EVALUATE THE EFFECT OF COARSE AND FINE RUBBER PARTICLE ON LABORATORY RUTTING PERFORMANCE OF ASPHALT CONCRETE MIXTURES

[1]Dr. Yusuf Mehta, P.E. (Corresponding Author) and [2]Dr. Kauser Jahan, P.E., [3]Jim Laicovsky, [3]Laura Miller, [4]Devi Parikh, and [3]Alicia Licon Lozano

Abstract

The nation faces ecological problems due to the accumulation of waste automobile and truck tires. In this study, the effect coarse GTR and crumb rubber on rutting performance of Superpave asphalt concrete mixtures as measured in the laboratory were evaluated. A percentage of the locally available coarse rubber, uniformly graded is used as a substitution for aggregate particles, at nine levels of rubber percentages, 0%, to 4.0 % at 0.5%, increments, while maintaining the well-graded Superpave gradation. In addition to coarse rubber, fine crumb rubber particles (minus No 80 and No. 20 mesh) in proportions of 5% and 15%, were evaluated using the compaction characteristics of the Superpave Gyratory Compactor to determine the optimum percentage of coarse and fine rubber particles that can be used in the asphalt concrete mixture. The coarse rubber particles exhibit increased rutting resistance as percentage of rubber increased up to 3.5 %. On the other hand, crumb rubber dissolved in the binder and stiffened to increase its rutting resistance. Even though only up to 2.5% coarse rubber particles could be were used as compared to 15 % of crumb rubber, the processing cost of coarse of rubber is much less than crumb rubber to make it cost effective.

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[1]Assistant Professor, [2]Associate Professor, [3]Students, Department of Civil and Environmental [4]Student, Department of Electrical and Computer Engineering, Rowan University, Glassboro, NJ 08028.

Phone: (856)-256-5327 Fax: (856) 256-5242. E-mail: Mehta@rowan.edu.

INTRODUCTION

Problem Statement

The nation faces a major ecological problem due to accumulation of waste automobile and truck tires. Environmental regulations prohibit the open burning or burying of tires in solid waste facility. These tires are accumulating at the rate of about 3/4th billion per year [1], [2], [3]. In order to solve this problem efforts are now being made to find uses for these waste tires.

Also, there are some performance characteristics of asphalt concrete mixtures for which the properties of asphalt cement binder play an important role, such as durability. Additionally, there may be situations where the properties of the aggregate portion of a particular mix cannot be changed because of local conditions, economics, or frictional characteristics. In these cases an improvement in the characteristics of the mix will need to be obtained through change or improvement of the asphalt binder cement. One of the asphalt modifiers or additives, which indicated some promise of improved binder properties, was relatively low percentages of finely ground tire rubber (GTR) [3], [4], and [5].

Rubberized asphalts resisted rutting better than conventional (unmodified) asphalt and about as well as polymer modified binder asphalts. Wheel tracking performances were similar for dry mix and wet mix asphalts, but the fatigue life for dry mix was three times as long as that of wet mixes. The type of rubber crumb used to make binders did not affect wheel tracking very much, but had a significant effect on fatigue resistance [6].

Therefore, the rutting performance of the pavement is known to improve in several states like Florida, Pennsylvania, Colorado and Kansas when crumb (fine) rubber is used to modify the binder. But the effects of various sizes and proportions of rubber on the rutting performance of pavements with local New Jersey aggregates are still to be evaluated.

Nearly 280 million tires accumulate annually in the United States. The use of reclaimed ground tires in road construction would solve a waste disposal problem and offer the benefit of resource recovery. In the past, asphalt cement has been blended with rubber to be used as a seal coat, a stress absorbing membrane or interlayer, or as a crack sealer. The performance of ground tire rubber modified asphalt concrete is highly dependent on the size and amount of the ground tire rubber particles, the mixing process, the aggregate sources and gradation, and asphalt cement. The purpose of this study is to determine the optimum percentage of fine and coarse rubber particles in asphalt concrete using well-graded New Jersey aggregates. The laboratory performance was determined by measuring the shear resistance of asphalt concrete mixtures in the Superpave Gyratory Compactor.

