Construction and Building Materials 189 (2018) 1045–1053

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Experimental study of the effect of filler on the ductility of filler-bitumen mastics

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HIGHLIGHTS

- The force-ductility curve is a function of the normalized filler concentration value.
- The normalized post-peak deformation energy is proposed for the ductility test analysis.
- Normalized filler concentration values close to 0.80 induce a clear reduction in ductility.
- Waste materials showed a similar effect on the ductility of filler-bitumen mastics.

ARTICLE INFO

Article history:
Received 30 July 2018
Received in revised form 11 September 2018
Accepted 12 September 2018

Keywords:
Ductility
Filler
Bituminous mastic
Suspension's rheological behaviour

ABSTRACT

This research investigated the effect of filler on the ductility of filler-bitumen mastics, as a surrogate of the cohesive behaviour and the tensile properties. Various fillers (industrial products, mineral fillers or waste materials) were mixed with one paving grade bitumen, in various filler-to-bitumen ratios, and tested under the force-ductility test. The force-elongation curve obtained is affected by the constituents, but the peak force and total deformation energy are a mainly a function of the normalized filler concentration value. Moreover, the effect of the filler type and concentration on the specimen's ductility is better perceived from the normalized post-peak deformation energy. Normalized filler concentration values close to 0.80 induce a clear reduction in ductility.

1. Introduction

Traditionally, the performance of bituminous mixtures is related to four main properties of the bitumen: rheology, cohesion, adhesion and durability [1]. Cohesion is associated with the amount of energy required to create a crack within the material, and, together with adhesion to aggregate, define the cracking resistance of bituminous mixtures [2]. However, cohesion is not directly evaluated; instead, the ductility in intermediate to low temperature conditions is commonly used to characterize the cohesive strength. A bitumen sample is stretched at constant rate, with force often recorded, till it fails or the maximum elongation defined in the test procedure is attained. The ductility performance is defined from the final elongation and/or the deformation energy. It is an empirical test and its usefulness is controversial for some researchers [3]. However, several studies conducted since the 1950s have reported a direct relation between the in-service pavement performance and the ductility of the bitumen used [4]. For instance, Kandhal [5] found that, in road projects built in the Pennsylvania state (USA), for the same penetration grade binders the ones with higher ductility values resulted in lower pavement distress levels. Thus, ductility testing is often required in material specifications [6].

According to Andriescu et al. [7] cracking of bituminous mixtures does not result exclusively from mechanical loading within the linear viscoelastic regime but it may also result from viscous flow and yielding at high strains, which are nonlinear. Failure in the ductility test results usually from extensional viscous flow.

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https://doi.org/10.1016/j.conbuildmat.2018.09.063
0950-0618/

In addition, the ductility test is also used to assess the effect of polymer modification, namely to distinguish between modified and neat bitumens. The post peak force-elongation plot is significantly affected by the polymer type and content [8]. Hence, the European specifications for polymer modified bitumen (EN 14023 [9]) propose a ductility test (EN 13589 [10]) to set the performance requirements in terms of cohesion.

Moreover, other empirically-based test methods are also adopted. The pendulum (Vialit) test (EN 13588 [11]) evaluates the cohesion properties of (thin film) bitumen based on the energy required to dislodge a cube from the support covered with bitumen. Similarly, the Pneumatic Adhesion Tensile Testing Instrument (PATTI) and the Peel test were used to evaluate the cohesive and adhesive properties of the bitumen-aggregate systems [12].

However, the binder of bituminous mixture is a suspension of the fine aggregate, which includes the filler, in the bitumen medium. Considerable research has shown that the properties of this suspension (bituminous mastic), are influenced by the bitumen and aggregate characteristics, and its proportion of the suspension. Specific physical and chemical interaction occurs at the particle surface, which may affect aspects as different as the resistance to moisture and ageing of bitumen. However, the viscosity of mastic is often the main concern because it will affect the coating of coarse aggregates during mixing, the air voids at the end of compaction and the mechanical response to thermal and loading actions.

The objectives of this study were (1) to investigate the effect of the filler characteristics and content in the ductility of filler-bitumen mastics, as a surrogate of the cohesive behaviour and the tensile properties; and (2) to analyse the effect of alternative fillers (e.g. wastes) on the mastic behaviour. To this, ten different fillers were mixed with one bitumen in two filler-to-bitumen ratios and tested using the force-ductility test. The ductility results were analysed and compared with other experiments on the filler-bitumen interaction. The extensional flow ability of mastics varies significantly when the mastic behaviour is more frictional than hydrodynamic, and therefore it is suggested the use of the normalized filler concentration for bituminous mixtures' design purposes.

