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Research Article

Use of Waste Tyre Rubber Crumbs in Stone Mastic Asphalt: Potential Use in Pervious Pavements

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Abstract

This study aimed to evaluate the performance of Stone Mastic Asphalt containing 6%, 8% and 10% waste tyre rubber crumbs. The study results revealed that the density decreased with the increase in the percentage of waste tyre rubber crumbs (6% addition of tyre crumbs with conventional asphalt resulted in a 1.52% reduction in density; 8% addition resulted in a 2.28% reduction and 10% addition resulted in a 2.6% reduction). Consequently, water absorption increased with the increase in the percentage of waste tyre rubber crumbs (6% addition of tyre crumbs with conventional asphalt resulted in an 8% increase in water absorption; 8% addition led to a 12% increase and 10% addition resulted in a 15% increase). As percentage of tyre increased, so did the load to penetrate an equal distance on the cone used in the penetration test (6% addition of tyre crumbs with conventional asphalt resulted in a 10.6% increase in penetration resistance in terms of loads; 8% addition resulted in a 14% increase, and 10% addition resulted in a 15% increase in penetration resistance). Tensile strength decreased with the increase in % waste tyre rubber. Tensile strength ratio (TSR) of the mixtures decreases with the addition of waste tyre rubber crumb; however, TSR values were above 70% indicating that all mixes may have adequate resistance against damage induced by moisture. The use of waste tyre rubber in asphalt is a waste reduction practice. Stormwater management; urban and traffic runoff management has provisions for low-density pervious bituminous pavements and surfaces where these Stone Mastic Asphalt can find their use.

Keywords: Stone Mastic Asphalt, Tensile Strength, Penetration Resistance, Pervious Bituminous Pavements

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1. Introduction

A tyre is a pneumatic covering over a wheel made of natural rubber or synthetic rubber. Some tyres are made of both natural and synthetic rubber. It is made of several components such as rubber, carbon black, silica, metal, zinc oxide, sulphur, copper compounds, cadmium, and lead compounds, organic halogen compounds in different proportions depending on the type of vehicle [1]. The problem of waste tyre disposal is taking increasingly worrying dimensions in Bangladesh. It is estimated that about 90000 metric tons of tyres become scrap and are disposed of every year in Bangladesh [2]. The disposal of non-biodegradable waste tyres is a growing environmental problem, especially in developing countries.

Waste tyres can be reused as plant pots, decorative chairs and tables, and swings for children. In recent years, many attempts have been made to find new ways to recycle tyres. like: 1. rubbering of damaged tyres, 2. incineration to supply thermal energy in utility boilers to produce electricity, in cement kilns and brickfields, 3. pyrolysis of waste tyres to produce oils, chars and gases, 4. using waste tyres in asphalt concrete. Rubbering of waste tyres is popular in recycling tyres as it is simple and environmentally friendly, while incineration may produce hazardous polycyclic aromatic hydrocarbons during the combustion process.

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Stone Mastic Asphalt (SMA) first came to prominence in Germany in the 1960s as a tough surfacing designed to resist wear and damage from studded tyres and it was found that the mix also provided enhanced deformation resistance [3]. Since then, it has spread across Europe and across the world, although with some variations. Stone mastic asphalt (SMA), also called stone-matrix asphalt, is a durable and rut-resistant gap-graded asphalt mixture that relies on stone-on-stone contact to offer strength and a rich mortar binder to provide durability [4]. It provides a deformation-resistant, durable surfacing material, suitable for heavily trafficked roads. SMA has a high coarse aggregate content that interlocks to form a stone skeleton that resists permanent deformation. The stone skeleton is filled with a mastic of bitumen and filler to which fibres are added to provide adequate stability of bitumen and to prevent drainage of the binder during transport and placement. Good stone-to-stone contact exists between the aggregates forming a coarse aggregate skeleton, which provides better strength and rut resistance to the mixture. The coarse aggregate skeleton contributes to the shear strength and effective loading distribution pattern of vehicles to endure heavier traffic loads compared to the dense-graded mixtures. Typical SMA composition consists of 70−80% coarse aggregate, 8−12% filler, 6−7% binder, and 0.3% fibre. SMA is designed to improve rut resistance and durability through the use of a stable stone-on-stone skeleton held together by a rich mixture of asphalt cement, along with stabilizing agents such as fibres and/or asphalt modifiers. Several studies were undertaken to evaluate the field performance of SMA.

