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Exploratory study on bitumen content determination for foamed bitumen mixes based on porosity and indirect tensile strength

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HIGHLIGHTS

- Aggregate gradation framework based on packing theory was used to classify mixes.
- Aggregate porosity of 50% gave indirect tensile strength (ITS) values that exceeded minimum dry ITS of 125 kPa.
- Bitumen viscosity affected mix properties such as ITS.

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ABSTRACT

Optimum bitumen content determination is one of the major aims for foamed bitumen mix design. However, mix design procedures for foamed bitumen mixes are still under development. In this paper a method to determine the optimum bitumen content for given foamed bitumen mix based on primary aggregate structure porosity and indirect tensile strength criterion is proposed. Using packing theory concepts, the aggregate gradation is divided into three aggregate structures which are oversize, primary and secondary structures. Porosity for the primary aggregate structure is determined for given bitumen contents. A maximum value for porosity of 50% for the primary aggregate structure is used to choose initial bitumen content. Furthermore, a minimum indirect tensile strength criteria is suggested to refine this bitumen content. This method enables a bitumen content value to be chosen prior to the start of experimental work, as porosity is expressed in terms of physical parameters such as aggregate and binder specific gravity, and aggregate gradation which are known before the mix design process. The bitumen content is then later refined when the indirect tensile strength is determined in the laboratory. This method would reduce resources such as time and materials that may be required during the mix design procedure.

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1. Introduction

Foamed bitumen consists of hot bitumen, small quantities of water (typically 2%–3% by weight of the bitumen) and air (Castedo et al., 1984; Csanyi, 1957; Jenkins, 2000). It is produced when water and air are injected into hot bitumen at 150 °C–180 °C. Foamed bitumen was first used in road construction in the 1950s by Csanyi from Iowa State University. He treated various soils with foamed bitumen. The foamed bitumen used was produced with steam and hot penetration grade bitumen (Csanyi, 1957; Csanyi and Fung, 1956). In the late 1960s, Mobil Oil of Australia acquired the patent for foamed bitumen technology and modified the process of foamed bitumen production by using cold water instead of steam. Also, an expansion chamber and a system of nozzles where the foamed bitumen was produced and dispersed respectively were developed (Bowering and Martin, 1976; Lee, 1981). The patent rights for foamed bitumen technology by Mobil Oil expired in the early 1990s, and other companies such as Wirtgen group manufactured new equipment. Also various researchers gained access to the technology. Foamed bitumen may be used to stabilize a wide range of aggregates ranging from good quality to marginal aggregates. In addition, soils such as sand, granular, and recycled aggregates from pavements have been successfully treated with foamed bitumen (Asi, 2001; Csanyi, 1957; Lee, 1981). In contact with pre-wetted aggregates foamed bitumen combines with the fines (particles size less than 2 mm) forming bitumen mortar that binds the rest of the aggregate particles in a composite mass (Jenkins, 2000).

1.1. *Mix design for foamed bitumen mixes*

Mix design involves procedures that are concerned with the formulation of optimum quantities for the various mix constituents such that the resulting mix will be able to fulfill the application it is intended for. In general, mix design for foamed bitumen mixes involves the following steps.

1.1.1. *Aggregates, foamed bitumen conditions and characteristics*

Aggregates, bitumen type, bitumen temperature, foaming water content are selected. Aggregates must fulfill gradation requirements. Compaction characteristics (optimum moisture content and maximum dry density) of the aggregates are also determined. The bitumen temperature at which to produce the foamed bitumen is chosen normally through sensitivity analysis. The bitumen temperature and foaming water content that yield the best foamed bitumen characteristics (maximum expansion ratio and acceptable half-life) are chosen.

1.1.2. *Bitumen content determination*

At this stage, the optimum bitumen content is determined. Mixes with different bitumen contents (additives such as lime or cement may be used) are produced and specimens are made. Different compaction and curing methods may be employed in the production of the specimens. Volumetric properties such as bulk specific gravity, air voids are determined for the different specimens. In addition, mix specimens are tested for mechanical properties such as indirect tensile strength, Marshall stability, unconfined compressive strength, and resilient modulus. The optimum bitumen content may be determined as that bitumen content that yields either the maximum or minimum value of the mechanical or volumetric property. Some researchers have proposed that the optimum bitumen content to be determined on the basis of volumetric properties such as bulk specific gravity and air voids. Whilst others have recommended that it should be based on bitumen content that yields the minimum or maximum value of the indirect tensile strength (Muthen, 1998). Others such as Wirtgen (2012) and Asphalt Academy (2009) have recommended to take the bitumen content that gives the minimum acceptable dry or wet indirect tensile strength as the optimum bitumen content does.

However, using volumetric properties such as bulk specific gravity may not be appropriate as bulk density involved in computing the bulk specific gravity is normally determined from dimensional analysis. Since foamed bitumen mixes are characterised with high air voids (values of 5%–32% have been reported) (Lee, 1981) it is not possible to use the surface dried method to determine the bulk specific gravity in the case of hot asphalt mixes. Further, mechanical properties such as indirect tensile strength may be increased with the addition of bitumen thus not attaining an optimum value. This kind of trend presents a challenge in selecting an appropriate bitumen content value. Yet the optimum bitumen content should yield mixes with adequate strength and durability as well as minimizing cost.

1.1.3. *Further mechanical testing*

Further mechanical testing such as triaxial, creep may be carried out on mix specimens made at the optimum bitumen content.

1.2. *Aggregate gradation*

Within bituminous mixes aggregates constitute the largest component. Therefore aggregate properties (such as gradation, physical and chemical properties) and the way aggregate particles are arranged or packed within the mixes would influence the resulting mix properties. Within foamed bitumen mixes, studies have revealed that some mix properties such as permanent deformation and temperature susceptibility are mainly influenced by aggregate particle interlock. For example, Sakr and Manke (1985) showed that the Marshall stability of foamed bitumen mixes was greatly influenced by aggregate particle interlock rather than bitumen viscosity. Sunarjono (2008) analyzed the effect of foamed bitumen characteristics on permanent deformation (in terms of the axial strain) for foamed bitumen mix specimens. He observed that permanent deformation was mainly influenced by the aggregate skeleton and binder type rather than foamed bitumen characteristics. Jenkins and Van de Ven (2001) recommended the use of voids in mineral aggregates (VMA) for the sand fraction as a parameter to select suitable aggregate gradation for use with foamed bitumen mixes. They illustrated that the VMA for the sand fraction decreased with increasing sand fraction reaching a