Objective

The objectives of this study is:

1. To determine the optimum coarse rubber particle substituting aggregates in hot mix asphalt and
2. To determine the optimum fine rubber particles to be dissolved in the asphalt binder in hot mix asphalt in the laboratory using the Superpave Gyratory Compactor**.**

Scope

The scope of this study includes use of one aggregate gradation using typical New Jersey aggregates. Three rubber sizes were evaluated, fine rubber (passing No. 20 and no.80 mesh) and coarse rubber (9.5 mm). Various fractions of each were evaluated using one type of binder (AC-20). The results and conclusions were base don laboratory evaluation using Superpave Gyratory Compactor.

RESEARCH APPROACH

The research approach is as follows:

1. To develop a well-graded aggregate gradation using locally available aggregates. This was done using available Superpave guidelines.
2. To obtain coarse rubber particles, uniformly graded at a processing plant through sieve analysis and commonly used fine rubber particles passing No. 20 and No. 80 size.
3. Develop an experimental design for testing various percentages of coarse and fine rubber particles.
4. Prepare three specimens for compaction in the Superpave Gyratory Compactor. Collect data from the Superpave Gyratory Compactor (SGC)

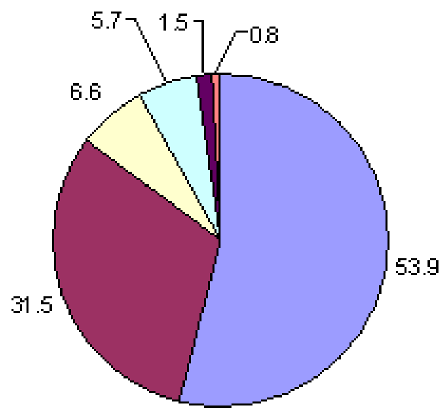
5. Conduct analysis to determine optimum percentage of coarse and fine rubber.

6. Make conclusions and recommendations to determine optimum percentage of rubber to be used both in fine and coarse.

Background

Waste Tires

Every year, at least 273 million tires are produced in the United States. This is the equivalent of nearly one scrap tire per person per year. Tires account for 1.5% of solid waste in the United States (Figure 1). Approximately eighty-four percent of these tires are from passenger cars.



Commercial and Industrial Waste	53.9%
Residential Waste	31.5%
Construction and Demolition Waste	6.6%
Yard Waste	5.7%
Tires	1.5%
Appliances/Metals	0.8%

Figure 1. The distribution of waste in the United States.

State and federal regulations now prohibit waste tires from being placed in landfills. They must be separated from other waste and dealt with in some other way. Tires left out in the open collect rainwater and are often a breeding ground for insects, rodents and other vermin. When stockpiled, they are highly combustible and can create an uncontrollable fire. From 1989 to present, it is estimated that nearly 31 million tires, in the State of New York alone, have burned up in vast, uncontrollable tires fires.

Attempts to reuse waste tire rubber include ground rubber use. There are five markets in which ground rubber is used. They are rubber-modified asphalt, new tire manufacturing, molded products (e.g. radiator shields), extruded products (sheets of rubber), and bound products (railroad crossing ties, soaker hoses). Rubber modified asphalt has been the single largest market for ground rubber in the United States for decades. However, only 33 million scrap tires per year are processed into ground rubber. That is only 12% of the tires produced in the United States every year.

Pavement Failure

There are three “ingredients” to an asphalt mixture. One these three ingredients are aggregate. Aggregate are the stone and sand particles that provide the mixture’s strength. The second ingredient is the asphalt binder. Asphalt is the black, sticky material that coats the aggregate particles, which gives the mix durability. The proper blend of the asphalt cement and aggregates is needed to make the mix durable and strong. The third ingredient is air voids. Air is not added to the asphalt mix; the binder and aggregates are blended to allow air voids to remain in the mixture. Rutting can occur from too few air voids. Too many air voids can result in cracking and raveling.

Asphalt pavement has many forms of failure that may occur. These failures are a result of different design techniques, temperature, traffic load, and chemical makeup. There is a high cost involved in the maintenance and repair of these asphalt failures.

Rutting is a failure that causes channels in the pavement. Heavy traffic loads and high tire pressure in combination with poor pavement design and strength cause this. Rutting is a serious problem because of the puddles that form in the channels, which can ultimately cause disaster. Rutting occurs more commonly where temperatures are high because the asphalt turns soft.