Longer life and enhanced performance can result in SMA being cost-effective even though the high binder content, additional filler and the use of binder drainage inhibitors may result in costs that are some 20% higher than conventional mixes [3]. The concept behind the SMA mix design was that traffic loading was carried by the coarse aggregate skeleton and that a mastic (fine aggregate/filler/binder) was "added" to fill most of the void spaces and ensure durability [3]. Stone mastic asphalt (SMA), porous asphalt or open graded friction course (OGFC) have a reputation for low tyre noise and high resistance to rutting and skidding, and are therefore preferred to hot rolled asphalt (HRA) for road surface that is subject to heavy traffic in terms of volume and loading [5].

One of the most notable studies was the National Cooperative Highway Research Program (NCHRP) project D9-8, which monitored the performance of 85 SMA pavement sections in the United States [6]. In addition to improved field performance, SMA pavements offer functional benefits such as improved visibility, reduced splash and spray, increased frictional resistance, and noise reduction [7]. The rough surface of SMA provides sufficient friction between the asphalt mixture and tyres. SMA has other features that make it the preferred mix compared to other kinds of conventional hot mix asphalt (HMA) [8]. The significant disadvantages of SMA are its higher initial expense and binder drainage. Since SMA has a gap-graded nature and high bitumen content, to prevent the binder from draining down, it needs stabilization to inhibit binder drain down, such as a polymer or fibre in the mixture [9]. The application of polymers and waste tyres to bitumen has been proven to help enhance performance. The specific objective of this study is to find the best proportion of waste tyre crumbs to be used in the stone mastic asphalt.

2. Materials and Methods

The research was conducted at the Concrete and Materials Testing Laboratory of the Department of Farm Structure and Environmental Engineering at Bangladesh Agricultural University, Mymensingh. The details of the methods followed and materials used in the study are described.

2.1 Materials

2.1.1 Waste tyres

Waste tyres to be used in asphalting were collected from local workshops and garages. Waste tyres were shredded into crumbs of size 0.15–0.6 mm. These crumbs were mixed and melted with conventional asphalt in varying volumetric proportions; at 6, 8 and 10% by weight of conventional bituminous pitch.

2.1.2 Sand

Sand is one of the normal natural fine aggregates used in construction. The colour of the used sand is grey. The shape of sand particles is angular, sharp and rounded. The fineness modulus of used sand was 1.62; the sand was used at 7% of the total weight of stones.

2.1.3 Gravel

Gravels or coarse aggregates are the major constituents in stone mastic asphalt, making 70% to 80% of the total volume. The aggregates used in this research were angular in shape. The average size of the aggregate was 9.5mm.

2.1.4 Dark Bituminous Pitch

Dark bituminous pitch is heated to 150°C for about 1 hour prior to blending with the aggregate. The pitch was collected from the LGED office, Narail. Figure 1 shows the waste tyre crumb, sand, gravel and bitumen used in this study.

