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Effect on Pavement Performance of a Subbase Layer Composed by Natural Aggregate and RAP

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Reclaimed Asphalt Pavement (RAP) recycling in pavement engineering can be actually carried out by means of hot recycling and cold recycling. An additional option arise from mixing with natural aggregates to build the sub-base layer. This paper shows the first results of a research activity undertaken on a test track specifically constructed with the aim to analyze the effect on pavement performance of a sub-base layer mixture with 50% of natural aggregates and 50% of RAP. The investigation is based on LWD and FWD analysis, comparing results with those obtained on the subsequent section of the test track made by only natural aggregates.

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1. Introduction

The environmental issues emerged in the last years led designers, contractors and government agencies to look for ways to decrease the impact of roads construction. Gone are days when roads were built without a worry about the resources that were being used or the pollution that were being created. In this context, the use of the RAP a subbase material, even though blended with virgin aggregates, is focus increasing worldwide thanks to the possible high amount of RAP to be recycled compared to other recycling techniques. Recycling of RAP is usually carried out by means of three different techniques: hot recycling, adding RAP in the hot mix asphalt plant production, and cold recycling with emulsion bitumen or foam bitumen. Hot recycling allows a very small amount of RAP to be recycled. EN Specification (EN 13108-1) suggests using no more than 10% for surface layers and 20% for binder and base layers (EN 13108 – 2006). Exceeding this percentage, additional tests are needed to evaluate the effect of aged binder on the stiffness and durability of the mix. Cold recycling allows, is

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some cases, to recycle the 100% of RAP extracted from the bituminous layers, and use it to make base or binder layers (depending on the importance and structural requirement provided for the infrastructure).

Many researches have been carried out in the recent years regarding the use of RAP for subbase layers. D’Andrea et al. (2001) suggest that the use of RAP for subbase layer and subgrade is a useful solution in order to dispose of the large amount of waste produced during maintenance and rehabilitation activities. To avoid the problems related to the excessive deformations provided using only RAP is necessary to blend it with other type of aggregates, like Construction and Demolitions aggregates, able to strengthen the mixture until reaching a suitable level of resistance to static and dynamic loads. A study from Taha et al. (1999) recommended blending granular RAP with virgin aggregates in order to attain the proper bearing strength since the RAP bearing capacity is usually lower than conventional granular aggregates. Garg N. et al. (1996) conducted a field testing in order to demonstrate the potential of use RAP as a pavement base. This study demonstrated that the performance of the RAP base was comparable to that of a crushed stone base. Study carried out by Cosentino et al. (2003) state that comparison of RAP to limerock behavior using the Clegg impact hammer, Falling Weight Deflectometer (FWD) and Soil Stiffness Gauge (SSG) show that RAP achieved 80 to 115% the stiffness of limerock during the eight-week testing intervals. Thus, the Clegg, FWD and SSG tests indicate that RAP is equivalent in stiffness to limerock. Furthermore, adding 20% of virgin aggregates provide the best strength properties while maintaining a reasonable permeability coefficient. Locander (2009) conduct different experimental tests on RAP showing that RAP have the same engineering properties of unbound aggregates for base course, thus demonstrating its suitability as alternative design and construction approach. An extensive research study on the hydraulic and mechanical effects of recycled materials as substitutes for virgin aggregates was conducted by Kang et al., 2011; they mixed four different recycled materials, including RAP, with virgin aggregates at various proportions to create 17 mixtures. Resilient modulus test and shear test on a triaxial cell were conducted to mechanically characterize the mixtures. They demonstrated that at a given confining pressure, for all cases, RAP in mixtures enhances resilient modulus. Furthermore, they demonstrated that the addition of RAP generally improves the drainage characteristics of base and subbase layer mixtures. More recently, results undertaken on a experimental field, show that cement treated mixture containing high percentage of RAP perform similar to that made by only natural aggregates (Isola 2012).

In the effort to assess the effects of RAP for subbase granular mixtures, University of Parma developed a full scale test track, subsequently tested in collaboration with University of Pisa. The basic idea of this research is to investigate the effect on subbase layers produced by the substitution of natural aggregates with RAP. The research work was organized in two phases: the first one in laboratory to characterize the materials. The second phase is a long term investigation aimed to study the development of mixtures performance and characteristics using nondestructive testing devices such as the Lightweight Deflectometer (LWD), the falling weight deflectometer (FWD) and the Ground Penetrating Radar (GPR). This paper describes the test truck and the materials characterization, deeply analyzing the potential to use the RAP as substitution of virgin aggregates. Results of non-destructive tests will be presented and discussed.

