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Utilization of waste nylon wire in stone matrix asphalt mixtures

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ABSTRACT

A lot of waste nylon wires are produced during the production of brush wire products such as toothbrush, hairbrush, paintbrush, and so on. How to recycle and reuse waste nylon wire is a new problem This research presents a study of the behavior of waste nylon wire on Stone Matrix Asphalt (SMA) mixtures using Marshall design method. The specimens were tested using several common laboratory test procedures: Marshall stability test, rutting test, three-point flexural test and moisture susceptibility test. The related results indicate that waste nylon wire can effectively improve the high temperature stability, low temperature crack resistance and moisture susceptibility of SMA. Also, oil absorption, adhesion and the retarding effect of waste nylon wire on the crack propagation of asphalt mixture are attributed to the reinforcing mechanism. The research result can offer technical support for waste nylon wire used in road construction materials.

1. Introduction

With increasing traffic volume and load of vehicles on highways, it becomes increasingly important that pavements meet the requirements of high durability and security, providing ease and comfort ride to the user. High durability mixtures reduce maintenance and operation costs during the pavement service life. In the developing countries, it is growing the use of more resistant and durable asphalt mixtures in the surface layer, such as mixtures with discontinuous graduation, e.g. SMA (Aline Colares do Vale, 2013). These mixtures have been with high structural and functional performance. They are characterized by presenting discontinuous gradation with predominance of coarse aggregates (70–80% by weight) to give a solid skeleton of high stability. Due to its gradation, SMAs require the addition of fibers to avoid the drainage of asphalt through the air voids of the mixture (Casey et al., 2008). Fibers added to SMA mixtures can be organic, inorganic or mineral material, in order to avoid the draindown of the binder during construction (production, transport and application of the mixture). Fibers generally have no influence on the performance of the mixture after compaction, but allow a higher binder content, which creates a thicker film around the aggregate (Xue et al., 2013). Thicker films retardate oxidation, helping against moisture penetration and separation of aggregates. These advantages are to increase the wear resistance of asphalt concrete (Oda et al, 2012; Casey et al., 2008).

The commonly used reinforced fibers include inorganic fiber like steel fiber, carbon fiber, boron fiber, glasses fiber and organic fiber like polyester, polypropylene fiber and lignin (Paredes et al., 2016; Abtahi et al., 2010). Steel fiber, carbon fiber and boron fiber are not normally applied due to the high price. In spite of high strength and low price, glass fiber is fragile and non-biodegradable (Guo, 2013; Wu et al., 2016). Organic fibers, such as Polyester, polypropylene fiber and lignin, easily intertwine with each other in the asphalt mixture (Zhang et al., 2014; Gao et al., 2014).

Liu (2006) pointed out that the fiber should have such properties as heat resistance, high modulus and easy to disperse so as to increase the performance of the asphalt mixture.

There are 80,000 tons of nylon wire produced in China every year. About 10 percent of nylon wire wastes and leftovers are produced during the production of brush wire products such as toothbrush, hairbrush, paintbrush, and so on. If these waste nylon wires could not be recycled and reused reasonably, these will cause waste and environmental pollution (Ogunbiyi et al., 2016; Wang et al., 2017).

Therefore, the recycling and reusing of waste nylon wires is an urgent problem to be solved. Waste nylon wire still has good physical and mechanical properties, commonly used as reinforced materials for rubber and concrete products. Compared with inorganic fiber, waste nylon wire has the advantages of smaller density, lower price and being recyclable. Compared with organic fiber, waste nylon wire has a high strength property and easy to disperse in asphalt mixture.

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Adding waste nylon wire into asphalt mixture will promote the recycling and reusing of waste nylon wire, also the development of green road materials.

This research aims to evaluate the viability of waste nylon wire incorporation in asphalt mixtures with discontinuous grading. To evaluate the performance, the SMA mixtures were designed by Marshall method and the following mechanical tests were performed: Marshall stability test, rutting test, three-point flexural test, and moisture susceptibility test.

2. Materials and experiment

2.1. Asphalt binder and aggregate

In this experiment, asphalt rubber binder obtained from ZhongHai Refinery was mixed with aggregates made from limestone, using a Stone Matrix Asphalt (SMA)-13 mixture design. The properties of asphalt rubber binder are given in Table 1.

Table 1
Properties of asphalt rubber binder.

Parameter measured		Value
Penetration (25 °C, 5 s, 100 g)/0.1 mm		60
Softening point (ring and ball)/°C		78
Ductility (15 °C, 50 mm/min)/mm		>1000
Viscosity (177 °C), /Pa S		3.2
RTFOT (163 °C, 5 h)	Mass loss/%	0.05
	Penetration ratio/%	75%
	Ductility (25 °C, 50 mm/min)/mm	≥600

by Standard of Asphalt Rubber for Highway Engineering.