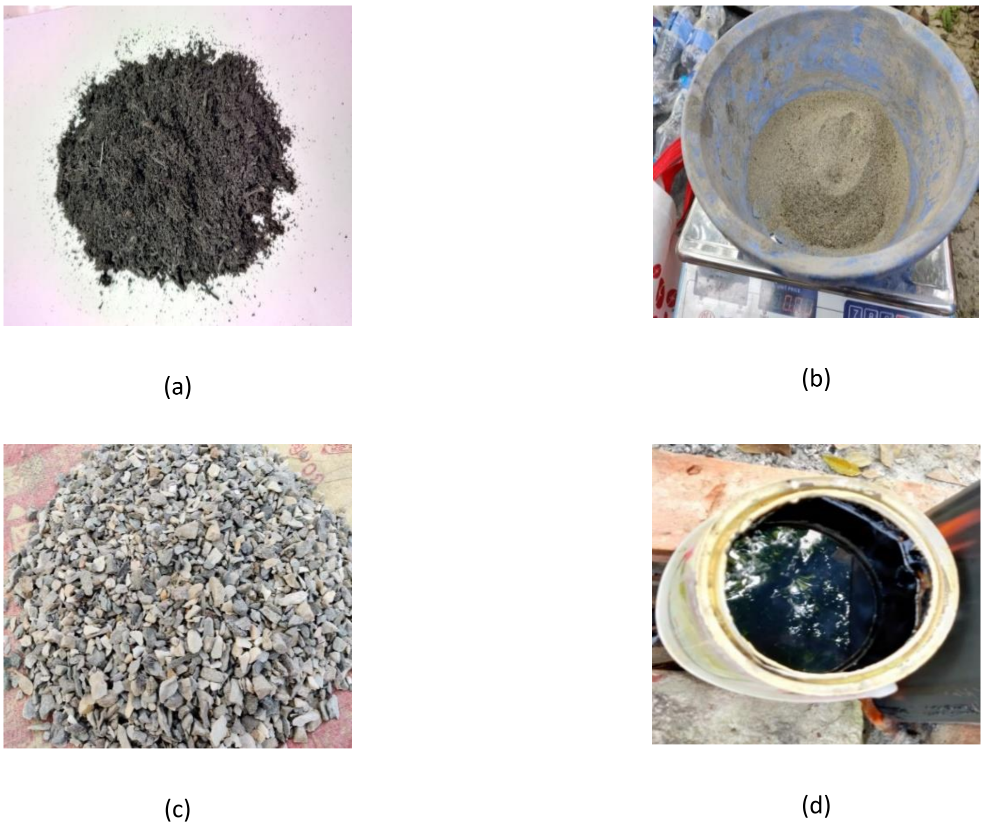

Figure 1. (a) Waste tyre crumb, (b) Sand, (c) Gravel and (d) Bitumen

2.2 Apparatus Used

In this study 3"×6" cylindrical mold, weighing balance, sieve, infrared thermometer, trowel, tapering rod, proving ring penetrometer etc were used. Figure 2 shows some of the apparatus used in this study.

(a) (b) (c)

Figure 2. (a) Cylindrical mold, (b) Laser thermometer and (c) Proving ring penetrometer

2.3 Preparation of sample specimens

To prepare the samples, the steps are followed are described below. The Figure 3 shows the steps in preparing the waste tyre asphalt. The mixing proportions are given in Table 1.

(a) (b)

(c) (d)

Figure 3. Steps in preparing the waste tyre asphalt: (a) Heating of gravel at 200°C for a period of approximately 2 hours; (b) Heating of bituminous pitch at 150°C for about 1 hour; (c) Mixing and melting tyre crumbs with conventional asphalt; and (d) Mixing aggregate, bitumen and filler at a temperature of 160 ± 5°C for around 5 minutes.

- Before adding aggregate to the mixture, it was heated to 200°C for a period of approximately 2 hours.
- The selected bitumen was heated to 150°C for about 1 hr before blending with the aggregate.
- Waste tyres were collected and shredded into crumbs.

- Waste tyre crumbs were mixed and melted with conventional asphalt in varying volumetric proportions i.e. 6%, 8% and 10% of bitumen pitch.
- The combination of aggregate, bitumen and filler was mixed at a temperature of 160±5°C for around 5 minutes.
- 9 samples were made using the 3"×6" cylindrical mold with 6%, 8% and 10% tyre crumbs.
- 3 conventional SMA samples were made without using tyre crumbs as control.

Table 1. Mix proportions in waste tyre asphalt

Sample name	Amount of Gravel (gm)	Amount of Sand (gm)	Amount of Pitch (gm)	Amount of Tyre Rubber (gm)
0% Tyre	3300	230	260	0
6% Tyre	3300	230	260	16
8% Tyre	3300	230	260	21
10% Tyre	3300	230	260	26

2.4 Casting

After mixing all the ingredients the hot mixture was cast into the cylindrical molds which were previously greased to facilitate demolding. The materials were cast in three layers. Each layer of sample was compacted by a tamping rod applying 25-30 strokes. The top surface of the cylinder was finished smoothly. The samples were taken out of the molds after 3 days. Then the weight of samples were recorded. Figure 4 shows the casting process of tyre asphalt cylinders.