Ground Tire Rubber (GTR) In Asphalt Concrete

Ground tire rubber has been evaluated for a number of years as a recycled material for use in many different applications. In studies conducted by Dana N. Humphrey, University of Maine, GTR has shown viable usefulness as a lightweight backfill component in retaining wall applications with it lower earth pressure loading capabilities. Additionally, Humphrey’s research has shown that GTR contributes to improved road performance by reducing soil settling and prost depth penetration.

Within the structure of pavements, the incorporation of GTR into hot mix asphalt (HMA) had been viewed as a possible means to improve its performance. Particularly in rutting and flexure related issues. An added advantage of this is that solid waste management concerns could be simultaneously addressed.

A general type of asphalt modifier known as crumb rubber modifier contains scrap tire rubber. Asphalt pavements that are made with these rubber modifiers are produced using either the wet or dry process. Crumb rubber modified asphalt (CRMA) binder primary applications include crack and joint sealants; chip seal, interlayer, and hot-mix asphalt binder; and membranes. CRMA binders are less susceptible to changes in temperature, and possess superior properties. Because asphalt rubber binders are softer at lower temperatures when concerned about brittleness and stiffer at higher temperature where traffic loading can cause rut formation, CRMA binders alleviate road failures to some extent. The disadvantages of these types of binders are their higher processing costs than conventional asphalt binders. The ultimate goal would then be the development of a binder that is cost competitive to normal binders.

Other areas of asphalt research included surface treatments known stress-absorbing membranes (SAM). In a study conducted by the Virginia Department of Transportation, SAMs was evaluated as a means to absorb the stresses developed by movement of underlying cracks, and prevent reflection cracks in the new surface. The binder used in such SAM system is composed of 80% asphalt cement and 20% GTR. In the test section, excess stone loss led to bleeding not to excess binder. Although the test section demonstrated that SAMs do effectively seal cracks on old surfaces, the excessive loss of coarse aggregates under traffic caused vehicular damage.

By in large, the studies conducted in HMA systems modified with rubber have conclusively shown that crumb rubber particles added into the mixtures works well. There is however an apparent insufficient amount of research in evaluating coarse particle substitution. The question then ultimately is how would coarse rubber particles perform in HMA mixtures? Would the flexure as well as elastic properties inherent in rubber improve the performance of HMA especially in rutting and cracking issues?

SUPERPAVE GYRATORY COMPACTOR

The Superpave gyratory compactor (Figure 2) produces asphalt mix specimens to densities achieved under actual pavement climate and loading conditions. With its 150 mm diameter mold, it is capable of accommodating large aggregate mixtures. A key feature is its ability to estimate specimen density at any point during the laboratory compaction process. It is the key laboratory device used in Superpave mix design. A Superpave gyratory compactor consists of a rigid reaction frame, loading system, and specimen height measurement and recordation. It compacts asphalt mixture specimens at a constant pressure of 600 kPa. The mixture is compacted by a gyratory kneading action using a compaction angle of 1.25 degrees and operating at 30 rpm. By knowing the mass of the specimen being compacted and the height of the specimen, specimen density can be estimated during the compaction process. This is accomplished by dividing the specimen mass by the specimen volume. To estimate volume, the specimen is assumed at any point to be a smooth-sided cylinder of 150 mm in diameter and measured height.

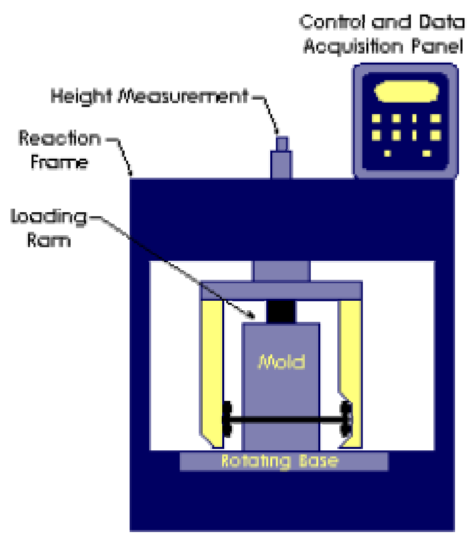


Figure 2. Superpave Gyratory Compactor

SUPERPAVE GYRATORY COMPACTOR PARAMETERS

During compaction height of specimen versus number of revolutions is measured. The height versus log (number of revolutions) is a straight line, the area under the curve reflects the amount of energy absorbed by the specimen during compaction at a given gyration level. A smaller value indicates lesser susceptibility to external loads, thus less rutting and a better mix

