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A laboratory and filed evaluation of Cold Recycled Mixture for base layer entirely made with Reclaimed Asphalt Pavement

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HIGHLIGHTS

- Main research goal: use of 100% RAP for Cold Recycled Mixture base layers.
- Laboratory and trial field comparison between Cold Recycled Mixture and Hot Mix Asphalt.
- The presence of 100% RAP does not seem to worsen the compactability of the bituminous mixture.
- ITS and ITSM test results confirmed the difference in terms of resistance and stiffness between CRM and HMA.
- The mechanical and physical properties of CRM are strictly related to the mix design and to the quality of RAP.

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ABSTRACT

Asphalt concrete (AC) recycling is probably the most cost-effective technique for the rehabilitation of stressed road pavements and for the construction of new ones. The increased interest in this technology comes from the need of reducing the costs connected to the production processes and to the use of virgin raw materials. In fact, the benefits connected to the use of Reclaimed Asphalt Pavement (RAP) are related to the possibility of substituting the natural aggregates and the virgin binder of an AC mixture, without negatively affecting its mechanical properties. When this process is made at ambient temperature (Cold Recycled Mixes – CRM), more advantages are brought about with, above all, the reduction in energy consumption and emissions during in plant production and laying, in addition to the actual possibility of achieving durable pavement layers. A CRM totally made of RAP is proposed in this research, the main goal of which was to evaluate the different physical and mechanical characteristics derived by the large use of recycled materials. According to the final mix-design, CRM does not show significant differences in terms of physical properties, when compared to a Hot Mix Asphalt (HMA) for base layers. Moreover, even if the experimental mixture shows lower mechanical values, these are acceptable and higher than the limits imposed by the most common Italian technical specifications for Cold Mix Asphalts containing up to 30% RAP.

1. Introduction and scope

In recent years, a constant decrease of costs related to the construction and maintenance of civil infrastructures has been recorded. This is due to the increasing interest of public opinion in the concept of sustainable development and to the growing political awareness of environmental issues [1] that leads practitioners to adopt more sustainable technologies and design approaches.

In this context, the pavement construction industry still represents one of the largest consumers of natural resources and raw materials [2] and its negative environmental and economic effects are enhanced by the production of quantities of wastes during the maintenance and the rehabilitation of stressed roads [3,4].

The limited availability of virgin aggregates, the rise in prices of materials and the additional costs related to the disposal of wastes, have promoted the use of recycling technologies for the rehabilitation and construction of asphalt pavements[5,6,7].

The recycled materials used in the road construction industry are generally classified as:

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- Industrial by-products, such as steel slags, blast furnace slags, fly ashes and similar;
- Road by-products, mainly Reclaimed Asphalt Pavement (RAP) materials;
- Construction and Demolition by-products, such as crushed concrete, mortars, tiles, bricks and similar [8,9,10].

In the last ten years, an ever-increasing number of these materials has been tested in addition, partial or total substitution of constituents commonly used in paving applications.

Thus different innovative and eco-friendly materials are now available on the market and a number of second-hand materials are studied, being the step of physical and mechanical characterization necessary to assess their real benefits [11,12,13].

RAP, being readily available, is by far the most known and common recycled material used within asphalt mixtures, also because it partially covers the need of virgin aggregates and new asphalt binder [14]. In the last years, different techniques and approaches have been extensively studied and applied to incorporate increasing amounts of RAP in the production of ACs. Among them Cold Mix Asphalt (CMA) recycling is now popular due to its versatile properties and proven environmental advantages [15]. From an economic and environmental point of view, the possibility to produce bituminous mixtures without the addition of heat, results in a significant reduction in energy consumption and emissions during the in plant production and laying processes [16,17,18]. More recent studies [19,20,21] also assessed the possibility of incorporating up to 100% of RAP in fully recycled mixtures.

The present research starts form the idea that 100% RAP can be advantageously used in cold recycling technique for the production of bituminous mixtures for eco-friendly and durable pavements. The aim is to evaluate the positive properties conferred to the mixture by using high amount of recycled materials together with binder emulsion and cement. Starting from the laboratory mix-design a full scale trial field was constructed, in order to evaluate the development of the mechanical and physical properties of the proposed CRM when compared to a high-modulus HMA for base layers.