The result of mineral aggregate component test was shown in Table 2; the aggregate gradation used in SMA-13 mixture gradation was presented in Fig. 1.

2.2. Waste nylon wire

The waste nylon wire (Fig. 2) used in this research was provided by BangDa nylon factory, located in Yangzhou city, China. The type of waste nylon wire is Nylon 610. Table 3 shows the characteristics and properties of the waste nylon wire.

2.3. Preparation of SMA mixture

In the experiment, the asphalt rubber content was 6.0%, and the waste nylon wire content accounted for 0.5%, 1.0%, 1.5%, and 2.0% of the mass of asphalt mixtures (by weight) respectively. SMA mixture was prepared in accordance with the Standard Test Methods of Bitumen and Bituminous Mixtures for High Way Engineering [16], which was published by the Ministry of Transport of the People's Republic of China.

Firstly, each batch of aggregate was maintained at a temperature of 163 °C for 4 h, and then mixed with waste nylon wire fully and evenly, as shown in Fig. 3. Secondly, the thorough mixture was added with asphalt rubber binder, and then kept stirring for 3 min. The final mixture was SMA mixture.

Table 2
Particle size distribution (grading) of the components of aggregate mix.

mineral aggregate	Mix proportion %	Passing percentage of the following sieve (mm)/%										
		19	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
1#	40	40	40	30.7	3.7	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2#	32	32	32	32	30.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7
4#	18	18	18	18	18	18	14.5	11.6	7.4	4.1	2.4	1.5
Stone powder	10	10	10	10	10	10	10	10	10	10	9.9	8
Mixture gradation		100	100	90.7	62.5	28.8	25.3	22.4	18.2	14.9	13.1	10.3

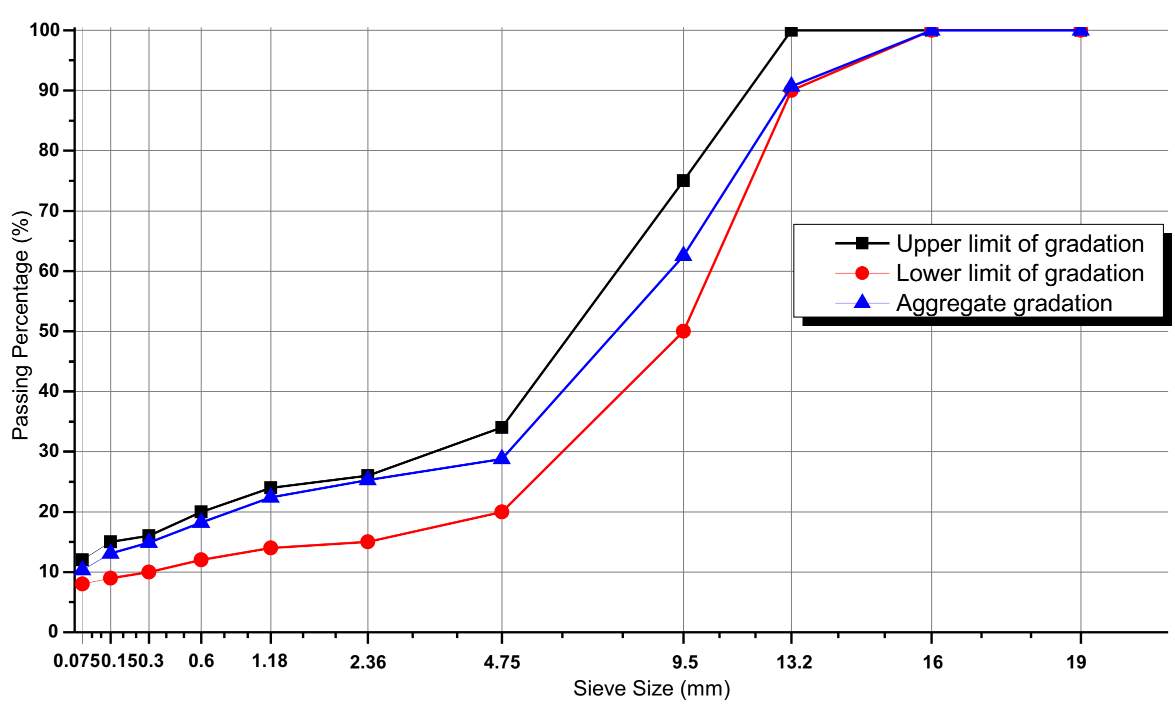

Fig. 1. Aggregate gradation.