Bulk Specific Gravity

The bulk specific gravity, the maximum specific gravity of the compacted samples were measured using ASTM standards [7]. The air voids of the compacted specimen was calculated using the following equation:

$$\% AirVoids = 100x(1 - \frac{G_{mb}}{G_{mm}}) \tag{1}$$

where:

G_{mb}	=	Bulk specific gravity
G_{mm}	=	Maximum specific gravity
% Air Voids	=	Air voids of compacted specimen, %

K*Air voids

The product represents the condition of the material at the end of a given gyration level. The lower value indicates poor aggregate structure and over compaction, which may lead to more rutting and thus a worse mix. The values of these parameters at design binder content are shown in Table 1.

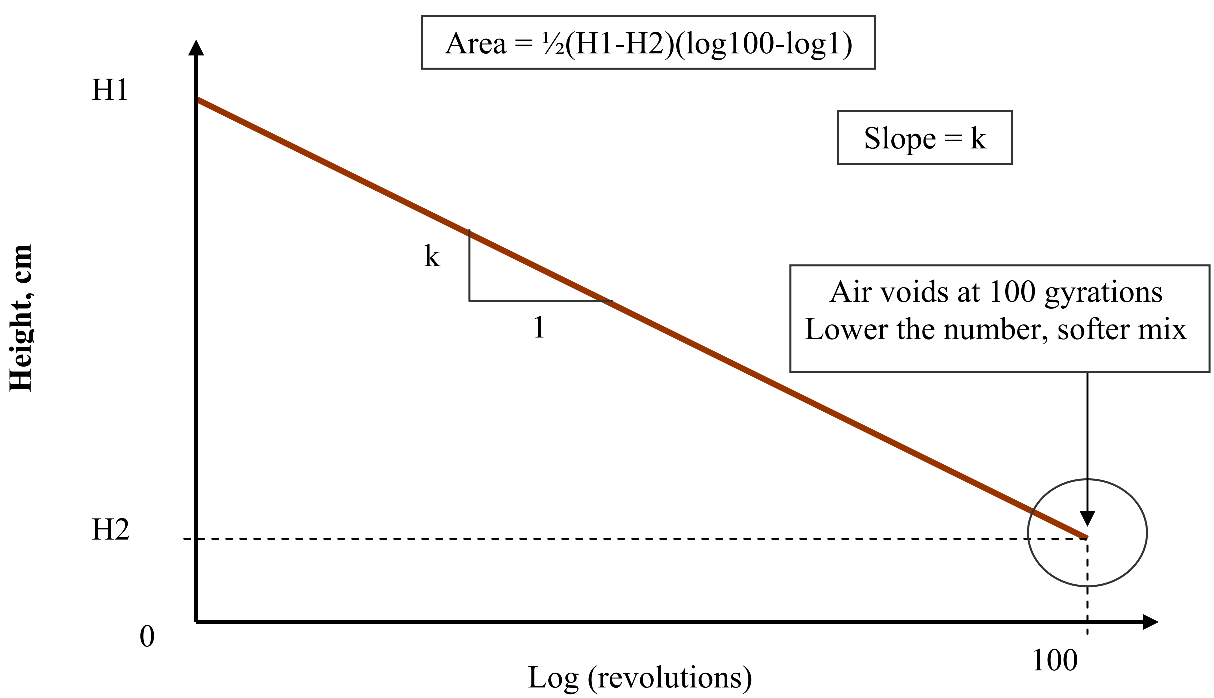


Figure 2. Height versus log(number of revolutions)

Area under the curve

Area under the curve reflects the amount of energy absorbed by the specimen during compaction at a given gyration level. A higher value indicates lesser susceptibility to external loads, thus less rutting and a better mix.

Both these parameters are analogous and provide similar information in terms of the laboratory resistance of the asphalt concrete mixtures. However, the area under the curve is more sensitive to gradation and the aggregate sources in the mixture rather than the properties of the binder. On the other hand, the binder is more sensitive to the "k x Air voids" parameter.

MATERIALS

Asphalt Binder And Aggregates

The asphalt binder that is commonly used in the state of New Jersey (AC-20) was used in the study. The four aggregate sources and their particle distribution as shown in Figure 3.