2. Objective and scope

The primary objective of this study is to evaluate the possibility to use RAP as a virgin aggregate supplement into unbound mixture to be placed in subbase layers. To achieve this objective different non-destructive tests have been performed in order to assess the short and long term performance of a mixture blended with 50% of RAP (Section_R), comparing results with those obtained on a mixture composed by only natural aggregates (Section_N).

FWD testing setup was planned in order to apply different stress level in the pavement layers, allowing to investigate the stress dependency of unbound materials.
3. Experimental method

RAP is a reprocessed asphalt paving material containing asphalt and aggregates. It is commonly reused in virgin hot mix asphalt (HMA) or cold recycled mixture. Due to its nature, particle size distribution of RAP may vary to some extent, depending on milling/crushing method, type of aggregate in the pavement and milling depth. In particular, it is governed by the spacing of the teeth, and the speed of the grinding unit.

To guarantee homogeneity and obtain a constant particle size gradation, RAP is commonly stockpiled based on its source (surface layers, base layers) before being crushed and sieved by asphalt producers. In this study the particle size distribution of virgin aggregate and RAP was obtained through sieve analysis on oven dried material. Each sieve analysis was conducted on triplicate specimens to guarantee repeatability. Particle size distribution of RAP showed a typical range for medium to fine gradation, typically obtained milling wearing course together with base layer.

The research project presented in this paper is a part of a more extended project aimed to assess the performance of mixture with high percentage of RAP when used as a subbase or base layers. To achieve this objective a pavement test truck have been specifically designed and constructed inside an asphalt concrete plant production, trying to simulate a real pavement subjected to heavy vehicle loads moving at low speed. Performance characteristics of unbound layers were monitored immediately after construction, with LWD device, and during time by means of FWD + GPR.

The test track consists of two consecutives sections 30 m long and 5 m wide made by two different subbase mixture compositions: the first is made by 100% natural aggregates while the second is a blend of 50% natural aggregates and 50% RAP. Grading composition mainly contribute to improve compaction of unbound layers, thus performance expressed on site. For this reasons, the two different mixtures were designed with the aim to have almost the same grading curve (Figure 1 – Grading Band from Italian highway administration). Pavement structure was than completed laying 15 cm of cement-treated base course and 10 cm asphalt concrete layer (30 mm NMAS) with 4 % asphalt content and 5.5 % air voids. A vertical and horizontal layout of the pavement structure with the two different subbase layers is shown in Figure 2 and Figure 3. It should be noted that letters reported after section identification number refers to the composition of the construction layers. In particular, N refers to subbase made by only natural aggregate and R to subbase made by blending 50% of natural aggregates with 50% RAP.

![Figure 1 Grading curve of subbase with only natural aggregates and blended with 50% RAP.](image-url)
The location of the test track was specifically selected to be along the way to the weighbridge of the quarry along the truck route. A trench 60 m long, 5 m wide and 0.45 m deep was excavated in the selected location; test track was decided to be placed at ground level in order to have better confinement. Subgrade was compacted using vibratory tandem roller (15.8 kg/cm) and then characterized using LWD to obtain an evaluation of subgrade modulus. Subbase mixture was mixed in plant, then placed and compacted separating the one with only natural aggregates and that blended with 50% RAP. Subbase performance has been analyzed by means of LWD tests. After the placement and testing of subbase layer, tests truck pavement was concluded laying the cement treated base layer and the bituminous one. In subsequent Figure 3 are shown two pictures taken during the trench preparation and compaction of subbase layer.
4. Results and discussion

4.1. LWD test results

The LWD testing device is usually used to characterize the half-space bearing capacity of unbound, cement bound and cold recycled mixtures (Marradi 2011) in terms of Surface Modulus, calculated using subsequent Boussinesq equation:

\[ E = \frac{(1 - \nu^2) \cdot f \cdot \sigma_0 \cdot r}{d_0} \]  

where the factor \( f \) (plate rigidity factor) is 2 for uniform distributions and \( \pi/2 \) for the rigid case, which may be more correct for cohesive materials, \( r \) is the load plate radius, \( \sigma_0 \) and \( d_0 \) are respectively the maximum value of the applied stress and of the measured deflection. Poisson’s ratio \( \nu \) is assumed to be 0.4 for granular non-cohesive materials.

