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Performance evaluation of recycled rubber waterproofing bituminous membranes for concrete bridge decks and other surfaces

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HIGHLIGHTS

- A new waterproofing rubberized membrane for the protection of concrete bridge deck is proposed.
- The waterproofing membrane is composed of a mat sandwiched between two layers of SBS-modified bitumen.
- An extensive laboratory characterization confirms the product characteristics and the overall performances.

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ABSTRACT

In this paper a green waterproofing membrane for the protection of concrete decks is proposed. It is composed of a recycled rubber mat, sandwiched between two layers of SBS-modified bitumen. The rubber mat, itself, provides advantages in terms of environmental impact, because it is composed by a high density elastic mat made with granular rubber coming from the recycling of End of Life Tires, stuck with isocyanate and pressed. The polymer modified bitumen improves the interfaces adhesion and bonding, providing to the system a good water resistance. The rubber mat, different from the most common waterproofing membranes, is not supplied in rolls but can be applied in layers directly in work, according to the area to be covered. Laboratory characterization and a comparison to manufacturer's limiting values and tolerances of other available membranes confirm the overall performance and the use conformity of the proposed system.

1. Introduction

Efficiency and safety of road networks are strongly affected by the durability of concrete bridges, viaducts and overpasses. The construction and maintenance of these infrastructures, in fact, require a great effort from both the economic and engineering point of view, in the initial stage but also during the service life.

Due to limited economic resources available to public authorities, efficient and effective maintenance plans become very important for these works, in order to preserve them in a cost-effective manner and with minimum life-cycle cost.

One of the most extensive bridge maintenance problems is the deterioration of the concrete decks in terms of scaling, mortar flaking, spalling, abrasion damage, alkali-aggregate reactivity and cracking, which can cover small or large deck areas [1]. The first consists in a loss of surface mortar, caused by the pressure from water freezing inside the concrete, which can be aggravated by deicer chemicals. The second is similar to scaling, but takes place around coarse aggregates. It is caused by an early drying out of the surface mortar over these particles that produced an insufficient moisture for cement hydration thus a mortar layer of lower strength. Spalling is a surface defect larger than scaling or mortar flaking, caused by pressure and expansion inside the deck concrete, produced by steel reinforcement's corrosion and joints inadequately constructed or maintained. Abrasion damage, finally, is a surface defect that occurs mainly in correspondence of wheel tracks and consists in a polishing of aggregates that causes a slippery road surface.

Alkali-aggregate reactivity and cracking, instead, are linear defects that produce cracks on bridge decks caused respectively by a chemical reaction between alkalis of Portland cement and any aggregate constituents and by the low tensile strength of concrete [2].

In order to achieve a long service life with minimum maintenance, a concrete bridge deck should have a high resistance to freeze-thaw or abrasion damage, a very low permeability to

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chloride, an adequate skid resistance of the surface layer and a structural strength able to limit fine flexural cracks, associated with the structural behavior [2].

To obtain and maintain these features, a very useful solution can be the application of a concrete protective system, which may consists of:

- concrete cover, 75 mm or more;
- low-slump concrete overlay;
- latex-modified concrete overlay;
- waterproofing membrane and asphalt overlay.

The first three systems were found to be resistant, but not impermeable, to salt penetration. The last, instead, was found to be effective in preventing moisture and salt intrusion into the bridge deck, providing a protective barrier on its top [3].

Usually the use of waterproofing systems involves firstly the application of a primer over the clean concrete, in order to increase the adhesion between waterproofing membrane and deck. The waterproofing membrane is installed on this primer and then a tack coat is applied to its top surface, in order to improve the bond with the asphalt surface course. This protects the membrane and provides a surface with a good skid resistance.

The waterproofing membrane could be a sheet system, mainly based on bituminous materials, or a liquid-sprayed one, commonly made of acrylics and polyurethanes. These, however, have the following limitations [4]:

- low adhesion with asphalt layer, that might lead to premature deformation of the surfacing;
- the waterproofing membrane could be damaged by construction equipment, such as milling machines during pavement maintenance work.