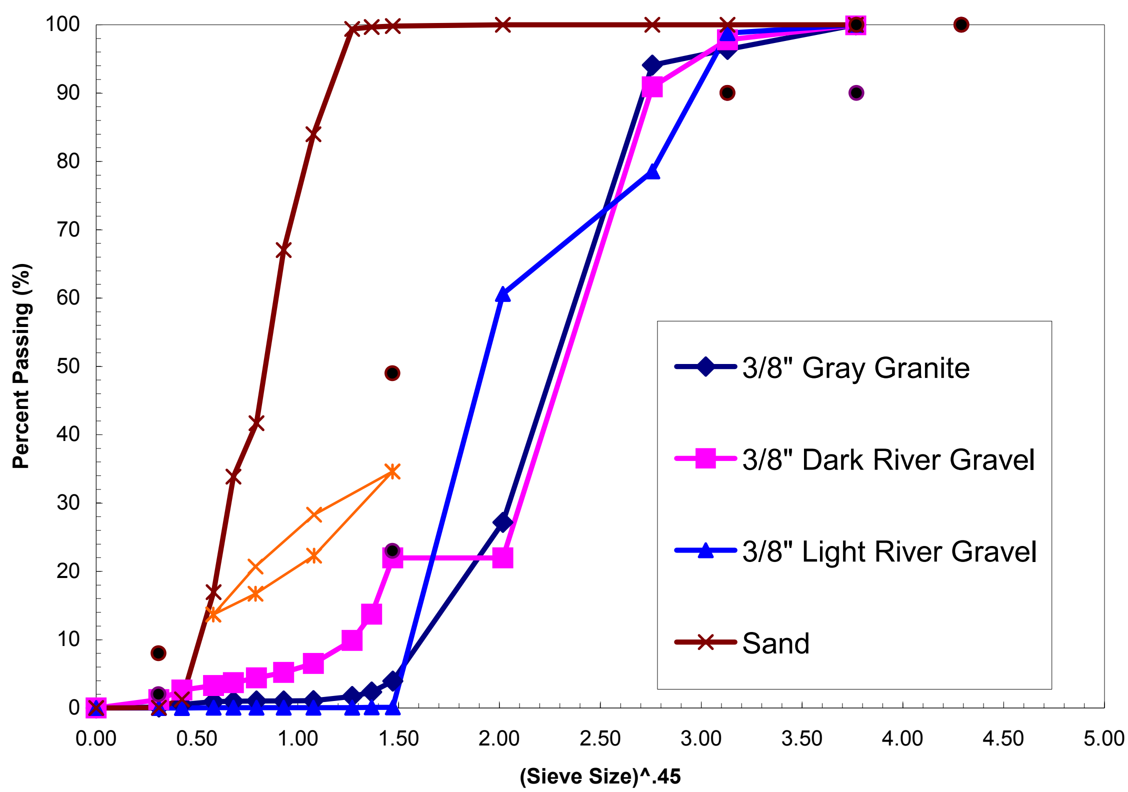


Figure 3. Particle Size Distribution

Aggregate Gradation

Based on the available aggregate stockpiles, a well-graded gradation was developed that passed the current asphalt concrete mixture design specifications. This aggregate gradation (Figure 4) will ensure a stable aggregate structure.

