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Influence of recycled concrete aggregate on volumetric properties of hot mix asphalt

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ABSTRACT

Volumetric properties of hot mix asphalt (HMA) are necessary requirements to ensure good performance for asphalt mixtures. This research is conducted to evaluate the influence of coarse recycled concrete aggregate (CRCA) on the volumetric properties of HMA. Mix design of HMA mixture was performed for CRCA at various percentages 0%, 15%, 30%, and 60%, and the effects of the utilization of CRCA on HMA volumetric properties were evaluated. Additionally, various treatment methods were performed to evaluate the effect of various treatment types of CRCA on the HMA volumetric properties. To achieve this objective, presoaking, heat treatment followed by a short mechanical treatment were conducted. The obtained results showed that the use of the combination approach between different treatments appears to be very successful for enhancing physical properties of CRCA. The natural aggregate (NA) replacement by CRCA leads to increasing the optimum asphalt content (OAC) for the mixtures, whereas the property voids in mineral aggregates (VMA) is decreased. Compared to the mixture with 30% untreated CRCA, a little improvement and a slight increase in VMA and voids filled with asphalt (VFA) properties, respectively, were seen for mixtures with 30% treated CRCA with different treatment techniques. The CRCA addition with different proportions is very successful for both untreated and treated CRCA due to achieving all Ministry of Transportation Ontario (MTO) requirements for volumetric properties of HMA. However, CRCA treated with various treatment methods appears to be more successful than untreated CRCA application.

1. Introduction

For the construction of road pavements throughout the world, one of the essential materials required is asphalt mixture (Liu et al., 2017). Asphalt concrete can be categorized as a complex mixture that consists of three main phases: aggregate, binder, and air voids. Additionally, various additives including fibers and polymers are generally utilized for enhancing its performance (Poulikakos et al., 2017). However, asphalt mixture is mainly composed of approximately 95% aggregate and 5% asphalt cement materials. It was estimated that one kilometre of road approximately 150 mm thick and 10 m wide needs roughly 3750 t of hot mix asphalt (HMA) mixture, whereas another study showed that a kilometre of pavement construction required 12,500 t of natural aggregate (Zoorob and Suparma, 2000; Ektas and Karacasu, 2012).

In terms of natural resources, natural aggregates are quickly becoming exhausted worldwide due to an overwhelming demand for raw materials. According to the Ministry of Natural Resources (MNR, 2010), the average consumption of aggregate reached approximately 179 million tonnes per year in Ontario during the period of 2000–2009, while this average is projected to amount to approximately 191 million tonnes between 2020 and 2029 (MNR, 2010).

Simultaneously, tremendous amounts of construction and demolition waste are generated from various human activities including but not limited to construction, renovation and the demolition of aged buildings and civil engineering structures. Recently, the amount of construction and demolition (C&D) waste generated annually has been estimated at 1183 million tonnes worldwide (Purushothaman et al., 2014).

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Table 1
Composition of construction waste in South-East New Territories landfills (Arabani and Azarhoosh, 2012).

Waste type	Construction site (%)	Demolition site (%)	General civil work (%)	Renovation work (%)
Metal	4	5	10	5
Wood	5	7	0	5
plastic	2	3	0	5
Paper	2	2	0	1
Concrete	**75**	**70**	**40**	**70**
Rock/Rubble	2	1	5	0
Sand/Soil	5	0	40	0
Glass/Tile	3	2	0	10
Others	2	10	5	4
Total	100	100	100	100

Bold values refer that concrete makes up a considerable proportion of the total C&D wastes.

Solid waste material consists of a significant proportion of construction debris, which is the result of C&D works. Among different types of C&D wastes, concrete is the most significant component, which makes up a considerable proportion of the total C&D wastes as shown in Table 1. The management of these huge waste quantities is becoming a serious challenge especially for large urbanized areas because of the continuous increase in waste quantities, shortage of dumping sites, and cost increases in transportation and disposal.

Due to the above factors, the accumulation of these large quantities is related to serious environmental concerns such as pollution and environmental deterioration (Rafi et al., 2011). Moreover, with the existence of a global critical shortage of natural aggregate sources (Ismail and Ramli, 2013; Güneyisi et al., 2014), concrete waste disposal in landfill sites is not a feasible and sustainable solution (Hossain et al., 2016).

To solve various problems including lowering the consumption of virgin materials, decreasing waste materials in landfills (Hossain et al., 2016; Jin et al., 2017) and reducing environmental problems, the utilization of recyclable waste materials, especially recycled concrete, as a sustainable solution has become highly required and an urgent priority in the asphalt industry.

