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Effect of crumb rubber gradation on a rubberized cold recycled mixture for road pavements

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ABSTRACT

Cold recycling technique represents the most environmental friendly solution for pavement rehabilitation nowadays. In fact, this technique allows the use of the highest percentage of reclaimed asphalt avoiding the energy consumption related to aggregates heating required by the traditional hot mix asphalt design. The mix design represents a key phase of the cold mix production. The study of workability and compactability properties combined with a deep laboratory investigation is required. The idea of introducing crumb rubber in the cold mixtures was developed based on the concept of maximizing the valorization of recycled materials together with the goal of achieving high performance. In the present research project, two different gradations of crumb rubber, processed with the traditional grading method, have been adopted for the production of a cold recycled mixture stabilized with bitumen emulsion and cement. The spring-back effects of the rubber particles, which occur after compaction, together with the Indirect Tensile Strength and the Indirect Tensile Stiffness Modulus have been studied. The results show that the gradation of the adopted crumb rubber sensibly affects the compaction and mechanical properties of the cold recycled mixture.

1. Introduction

The public, industry and governments recently raised their interests in green design and engineering in order to achieve and guaranty better environmental quality and sustainable development. Pavements construction is one of the largest consumers of natural resources [1] but their environmental loading can be sensibly reduced if recycled materials are incorporated in both new and maintenance road project [2]. In Europe and the United States [3], recycled materials used in construction are normally classified as industrial by-products, such as steel slag and coal fly ash; road by-products, such as reclaimed concrete pavement materials and reclaimed asphalt pavement materials; or demolition by-products, such as crushed concrete, tiles, and bricks [4]. Most of these material groups can be valorized during pavement construction and rehabilitation. At the present time, the use of reclaimed asphalt with the cold recycling technique represents one of the primary ways to rehabilitate pavements, toward a sustainable development, that combines the reduction in virgin aggregates and energy consumption. In 2008 the importance of asphalt recycling was supported by the EU Waste Framework Directive 2008/98/EC, where a recycling target of 70% for non-hazardous construction and demolition waste (that includes asphalt waste) was defined to be achieved by 2020 [5].

The cold recycling technique is the solution that permits the use of the highest percentage of reclaimed asphalt. Without heating, it combines different pavement materials, stabilizing agents and, when required, raw aggregates to produce a new material that is expected to satisfy the specification for its use. Cold recycling can be achieved either "in plant" by hauling material recovered from an existing road to a central depot or "in place" using a mixing unit. Plant process is usually expensive but it becomes a valid and competitive alternative when additional pavement layers are required, where different materials are to be blended in different proportions and when the material in the existing pavement necessitates a process of selection. Lower amount of energy is required when the in place solution is adopted becoming more relevant when rehabilitating low volume roads [6]. In Italy these technologies were widely used and the adopted bitumen was normally emulsified or foamed. The road structure recycling strategy in Italy started in the 1970s and now is one of the main applications of recycling techniques used in the principal motorways and for pavement rehabilitation in general [7].

In the light of this scenario the efforts to improve the use of recycled materials in the road infrastructure construction process should be maximized together with the conception of high performance and durable materials that could be susceptible to further re-uses. Based on this concept, the idea to insert rubber particles, coming from shredded tires, in a cold recycled mixture, stabilized with bitumen emulsion, was developed [8]. This type of external waste product has already been incorporated in hot asphalt mixtures through two different processes

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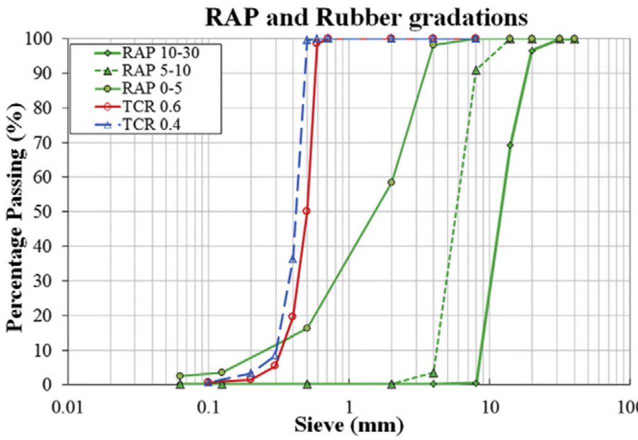

Fig. 1. Gradations of the black RAP fractions and TCR samples.

respectively in the asphalt cement of the mix (wet process) and directly in the mixture blend (dry process). The rubber particles in the first case act as bitumen modifier pairing the effects of traditional modifiers (SBS, EVA, etc.) [9], in the second they become part of the mixture mastic and contribute to the layer endurance during its service life. The rubber particles were adopted also in cement concrete for different applications showing different drawback and potential benefits. Even if rubcrete is actually weaker in compressive and tensile strength than traditional cement concrete, structural applications involving it may still be possible if appropriate percentages of rubber aggregates are used. With regard to the benefits, it presents good water resistance with low absorption, improved acid resistance, low shrinkage, high impact resistance, and excellent sound and thermal insulation [10]. Rubcrete mixtures usually absorb significant plastic energy and undergo relatively large deformations without full disintegration [11]. These properties can be exploited in various structural and geotechnical projects in which the deformation at peak load is a primary design concern [12].