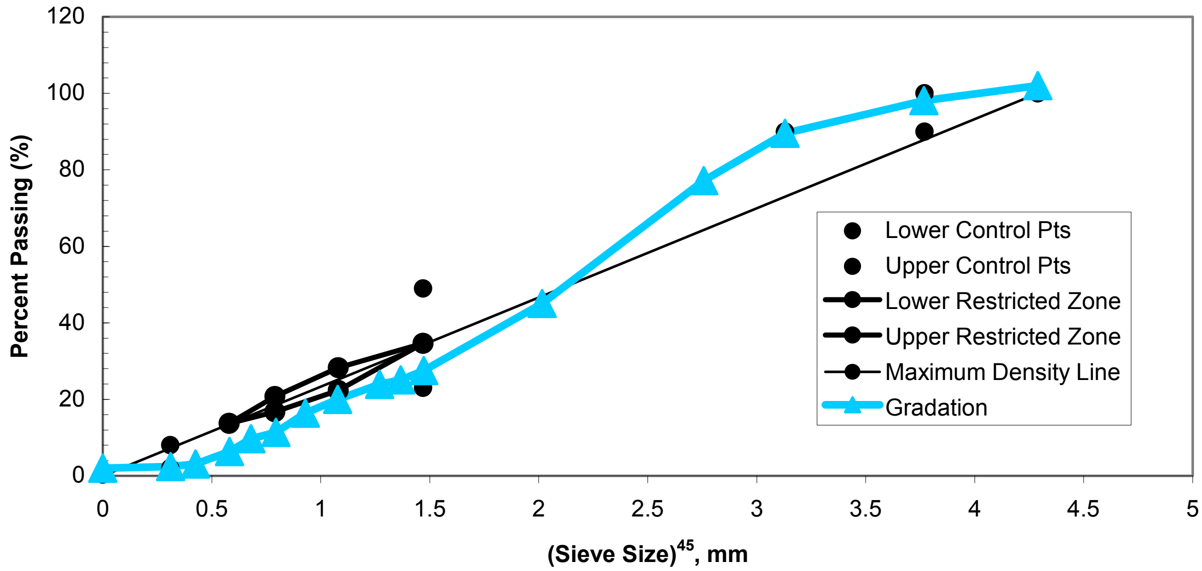


Figure 4. The aggregate gradation of the blend.

Rubber

The fine rubber particles were smaller than No. 20 mesh (0.9 mm) and No.80 mesh (0.2 mm). These particles were dissolved in the binder and did not substitute the aggregates. They were added as a percentage of total weight of binder.

The coarse rubber particles were uniform size of 9.5 mm obtained from the processing plant. These rubber particles were substituted as aggregates, while maintain9ng the same gradation shown in Figure 3.

Asphalt Concrete Mixture

Control Section

The control section consisted aggregates and gradation mentioned above and consisting of no rubber both coarse and fine.

Fine Rubber

The following five mixtures mixes were to be evaluated in order to study the effect of different sizes and proportions of rubber particles:

1. Binder with 5% of No. 20 rubber

2. Binder with 15% of No. 20 rubber

3. Binder with 5% of No. 40 rubber 4. Binder with 15% of No. 40 rubber***Coarse Rubber***

The uniformly graded coarse rubber particles were used at 0.5%, 1.0%, 1.5%, 2.0%, 2.5%, 3.0%, 3.5% and 4.0% of the weight of aggregates. In all cases, the rubber was substituted for the aggregates and the gradation was kept the same as that of the control section. Thus, evaluating only the effect of rubber particles and not the effect of gradation.

Design Asphalt Content

The design asphalt content was determined by conducting trial blends of different asphalt contents with aggregates and no rubber. The asphalt content that passed all the asphalt concrete mixture design specifications was selected for determining the optimum rubber content. The fine rubber particles dissolved in the asphalt and therefore the total asphalt content was kept constant at 6 % in all the four cases. In coarse rubber**,** the asphalt content was adjusted for absorption of asphalt by rubber.

LABORATORY TESTING

The aggregates, the asphalt and rubber were heated at 160ºC, they were mixed in a bucket mixer and compacted in the Superpave Gyratory Compactor at 100 gyrations which translates to a total of 3 million 180 KN axle loads, which is an average traffic on New Jersey roads. The bulk specific gravity and the maximum specific gravity of the compacted samples were measured using ASTM standards [7].

RESULTS

Superpave Gyratory Data

The typical height versus revolutions data from the Superpave Gyratory Compactor (Figure 5) is collected during densification. The height versus log revolutions would be a straight line (Figure 3).