2. Experimental program, test methods and materials

The experimental program was divided in two different and consecutive phases. The first one is a laboratory study in which the mix designs and the physical and mechanical properties of the two different mixtures were defined. One, labelled CRM, made out of 100% RAP material, the second one, labelled HMA, was a high-modulus asphalt concrete mixture for base layer.

In the second phase, the mixtures were laid in a full-scale test section open to heavy quarry traffic. In situ tests and samples collection were planned at regular intervals, for the evaluation of the development of the mechanical characteristics of each mixture under.

2.1. Laboratory phase

Nine specimens were prepared for each of the mixture with gyratory compaction (ASTM D6925). Each specimen had a dry mass of 4500 g and a diameter of 150 mm, made with a constant compaction pressure of 600 kPa, external angle of 1.25° and 180 revolutions.

Laboratory curing of CRM specimens has been carried out in a single way. After the production, specimens were placed in oven for 3 days at 40 °C. In order to attain a full curing condition, the specimens were then kept at 20 °C until maintained a constant mass. Tests were always carried out on fully cured specimens.

In this first step of the experimental program, the workability and volumetric properties of the mixtures were assessed by means of the compaction curves obtained at the end of the gyratory compaction. The volumetric characterization was then supported by the analysis of the air voids content of each specimen (EN 12697-8).

The static mechanical characterization included the Indirect Tensile Strength (ITS) both in dry (at 25 °C) and wet conditions (EN 12697-12). According to the EN 12693-23 standard, the specimen was loaded by a constant velocity of 50 mm/min until failure.

The consecutive dynamic mechanical characterization was based on the determination of the Stiffness Modulus applying indirect power to cylindrical specimens (EN 12697-26). The stiffness modulus was determined through a pulse loading with a 124 ms rise-time, to generate a horizontal deformation of 7 ± 2 μm in the core of the sample. Before testing, all the specimens were first conditioned for six hours at three reference temperatures: 5, 20 and 40 °C.

2.2. Trial field phase

Once defined the mix design and the physical and mechanical properties of the two different mixtures, these were laid to devise a full-scale trial field. In situ test and samples collection were planned in four dates, corresponding to 0, 60, 180 and 365 days of cumulative heavy traffic. A specific quantity of material was taken from the paving screed during the laying process and three samples for each mixture were prepared with gyratory compaction (ASTM D6925). Each specimen had a dry mass of 4500 g and a diameter of 150 mm, made with a constant compaction pressure of 600 kPa, external angle of 1.25° and 180 revolutions. The workability and volumetric characteristics of the mixtures were analysed by means of the compaction curves and the determination of the air voids content of each specimen (EN 12697-8). The volumetric analysis was also supported by the ITS test (EN 12697-23) at 25 °C. The evolution of the mechanical characteristic of the two different mixtures for base layer was evaluated by means of the ITSM test (EN 12697-26) at 20 °C carried out on cores. The physical properties of the two mixes were also analysed and compared to those obtained during the laboratory step, in order to define the potential differences given by the in plant production and in situ compaction with roller.

2.3. Materials

Two different mixtures for base layers were studied: a traditional HMA and a CRM.

Three materials were used for the recycled mixture: Reclaimed Asphalt Pavement (RAP), Cement (C) and Bituminous Emulsion (EM). A small amount of water was added to the mixture to control the workability and to achieve the maximum dry density during compaction.

RAP was collected and milled from a motorway asphalt concrete pavement. Later, the material was divided in to three different fractions: coarse RAP 20/40 (20–40 mm), coarse RAP 10/20 (10–20 mm) and fine RAP 0/10 (0–10 mm). Table 1 summarizes the properties of the aged bitumen recovered from the RAP.

As for binder materials, a typical Portland Cement 32.5 and a bituminous emulsion (61% bitumen content) with a 55 pen grade SBS modified bitumen (Table 2) were adopted.

For HMA mixture, a traditional 50/70 pen grade bitumen was used according to a dosage of 4.3% by the weight of aggregates.