(a)

(b)

Figure 4. Steps in casting the waste tyre asphalt cylinders: (a) Putting grease inside molds before placing hot mixture; and (b) Casting hot mixture into molds

2.5 Laboratory Tests

2.5.1 Density test

The density of a substance is its mass per unit volume. The mass of each cylindrical sample was determined using a balance. The size of each sample was 3"×6" (0.076m×0.152m). Once the volume of the cylindrical sample was determined it led to the density calculation of the samples.

2.5.2 Water absorption test

A water absorption test was conducted to determine the moisture content of the sample as a percentage of its dry weight. At first dry weight of the sample was recorded. Then the sample was placed in a water bath for 24 hours. After 24 hours, samples were collected from the water bath and sun-dried for 24 hours. Then the weight of the sample was recorded. The water absorption is then calculated using the following equation:

$$W = (W2 - W3)/W3 \times 100$$

Here, W= Moisture content, %; W2= Wt. of wet sample, gm; W3= Wt. of dry sample, gm

2.5.3 Penetration test

The test is extremely useful for determining the relative density and the angle of shearing resistance of asphalt roads and pavements. In this test a proving ring penetrometer was used for determining the penetration resistance of samples are shown in Figure 5. The proving ring penetrometer is a 30-degree cone penetrometer. To determine the penetration resistance, the penetrometer was firmly pushed into the sample at a uniform rate for 1.25-inch penetration. Then the reading of proving dial was recorded. The corresponding penetration resistance load can be determined from the calibration chart. The steps of penetration test of samples are given below:

- Dial indicator had been set to zero position.
- The assembly was held vertically on the top surface of the sample. The handle was grasped firmly and the cone point was pushed down into the sample at a steady uniform rate until the top of the cone went 1.25 inches below the surface.
- The dial indicator readings were taken. Using the proving ring calibration chart, maximum penetration resistance loads for 1.25-inch penetration were determined.

Figure 5. Penetration test of sample

2.5.4 Split tensile strength test

Split tensile strength is the ability of a material to withstand a tensile force. The cylinders used for the split-tensile strength test were 6 inches (0.152m) in length and 3 inches (0.076m) in diameter. For testing of tensile strength of specimen, the specimen was kept horizontally under the machine and the load was applied gradually and measured the load upto the ultimate point are shown in Figure 6. The ultimate load was recorded from the monitor of the machine. The tensile strengths of the cylinders were determined by using the following equation:

$$S = 2P/\pi DL$$

Here, S= Tensile strength of the cylinder (KN/m^2); P= Maximum applied load indicated by testing machine (KN); D= Diameter of the cylinder (m); L = Length of the cylinder (m);

Figure 6. Split tensile strength test of sample

2.5.5 Moisture susceptibility test

The moisture susceptibility of bituminous mixtures is defined as the vulnerability of the asphalt mixture to be damaged by water. When moisture collects within the bituminous mixture, it can cause damage to the bond between the aggregates and asphalt binder. The moisture susceptibility test was carried out in accordance with the AASHTO T283 procedure on four SMA mixes. Three specimens with 0% waste tyres (unconditioned dry group) and nine specimens with 6%, 8% and 10% shredded tyre rubber (conditioned wet group) were prepared. A tensile strength ratio (TSR) of the wet to dry group was calculated based on the outcomes of the tensile strength test. It is noteworthy to mention here that the higher the TSR value the better the asphalt mixture resistance against moisture damage. A 70% or more TSR value is required for normal SMA specification.

3. Results and Discussion

12 SMA samples were made; the physical and mechanical properties of prepared samples were determined and compared with the conventional asphalt.

