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Performance of different joining techniques used in the repair of bituminous waterproofing membranes

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HIGHLIGHTS

- Repair actions on aged OB membranes are discouraged.
- APP membrane joints showed little susceptibility to ageing of one of the membranes.
- Adhesive bonds were the most reliable and effective for repairing APP membranes.
- SBS membrane specimens failed mostly outside the joint and within the membrane.
- The flexibility/brittleness of SBS membranes should be evaluated prior to repair.

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ABSTRACT

This paper presents an experimental investigation on the performance of different techniques for executing joints between aged and new bituminous membranes in order to evaluate the performance of waterproofing repair systems. Three different types of fibre reinforced membranes were considered: (i) oxidised bitumen membranes, (ii) APP-modified bitumen membranes; and (iii) SBS-modified bitumen membranes. The membranes were aged by heat weathering in a thermal chamber at 70 °C, for periods of 4, 16 and 24 weeks. To simulate the repair operations, new (unaged) membranes were subsequently bonded to the artificially aged membranes either by (i) adhesive bonding or (ii) heat welding using a gas blowtorch. The membranes were tested in tension, and the joint specimens were subjected to shear and peeling tests. The results obtained show that regardless of the joining technique the joints between oxidised bitumen membranes are significantly affected by heat ageing of one of the membranes, particularly in peeling. APP membrane joints proved to be less susceptible to the effects of ageing; the behaviour of adhesive and welded joints was different, with the former joints exhibiting higher deformability. The joints between new and aged SBS membranes were consistently stronger than the membranes themselves, with failure typically occurring at the aged SBS membrane; the results obtained confirm that these membranes are significantly affected by heat ageing.

1. Introduction

Bituminous membranes are extensively used for waterproofing in civil engineering works, being the most common solution in building roofs and bridge decks. In the past, oxidised bituminous roofing membranes were very frequently used for this purpose before having been outperformed and replaced in most applications by polymer-modified bituminous membranes, such as atactic polypropylene (APP)-modified and styrene-butadienestyrene copolymer (SBS)-modified bitumen membranes [1]. Together, these two types of membranes represent the vast majority of the European market for construction of new or renovated buildings.

In the construction industry, waterproofing systems frequently require some sort of repair, as their service life is generally considerably shorter than that of the buildings or bridges where they are installed [2]. Anomalies may occur in the different layers of waterproofing systems for various reasons. The most common causes consist of design and/or application errors, external mechanical accidental actions, environmental actions, lack of maintenance, and changes in the predicted in-service conditions of the construction where the waterproofing system is installed [3]. The rehabilitation of waterproofing systems typically involves (i) the removal and replacement of the degraded layers or (ii) the application of

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Fig. 1. Example of a failed waterproofing membrane repair.

new waterproofing layers over the damaged areas, which requires the execution of joints between the new membranes and the existing (aged) membranes. For the latter approach, two basic methods are used to join existing (aged) and new membranes: heat welding with a blowtorch and adhesive bonding. The use of the correct repair techniques and of compatible materials are essential to the effectiveness of the repair. Fig. 1 shows an example of an unsuccessful repair carried out on a damaged waterproofing membrane, illustrating how poor adhesion in the joints between the new and the existing membranes can result in failure of the repair.

In spite of the above mentioned standard repair procedure, there are still several uncertainties about the effectiveness of joints between new and aged bituminous waterproofing membranes, which raises some concerns. In fact, membranes ageing and the possible subsequent degradation of their properties may negatively affect the quality of new joints. Furthermore, it is also unclear which bonding technique (adhesive bonding *vs.* heat welding) is the most appropriate for the execution of joints between new and aged membranes. In this context, there is a need to assess the behaviour of such joints and to determine the influence of the ageing extent on their performance.