As reported in IAN 73/9, Surface Modulus can be defined as a measure of “Stiffness Modulus” based on the application of a known load at the top of the tested layer; it is a composite value with contribution of all underlying layers even though the influence of the upper layer is considered predominant. In this research the Surface Modulus of subgrade and subbase layers have been evaluated performing several LWD tests immediately after compaction process, and average results are shown in the graph below. The type of device used, belonging to “Category a” provided by the PFG (Pavement Foundation Group) in the LWD Best Practice Guide (Edward P. et al 2011), allows to record the time histories during tests execution. This data have been used in order to calculate the energy provided to the soil during the LWD tests, by means of the integration of the graph obtained plotting together the load deflection time histories, Hysteresis Loop (Figure 5). This parameter, usually called Energy Loss, is actually trying to be correlated to the compaction of tested soil (Van Gurp et al 2010) even if, at the moment, no significant correlations can be found in literature.
Results reported in Figure 5, where the term “EL” refers to the value of “Energy Loss”, allow stating that no significant differences can be underlined between performance of subbase with RAP and subbase with only virgin materials, even though the energy provided to the soil seems to be slightly higher for mixture with 50% RAP.

4.2. FWD+GPR test results

FWD is a non-destructive testing device used for the evaluation of the structural state of the pavement. This method consist in reproducing the solicitation due to a heavy vehicle and estimating the pavement’s response by measuring the basin of deflection using sensors fixed on a beam. The conventional FWD is able to apply loads in the range 7-120 kN but the standard load used for structural pavement analysis is usually 30-50 kN. The load is applied to the pavement surface through a standard loading plate, normally 300 mm in diameter. The generated duration of the half sine pulse is typically 30 ms, corresponding to the loading time produced by a truck moving from 65 to 80 km/h.

Measured deflection are usually used for backcalculation process. This is essentially a mechanistic evaluation of pavement surface deflection basins where measured and calculated surface deflection basins are matched (to within some tolerable errors) and the associated layer moduli required to achieve that match are determined. The backcalculation process is usually iterative and normally done with software.

The accuracy of the backcalculation process is strictly dependent on the accuracy of the layers thickness used to perform the analysis. As reported in the HD 29/94 “An under-estimate of as little as fifteen percent in thickness, which is not uncommon given construction thickness, can result in an over-estimate of over fifty percent in bound-layer moduli values, enough to give the impression of good integrity of a poor layer”. For this reasons thickness of the different test truck layers have been investigated by means of GPR prospecting, finding out the thickness of the pavement structure under each FWD test location. This technology consists of transmitting electromagnetic waves and analyzing the reflected signals. Since a flexible pavement is made of different layers, reflections of electromagnetic energy are expected at all interfaces.

In this study a system composed by two ground-coupled antennas (600 and 1600 MHz) with 3 channels (2 monostatics and 1 bistatic) was used, hand moving the instrument at 4-5 km/h speed. Radar measurements were acquired at three adjacent alignments (inner, central and external lane) and results are expressed in term of radar sections (Figure 6). Results obtained along the three alignments provided the thicknesses of the pavement layers to be used for backcalculation purpose (different calibration cores were undertaken). As reported in the Figure 6, the thicknesses of the tested tracks show a very high level of homogeneity for the constructed trial sections layers. Subsequent GPR tests, carried out in different period after construction, have not shown differences with the first data undertaken, indicating that no change occurred in material density and/or integrity.
Figure 6 GPR test results on the three alignments of the test truck.

Backcalculation process is mainly dependent on the thickness of the tested pavement layers. As reports by different authors (Ullidtz, Huang, Litton), many cares should be taken when analyzing thin layers, thick less than 10 cm. Huang, reports that “two agencies using the same computer program derived very different back-calculated results for the same pavement cross section. This is specially true for thin layers because the deflection basin is insensitive to their moduli and good match between computed and measured deflection can be obtained even if totally unreasonable moduli are derived for these thin layers”. Furthermore, as reported by Mehta and Roque (2003), “default values obtained from any program may give a good fit between the measured and computed deflections, but the modulus values obtained from the analysis may be of a little value”. For this reasons engineering judgments should be used when analyzing pavement with thin layers.

