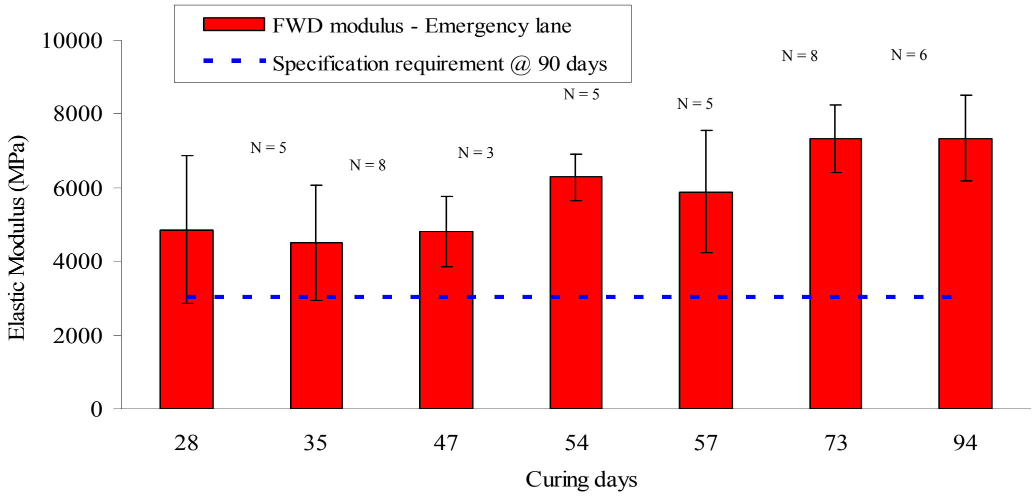

Fig. 5. FWD Results on New Emergency Lane.

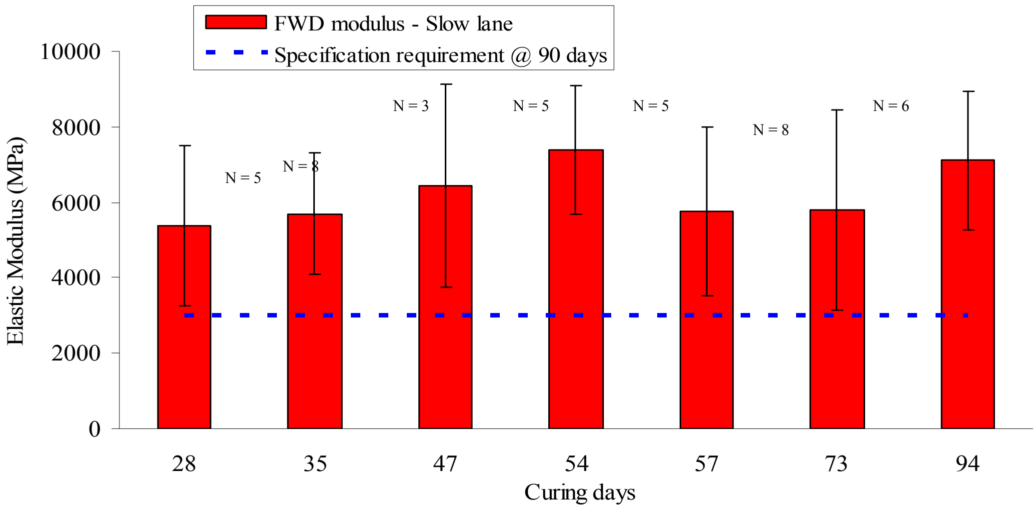

Fig. 6. FWD Results on New Slow Lane.

This study has mainly dealt with the environmental issues relating to the upgrading works for a six-lane dual carriageway facility of a 42-km long section of one of the most important Italian motorways. Three rehabilitation options are evaluated and compared in terms of their environmental impact, with particular emphasis on the construction of the sub-base course.

It has been possible to estimate that the adopted construction technique for the subbase layer allowed the obtaining of relevant environmental benefits in terms of saved natural resources and the avoiding of air pollutant emissions and energy consumption. Indeed, 150,000m^3 of materials, 75,000m^3 of which is RA, were recycled in situ in the subbase course with limited natural resources used and air pollutants emitted due to lorry trips and materials preparation.

In addition, the upgrading works allowed the recycling of 50,000m^3 crushed cement concrete coming from the demolition of old cement elements, 270,000m^3 soil and 35,000m^3 RA in the base and binder courses.

Finally, the results coming from FWD measurements on the subbase course demonstrated that the stabilized layer has a bearing capacity adequate for a heavy loaded motorway.

In conclusion, all adopted recycling techniques allow the obtaining of relevant environmental benefits without sacrificing mechanical performance. This highlights the need to use and further improve CIPR techniques.

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