3.1 Density

The densities of samples with 0%, 6%, 8%, 10% waste tyre rubber crumbs were determined. The densities of samples containing different percentages of waste tyre rubber crumbs are given in Figure 7. From the figure, it has been seen that density decreases gradually with the increase in different percentages of waste tyre rubber crumbs. 6% addition of tyre crumbs with conventional asphalt resulted in a 1.52% reduction in density. 8% addition of tyre crumbs with conventional asphalt resulted in a 2.28% reduction, and a 10% addition of tyre crumbs with conventional asphalt resulted in a 2.60% reduction in density. Tyre crumbs are lighter than bitumen and the addition of tyre crumbs creates some pore spaces between aggregates and this in turn decreases the densities of samples. The effect of using polyethylene in hot asphalt mixtures confirmed that the added polyethylene polymers helped to enhance the stability of the mixtures, slightly increased the air void and the voids of the mineral aggregate, and reduced the density of the asphalt mix [10]. The addition of tyre crumbs in the asphalt mix produced for this study had similar impacts on the voids and hence the density.

3.2 Water absorption

The water absorption values of samples containing different percentages of waste tyre rubber crumbs are shown in Figure 8. This figure shows that water absorption increases with the increase in the percentage of waste tyre rubber crumbs. The void in the mix increases with the increase of rubber content in the mix. This is because the added rubber absorbs the binder [11]. This process results in the samples being inadequately coated with the binder, thus resulting in voids between the aggregates. This would reduce the contact points between the aggregates and increase the voids. The nature of rubber that can expand when mixed in the bitumen also causes the voids to increase in the mix. Due to some increase of voids in the mix, there remains a small portion of water. The figure revealed that the water absorption value increases albeit slightly with the increase in different percentages of waste tyre rubber crumbs. In this study, the asphalt prepared in dry process, 6% addition of tyre crumbs with conventional asphalt resulted in an 8% increase in water absorption; 8% addition of tyre crumbs led to a 12% increase in water absorption, and 10% addition of tyre crumbs resulted in a 15% increase in water absorption.

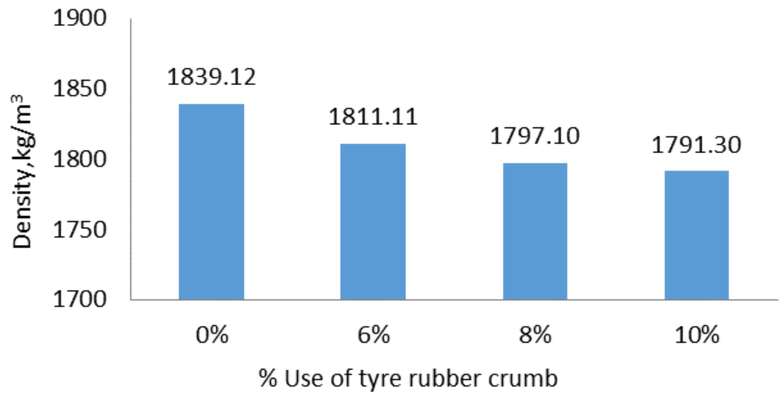

Figure 7. Comparison of densities among waste tyre rubber asphalt samples containing different percentages of waste tyre rubber crumb.

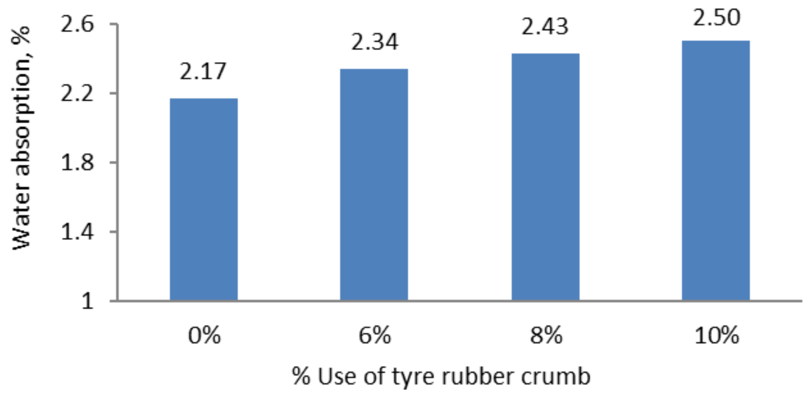

Figure 8. Comparison of water absorption among waste tyre rubber asphalt samples containing different percentages of waste tyre rubber crumb.