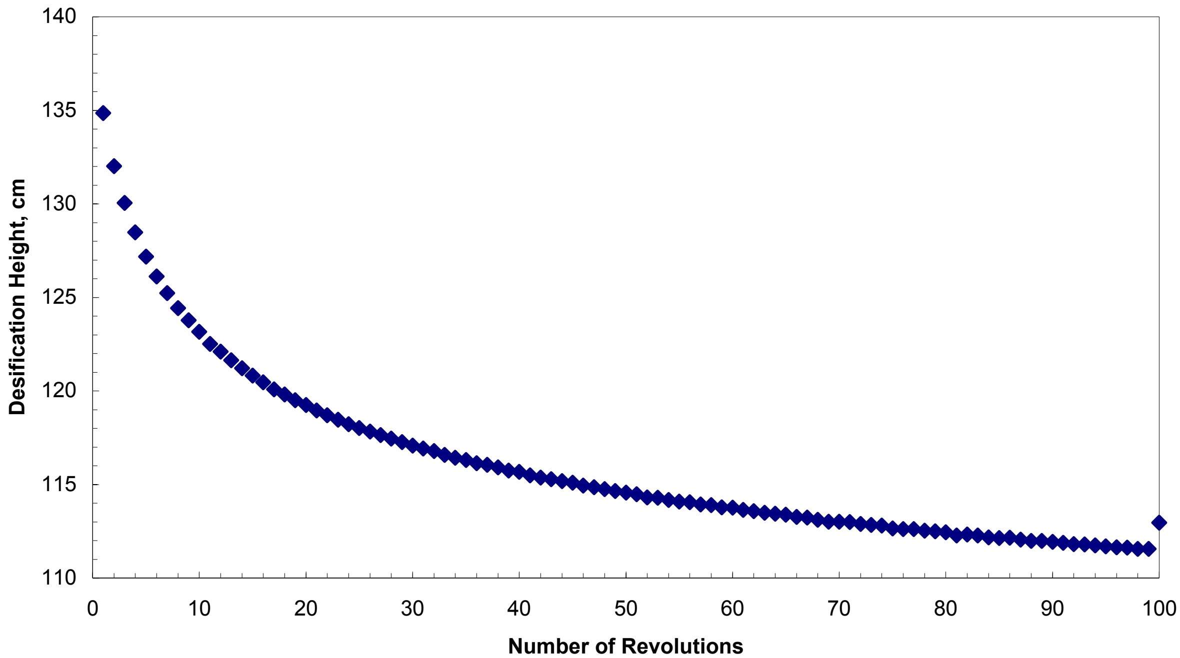


Figure 5. Typical Densification Height versus Number of Revolutions.

Fine Rubber

The data obtained above was plotted to obtain a comparison between the different mixtures. Figure 6 shows that the parameter k*Air voids increases significantly as the amount of rubber increases in the binder, which indicates improved rutting performance. This increase is more significant while going from 0 to 5% than it is while going from 5% to 15%. This may indicate that the improvement rate levels off. Also, the improvement is more significant for the No. 40 rubber particles than it is for the No. 20 particles. This may indicate that the finer particles are more effective.

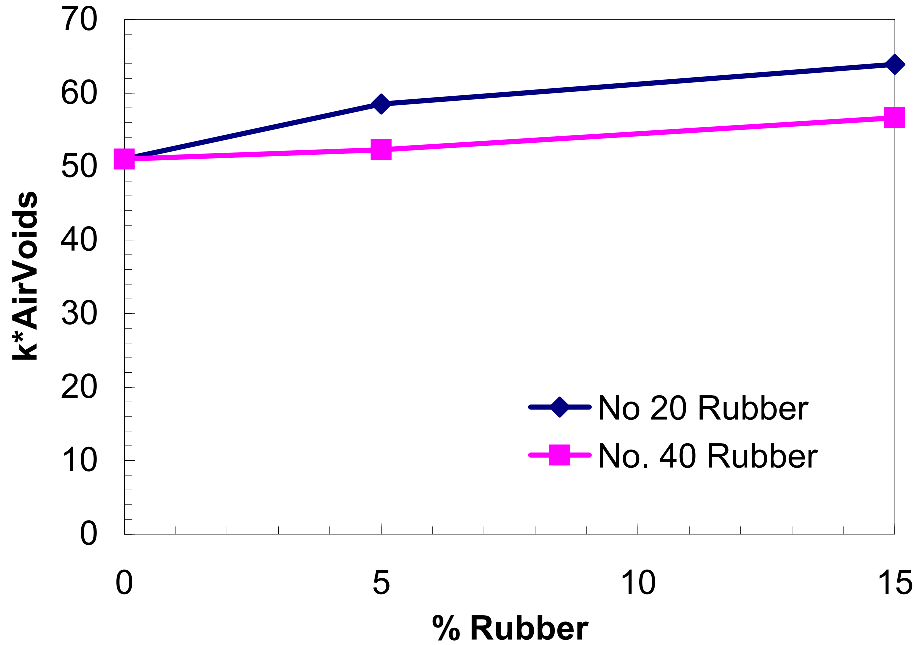


Figure 6. k*Air Voids versus Percentage of Rubber

COARSE RUBBER PARTICLES

The area under the log (number of gyrations) vs. the height of the specimen curve in figure 6 represents the resistant to shear. The data collected suggests that the ideal rubber substitution in regards to shear resistance is in the range of 2.5% and 3.5%. Figure 7 shows the trend that peaks at around 3.0 % rubber substitution.