This paper aims to address this issue by presenting an experimental assessment of the behaviour of joints between new and aged oxidised bitumen and polymer modified bituminous membranes. Oxidised bitumen (90/40 grade), APP-modified, and SBS-modified bitumen membranes were subjected to different durations of heat ageing. Then, joints between new and aged membranes were executed by adhesive bonding and heat welding, and their mechanical performance was assessed by means of shear and peeling tests.

2. Literature review

Overlapping joints in waterproofing membranes are mainly subjected to shear and peeling stresses [1]. These are particularly relevant in the case of mechanically fixed membranes subjected to wind uplift actions, justifying the relatively high number of studies performed regarding this topic (*e.g.*, [1,4–8]). Such studies typically consider joints between new membranes, either comparing the performance of different types of membranes or of different test methods. Oba and Björk [1], for example, highlight the differences between APP-modified and SBS-modified membranes regarding heat welding works, suggesting that such works need to be carried out more carefully in APP-modified membranes than in SBS-modified ones. The authors also found that joints in SBS-modified membranes exhibit more shear deformation ("gliding") when compared to those in APP-modified membranes, which are more prone to peeling. To avoid, or at least limit, the development of significant peeling stresses, the authors suggest that the bonded area should cover the mechanical fasteners (full-width seams across the membrane overlap area).

Sartori et al. [9] carried out a relatively large-scale field study of several roofing systems with APP-modified bitumen and polyvinyl chloride (PVC) membranes, using different thermal insulation materials installed in traditional and inverted roof configurations with different protection materials. The roofing systems were installed during the construction of the Italian Research Council (CNR) Science Park in Rome and monitored during a 6-year period. In parallel, the authors carried out accelerated artificial ageing experiments by conditioning samples for a 6-month period at a temperature of 80 °C. The authors reported fairly similar effects between the adopted artificial ageing programme and 3 years of natural ageing for the PVC membranes. For the APP-modified bitumen membranes, the mechanical characterisation tests were not carried out in a systematic way for all ageing periods and methods, thus preventing conclusions from being drawn.

A systematic study on the mechanical performance of lap joints in waterproofing membranes subjected to artificial weathering was performed by Gonçalves et al. [10]. The authors carried out shear and peeling tests on SBS-modified bituminous membranes. Joints were performed by heat welding (by propane gas torch and hot air gun) with different joint width values. The joined membranes were aged for 3 months in one of two environments: (i) heat weathering at 80 °C; and (ii) water immersion at 60 °C. Before ageing the joints executed by hot air welding presented higher peeling resistance than equivalent gas torch welded samples. However, after heat weathering hot air welded joints showed greater degradation in peeling resistance compared to gas torch welded samples. After water weathering all samples showed increased peeling resistance. Shear resistance of all samples increased with ageing independently of the weathering medium. However, heat weathered samples exhibited a significantly lower deformation capacity both in shear and in peeling, whereas this property was relatively unaffected by water weathering.

Other studies have been carried out concerning various aspects of the durability of bituminous waterproofing membranes, such as their dimensional stability [11], the adhesion of self-protection mineral granules [12], or the effects of soil radon and bacteria on the mechanical properties of the membranes [13]. These investigations focused only on the individual membranes, *i.e.* they did not address explicitly the behaviour of joints.

The studies reviewed in the previous paragraphs provided a reasonable understanding of the performance of bituminous waterproofing membranes, namely about the efficacy of different techniques in joining new membranes and of their ageing mechanisms. However, to the authors' best knowledge, there are no studies in the literature regarding the performance of repair techniques and the effectiveness of joints between aged and new bituminous membranes, although this is a very relevant situation in building rehabilitation.

3. Experimental programme

3.1. Materials

Three membranes were considered in the present study: (i) oxidised bitumen membrane (90/40 grade) with a glass-fibre reinforcement of 60 g/m^2 (OB), (ii) APP-modified bitumen membrane reinforced with a glass-fibre fabric of 55 g/m^2 and a polyester-fibre fabric of 150 g/m^2 (APP); and (iii) SBS-modified bitumen membrane reinforced with a glass-fibre fabric of 60 g/m^2 (SBS).