The cold recycled mixture, stabilized with bitumen emulsion or foamed bitumen and cement, could represent the optimal solution with low energy consumption for the application of crumb rubber in a structural layer of the pavement. Pettinari et al. [8] incorporated in a cold mixture, stabilized with cement and bitumen emulsion, different percentages of Cryogenic Crumb Rubber (CCR) with the maximum grain dimension of 1 mm. The study focused on the evaluation of effect of the percentage of adopted rubber on the volumetric and mechanical properties of mixtures stabilized with two different percentages of bitumen emulsion. In general crumb rubber introduces a variation in volume that appears after compaction which is not significant when the percentage of adopted rubber is below 3%. Indirect Tensile Strength (ITS) and Indirect Tensile Stiffness Modulus (ITSM) are reduced when rubber is introduced in the mixture. High percentage of bitumen emulsion acts positively in both directions reducing the variation in volume and limiting the drop in ITS and ITSM. The Indirect Tensile Fatigue Test showed that CCR can positively improve the fatigue resistance of the cold mixtures. Therefore, the obtained results showed an interesting potential of this mixture as a structural layer introducing at the same time the need of a deeper evaluation of importance of rubber gradation.

Based on the fact that CCR in Italy is not available at a competitive price compared to the one produced at the ambient temperature, the crumb rubber processed with the traditional ambient grinding method was the application of choice in this research project. This rubber, even if it generally presents irregularity of the particles' shape and a content of fiber, still [13], can be milled in different gradations similar to that adopted by Pettinari et al. [8,14] with the CCR. Furthermore a comparison study has been completed in order to understand the different effects of introducing cryogenic or ambient grinding rubber in a cold recycled mixture. The study confirmed that size distribution of the crumb rubber sample plays a significant role in the workability and mechanical properties [15].

The main purpose of this study is to evaluate the effect of two different gradations of crumb rubber on the Volumetric and Mechanical properties of a cold recycled mixture stabilized with bitumen emulsion and cement.

Table 1
Properties of the aged asphalt binder from RAP.

	Unit	RAP 10–30	RAP 5–10	RAP 0–5	Standard
% binder	%	3.10	3.27	6.13	–
Penetration @ 25 °C	dmm	9	7	7	EN 1426
Soft point	°C	73.8	75.5	78.8	EN 1427
Dynamic visc. @ 60 °C	Pa∗s	52625	58015	95305	EN 13702-1
Heptane insolubles	%	42.4	41.2	39.6	ASTM D3279

Table 2
Properties of the bitumen emulsion.

Characteristics	Unit	Value	Standard
Characteristics of the cationic emulsion			
Water content	%	39	EN 1428
pH value	°	4	EN 12850
Settling tendency @ 7 days	%	6	EN 12847
Characteristic of the extracted binder			
Penetration	dmm	55	EN 1426
Softening point	°C	62	EN 1427
Fraass breaking point	°C	−16	EN 12593

Table 3
Designation and composition of the cold mixes.

MATERIAL	Max density (g/cm^3)	1.5C_5.0E
RAP 10–30	2.62	49.0%
RAP 5–10	2.62	13.0%
RAP 0–5	2.53	35.0-a%
TCR[1] 0.4/0.6	1.08	a[1]%
Limestone Filler (L)	2.70	1.5%
Cement (C)	3.00	1.5%
Bitumen emulsion (E)	1.00 (at 25 °C)	5.0%
Additional water	0.99 (at 25 °C)	2.0%

[1] 0, 1, 3, 5% of RAP 0–5 was replaced with an equivalent volume of TCR.

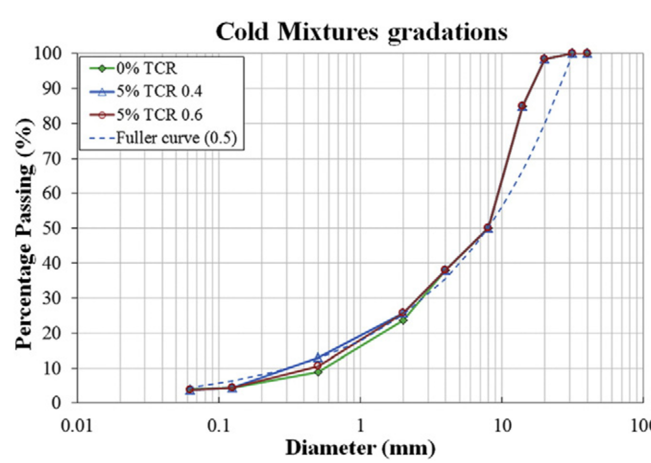

Fig. 2 Comparison between different mixtures gradation..