2. Significance

It is generally accepted that asphalt concrete (AC) is a heterogeneous material that is fundamentally composed of various substituents: asphalt cement, natural or artificial aggregate, mineral filler, additives, and air voids. Among various constituents, aggregate makes up the largest portion of pavement mixture and therefore, it has an important role and considerable impact on the engineering properties of the asphalt mix (Afaf, 2014). The design of asphalt mixtures can be described as a complicated process that requires very accurate proportions of aggregate and asphalt binder in order to achieve specific requirements of volumetric and mechanical properties. (Anderson and Bahia, 1997).

To achieve a desirable performance for the asphalt mixtures, the volumetric properties of pavement mixes are utilized. The concept of volumetric properties of asphalt mixtures has been progressively developed using various aspects as described in the following brief explanations. The significance of volumetric proportions of the constituents of asphalt mixtures regarding pavement performance was observed by Richardson in 1915. By the 1940s, the integration between two concepts; namely, the degree of saturation of the voids of the mixtures by asphalt, that can be named voids filled with asphalt and voids volume was suggested by Marshall. In the 1950s, the conception of voids in mineral aggregate and its significance in utilization for achieving asphalt durability had become highlighted and widespread due to the contribution of McLeod (dos Santos Bardini et al., 2013).

Currently, the volumetric properties of asphalt mixtures can be categorized into two main groups: primary and secondary volumetric parameters (dos Santos Bardini et al., 2013). While the primary volumetric parameters are directly related to the relative volumes of the individual constituents of asphalt mixtures: aggregates volume (Vs), air voids (Va), and asphalt binder volume (Vb), secondary volumetric parameters commonly referred to as volumetric properties of mixtures are Void Volume (Vv), Voids in Mineral Aggregates (VMA), and Voids Filled with Asphalt (VFA). Depending on the primary volumetric parameters, volumetric properties of mixtures (secondary volumetric parameters) can be determined. A summarized interpretation of the secondary volumetric parameters can be provided as follows: Vv is defined as the air volume between the aggregate particles surrounded by the film of asphalt, and can be expressed as a percentage of the total volume of the compacted mixture; VMA can be known as the sum of the Vv and volume effective asphalt binder (non-absorbed) (VEAC). This can be expressed as a percentage of the total volume of the compacted mixture whereas VFA is described as the degree of VMA filled by asphalt or the ratio of the volume of effective binder to the VMA and can be expressed in percentage (Hislop, 2000; dos Santos Bardini et al., 2013). The terminology of volumetric properties for the components of a compacted asphalt mixture can be found in Fig. 1.

It is generally accepted that the three volumetric parameters, namely, air voids (sometimes abbreviated VTM), VMA, and VFA have been identified an important indicators of mix performance. While

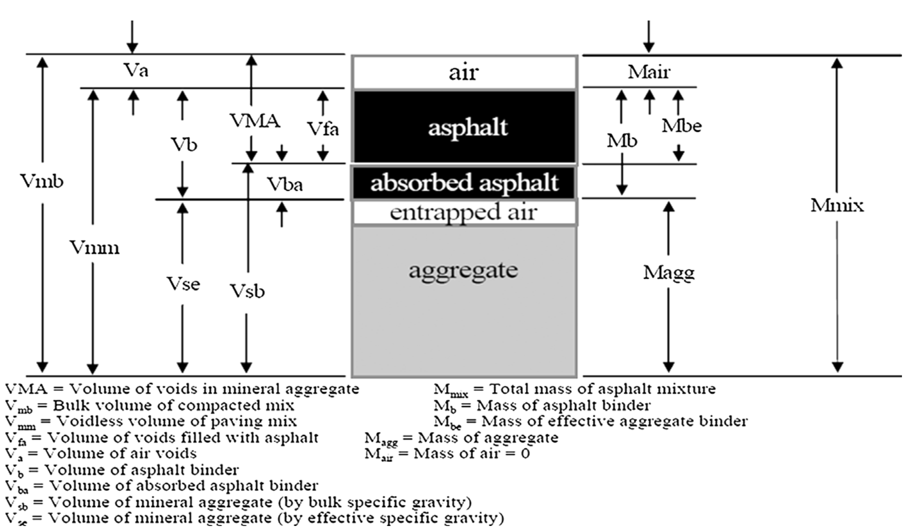

Fig. 1. Components of a compacted HMA specimen (Hislop, 2000; Huner and Brown, 2001).