The structure of the tests track, characterized by a 10 cm thick bituminous layer, results rather difficult to be correctly analyzed. A sufficient level of backcalculation reliability can only be found merging the first two superficial thin layers, asphalt concrete and cement treated base. For this reason the backcalculation analysis was carried out using a three layers model: the first layer combines the bituminous layer and the cement treated base layer, the second layer schematizes the subbase and the third one is the subgrade half space. The results, obtained using Odemark’s method MET (Method of Equivalent Thickness) for backcalculation process, are reported, in terms of elastic layers moduli and percentage difference referring to the ones evaluated on section with subbase made by only natural aggregates. Test have been undertaken at three different periods from construction; one just after construction, one in the cold season and one in the spring. The aim of this kind of tests planning was to monitor performances of test truck during time, but also to investigate the temperature sensitivity of the recycled mixture due to the presence of a high percentage of RAP. Furthermore, different testing setup was arranged during the second and third tests campaign in order to apply different loads levels to the tested surface. As reported in the COST 336 (2005), in case of stress dependent pavement materials a target load equal to the standard pavement design wheel load may be preferred, but in special cases, e.g. an investigation on the non-linearity of the (unbound) granular layers, more load levels can be used on each test point.

Results of backcalculation for surface layer are not shown in order to focus attention only on subgrade and on the two different mixtures composing the subbase layer.
Elastic moduli of the subgrade appear to be very similar, close to 80 MPa, when comparing tests undertaken in different periods and with different load levels, evidencing a no stress dependency behavior of this material.

Results reported in the previous graph allow underlining that performance expressed by subbase with RAP is very similar to that evidenced by subbase with only natural aggregates. Percentage differences remain always lower than 14%. Comparison between results obtained with tests carried out applying different load levels reveals
a clear stress hardening behavior. The increasing of elastic modulus from 800 kPa to 1700 kPa applied stress is about 30%, as shown in Figure 10, seems to be somewhat higher for subbase with only natural aggregates.

The potentiality expressed by these two types of subbase, both natural and recycled, to improve performance increasing the stress applied, can be useful in order to bear the different type of loads within a generic traffic spectrum. Higher is the stress applied to surface and higher will be the performance of the subbase layer, according to the k-θ non-linear model for granular materials. Furthermore, comparing results undertaken at different period is possible to underline the different level of non linearity of these materials, expressed in terms of percentage increasing of E2 carried out applying 800 kPa to those referred to 1700 kPa stress level.

5. Conclusions

In this paper the performances of a subbase made by blending 50% of natural aggregates with 50% RAP have been analysed. A specific tests truck have been designed and realized inside an asphalt concrete plant production, aiming to reproduce a short line of road subjected to heavy vehicle traffic, moving at low speed. Different on site tests (LWD and FWD+GPR) have been carried out in order to investigate the short and long term performance of this mixture, comparing results with those obtained with a mix made by only natural aggregates. Results obtained both with LWD and FWD+GPR allow stating the following considerations:

- LWD tests carried just after construction shows a similar performance of mixture blended with 50% RAP and mixture with only natural aggregates. Analysis of time histories suggest that the energy provided to the subbase with RAP mix is slightly higher than those of natural mix, even if the peak of deflection seems to assume almost the same values;
- GPR tests shows a homogenous trend of thickness of the test truck. No variation can be recognized doing tests in different periods after construction.
- FWD tests carried out in different periods and applying a different stress level evidence similar values of elastic moduli for subbase with RAP and with only natural aggregates. Moreover, a low stress hardening behaviour can be recognized performing tests applying different stresses levels. Increasing performance with increasing the stress applied to surface can be useful in order to bear the different type of loads within a generic traffic spectrum, preserving the subbase to a premature failure.

Results reported in this paper allow concluding that, in this case, subbase made blending high percentage of RAP with natural aggregates evidence the same short and long term performances, appearing to be slightly higher. Further triaxial tests will be undertaken in order to investigate the internal friction angle and to make a precise mechanical characterization of unbound mixtures with high percentage of RAP, aiming to understand the effects due to the presence of aged binder.
References