2. Background

2.1. Force-ductility test

The conventional ductility test consists of a tensile test in which a moulded bitumen specimen, conditioned at the test temperature, is extended in a traction instrument at a constant rate until fracture or the maximum defined elongation is achieved. If the tensile force is recorded, the test is usually referred to as force-ductility test. Fig. 1 illustrates different geometries of specimens used in testing.

Three different types of failure may occur in the test: brittle fracture, flow failure and intermediate tensile failure. Brittle fracture occurs with the formation of a single rupture surface, separating the specimen in two blocks, without significant deformation of the specimen. With flow failure the specimen is highly deformed due to extensional flow, and a thread is formed with the reduction of the cross section in part or most of the specimen. Finally, intermediate tensile failure is characterized by tensile facture of the deformed specimen (mid-range deformation level). The type of failure is influenced by the experimental variables (specimen geometry, temperature and rate of deformation) and the bitumen. Depending of the bitumen, the test temperature ranges from 0 to 25 °C. Very low and very high temperatures are avoided because the test is intended to assess the ductile behaviour of the bitumen.

Fig. 2 illustrates a typical force-elongation curve, with a constant cross-section (see Fig. 1), of paving grade bitumen and

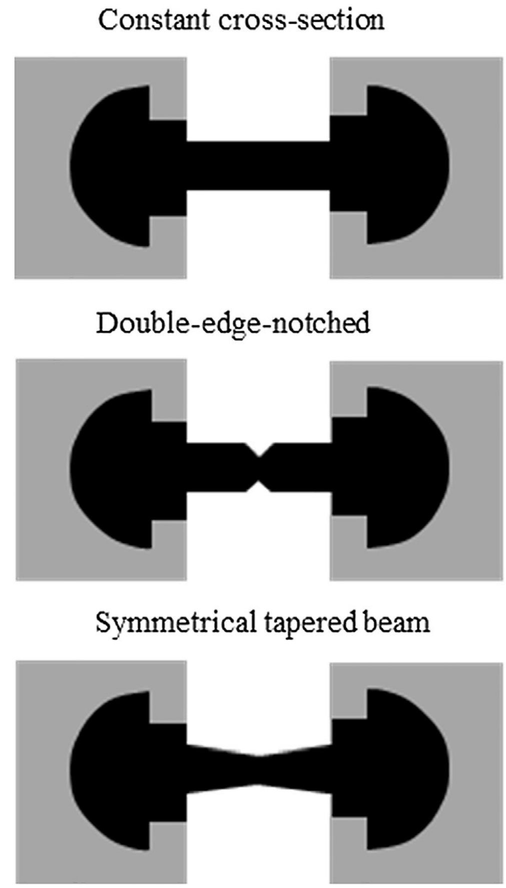

Fig. 1. Specimen geometry for force-ductility test.

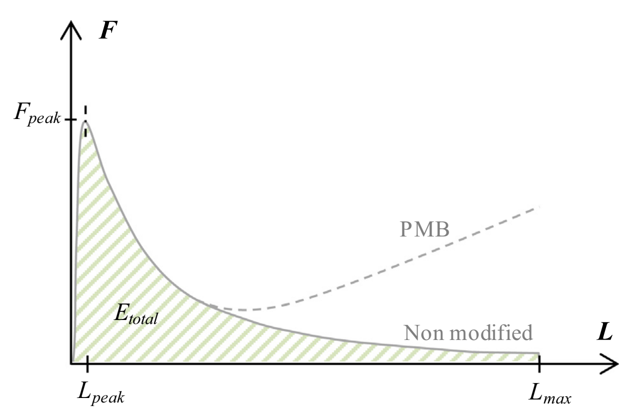

Fig. 2. Example of typical curves of force-ductility (constant cross section specimen).

polymer modified bitumen (PMB). As the cross-head speed remains constant during the test, the nominal strain rate ($\dot{\varepsilon}_N$) is also constant. Deformation is essentially elastic until the peak in force is attained (F_{peak}), and elongation is quite small (L_{peak}). The tangent to the F-L curve is referred to as elastic or bitumen stiffness/modulus (K_b). Fragile rupture occurs at or immediately after this peak. Afterwards, the resistance (force) decreases systematically with the increase in elongation. The strong polar interactions between the molecules of the bitumen components break, thus decreasing the resistance to extensional flow [13]. This decreasing resistance trend continues to the end of the test (L_{max}) in paving grade bitumen, whereas in modified polymer there is usually an