3.3 Penetration test

The penetration resistance values of samples containing different percentages of waste tyre rubber crumb are shown in Figure 9. The higher the percentage of rubber crumbs added, the lower the penetration [12]. There are two methods of adding waste tyre crumbs in asphalt mixture. In the wet process waste tyre rubber crumbs are added to hot bitumen and in the dry process, tyre crumbs are added to hot aggregate prior to adding the bitumen. A 1% addition of tyre crumbs with hot bitumen resulted in a 35.72% reduction in penetration, 2% addition of tyre crumbs with conventional asphalt resulted in a 30.6% reduction, and 4% addition of tyre crumbs with conventional asphalt resulted in a 30.8% reduction in penetration [12]. In the dry process employed in this study, 6% addition of tyre crumbs with hot aggregate resulted in a 10.6% increase in penetration resistance in terms of loads; 8% addition resulted in a 14% increase, and 10% addition resulted in a 15% increase in penetration resistance. Basically, the load needed to penetrate 1.25 inch of the penetration cone increased with the increase in percent tyre crumb.

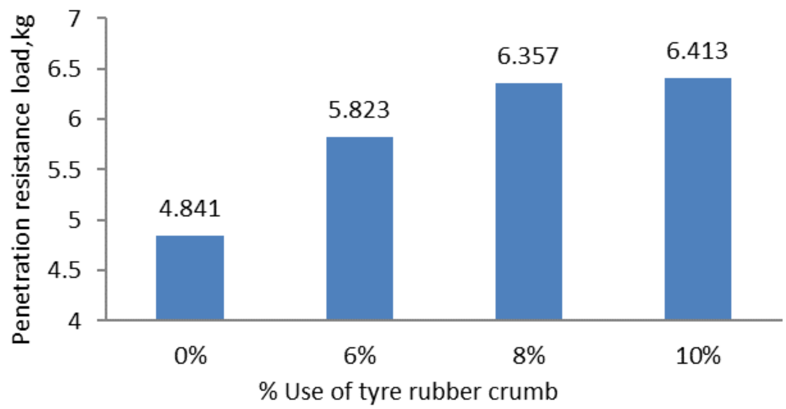

Figure 9. Comparison of penetration resistance load among waste tyre rubber asphalt samples containing different percentages of waste tyre rubber crumb

3.4 Split tensile strength

The results of split tensile strength test are shown in Figure 10. It was concluded that as the percentage of waste tyre rubber used in sample increased, the tensile strength decreased slightly. In India found the same effects on tensile strength [13]. Indirect tensile strength test using MTS 810, it was found by a study that tensile strength of rubber modified asphalt mixtures decreased with the increase in rubber content; a 1% addition of tyre crumbs with conventional asphalt resulted in a 9% reduction in tensile strength, a 2% addition resulted in a 23% reduction, a 4% addition in a 30.8% reduction in tensile strength [14]. It concluded that based on the analytical results of the rutting test and indirect tensile test, the addition of tyre rubber in asphalt mixtures using a dry process could improve the properties of resistance to permanent deformation at high temperatures and cracking at low temperatures [14]. Here it was found that 6% addition of tyre crumbs with conventional asphalt resulted in a 17.6% reduction in tensile strength, 8% addition resulted in a 27.7% reduction, and 10% addition resulted in a 30% reduction in tensile strength. The addition of tyre crumbs creates some pore spaces between aggregates. Thus, it decreases the density of samples and creates some reduction in tensile strength of samples. It is seen that the reduction of tensile strength in 8% and 10% addition of tyre rubber crumbs is almost the same.