In this paper a new waterproofing membrane, composed of a recycled rubber mat sandwiched between two layers of SBS-modified bitumen is proposed. These improve the interfaces adhesion and bonding, and they provide to the system a good water resistance under all conditions. The membrane, instead, provides advantages in terms of environmental impact because it is a high density elastic – resilient mat, made of pressed and vulcanized granular rubber coming from the recycling of End of Life Tires (ELTs). The increasing number of vehicles on the roads of industrialized and developing nations, in fact, generates millions of scrap tires every year. These tires are among the largest and most problematic sources of waste, due to the large volume produced and their durability. The inadequate disposal of tires may, moreover, pose a potential threat to human health (fire risk, haven for rodents or other pests such as mosquitoes) and potentially increase environmental risks [5]. In recent years the crumb rubber from ELTs has been used in the asphalt mixture in substitution of the fine part of the grading curve or as bitumen modifier, in order to improve asphalt mixture resistance to permanent deformation [6]. In this context, the use of rubber as construction material must be improved and developed.

The rubber mat used in this research has a thickness of 3 mm, while the two layers of bitumen are both two mm thick, for a total thickness of approximately 7 mm, and it can be applied in layers directly in work, according to the area to be covered.

2. Methods and materials

In order to evaluate the overall performances of waterproofing membrane proposed and to assess its quality, a deep research study has been conducted with:

- laboratory characterization of the constituent materials of the waterproofing membrane: the mat and the bitumen have been subjected to different tests, in order to evaluate both their individual performances and their affinity to form a single system;
- determination of product characteristics: according to EN standards the mat and the waterproofing membrane have been subjected to different laboratory tests, in order to evaluate the product characteristics and the overall performances. The lab results have been compared to manufacturer's limit values and tolerance of other products available on the market;
- evaluation of conformity of the waterproofing membrane: according to EN standards the mechanical characteristics of the system composed of concrete, waterproofing membrane and asphalt mixture were evaluated. In particular the pull-off test and shear stress test were implemented to evaluate membrane mechanical performances, while water tightness tests were conducted to evaluate the membrane water sensitivity. In this section all the configuration tests have been adapted to the construction requirements of the used technique. All the obtained results have been compared to manufacture's limit values and tolerance of other products.

Fig. 1 shows the experimental approach followed for this research.

The rubber mat is made up of natural and synthetic elastomeric compounds, coming from the recycling of End of Life Tires, bound by mass-polymerized polyurethanes.

The characteristics of the mat, that has a density of 950 kg/m^3, provided by the manufacturer, are shown in Tables 1–3.

The characteristics of the SBS-modified bitumen are shown in Table 4. The SBS produces reduction of penetration grade and increase in softening point, improving the interfaces bonding and the water resistance of the waterproofing membrane.

On the bitumen a dynamic rheological analysis using Dynamic Shear Rheometer (DSR) has been performed. The tests have been executed under controlled strain and the strain amplitude has been limited within the linear viscoelastic (LVE) response of the samples. Frequency sweep tests have been conducted between 0.01 and 10 Hz, from 0 °C to 60 °C, adopting 8 mm measurement system with 2 mm gap, according to UNI 14770 [7]. Adopting the principle of Time–Temperature Superposition the master curves of the complex shear modulus (G^*) and phase angle (δ) were constructed at the reference temperature of 30 °C (Fig. 2) [8,9].

At all frequencies the master curves show greater complex modulus values and lower phase angle values than a traditional unmodified bitumen. The SBS modification is evident particularly at high temperatures, at which the complex modulus tends to the horizontal asymptote. At high frequencies, moreover, the bitumen shows a G^* value lower than the glassy modulus (equal to 1 GPa). The phase angle, which is close to 45°, shows the perfect visco-elastic behavior. So the SBS modified bitumen used in the proposed waterproofing membrane exhibits good shear resistance and low thermo-sensitivity, increasing the visco-elastic range.

3. Determination of waterproofing membrane characteristics

According to EN 14695 [20] the mat and the waterproofing membrane have been subjected to different laboratory tests, in order to evaluate and validate the product characteristics.

This standard has been used to verify the characteristics and performance of the proposed waterproofing membrane, even if it specifies characteristics and performance of reinforced bitumen sheets for waterproofing of concrete bridge decks.