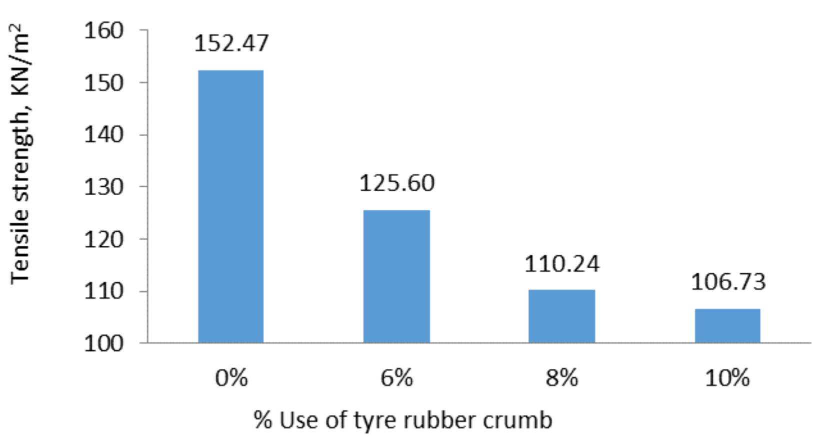

Figure 10. Comparison of split tensile strength among waste tyre rubber asphalt samples containing different percentages of waste tyre rubber crumb.

3.5 Moisture susceptibility

It was found that the tensile strength ratio (TSR) of the mixtures decreased with the addition of waste tyre rubber crumb. TSR values between 70% and 80% have been set as the minimum requirement by AASHTO T 283 and ASTM D 4867 standards [15]. Figure 11 shows, all values of TSR are above 70% indicating that all mixes may have adequate resistance against damage induced by moisture. However, the addition of waste tyres does not improve the moisture susceptibility of the mixture.

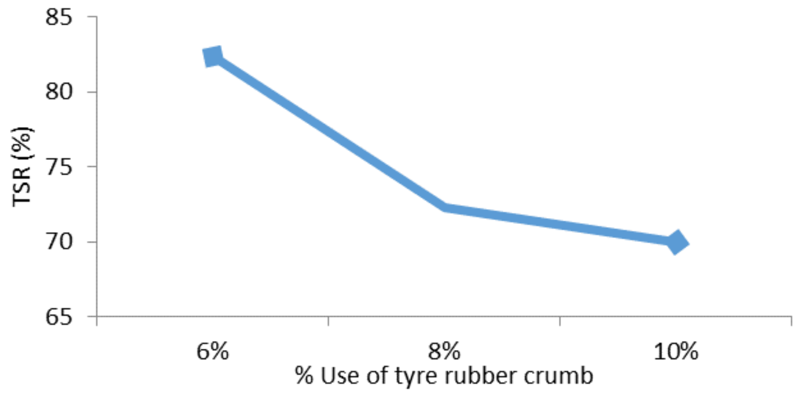

Figure 11. TSR for asphalt mixtures containing different percentage of waste tyre rubber crumb.

4. Conclusions

This study focused on a laboratory evaluation of the performance of waste tyre rubber crumbs added to Stone Mastic Asphalt. From this study, the following conclusions may be drawn:

- The density decreased with the increase in the percentage of waste tyre rubber crumbs. A 6% addition of tyre crumbs with conventional asphalt resulted in a 1.52% reduction in density; an 8% addition of tyre crumbs with conventional asphalt resulted in a 2.28% reduction, and a 10% addition of tyre crumbs with conventional asphalt resulted in a 2.60% reduction in density.

- Water absorption increases with the increase in the percentage of waste tyre rubber crumbs. A 6% addition of tyre crumbs with conventional asphalt resulted in an 8% increase in water absorption; an 8% addition of tyre crumbs led to a 12% increase in water absorption, and a 10% addition of tyre crumbs resulted in a 15% increase in water absorption.

- A 6% addition of tyre crumbs with conventional asphalt resulted in a 10.6% increase in penetration resistance in terms of loads; an 8% addition resulted in a 14% increase, and a 10% addition resulted in a 15% increase in penetration resistance load.

- As the percentage of waste tyre rubber used in the sample increased, the tensile strength decreased slightly; a 6% addition of tyre crumbs with conventional asphalt resulted in a 17.6% reduction in tensile strength, an 8% addition resulted in a 27.7% reduction, a 10% addition resulted in a 30% reduction in tensile strength.

- Tensile Strength Ratio (TSR) of the mixtures decreases with the addition of waste tyre rubber crumb; however, TSR values are above 70% indicating that all mixes may have adequate resistance against damage induced by moisture.

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