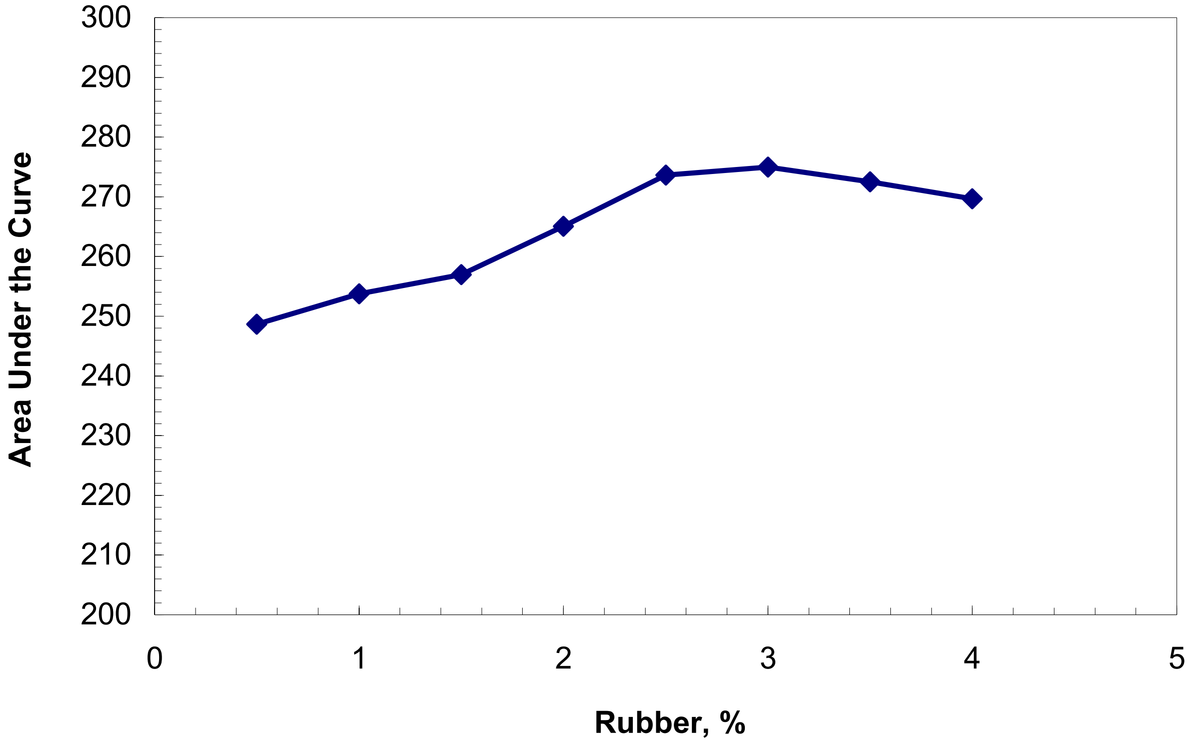


Figure 7. Area Under The Curve.

BENEFITS OF USING RUBBER IN ASPHALT CONCRETE

These are some of the benefits of using of rubber in asphalt concrete.

To reduce the amount of tires waste

Rubber in asphalt concrete technique is the best one to reduce the big amount of tire waste due to 2 billions of tires is used in the construction and rehabilitation of roads annually. If tires are no used in a practical and environmental way, in a few years it will be an immense surroundings problem because their consumption is increasing every single day.

To reduce tire fires

Tires burn very hot and are very difficult to extinguish. This is due to the 75% void space present in whole waste tires. In addition, the shaped tires permit air drafts to stoke the fire. A large tire fire can fumes for several weeks or even months, sometimes with dramatic effect on the surrounding environment.

To reduce traffic noise

Studies have shown that the use of rubber in asphalt concrete pavements can reduce traffic noise up to 85% in some cases. It is because at the moment that tire contacts rubber asphalt concrete is smoother and quieter than the contact tire and asphalt concrete. As a result, it can reduce costs regarding the construction of sound walls, which cost is very high.

COST

Fine Rubber

The cost of fine rubber particles is $0.25 per kg. If approximately 15% of rubber by total weight of asphalt content is used in the asphalt concrete mixture. The additional cost would be $3.00 per metric ton

Coarse Rubber

For 3.5 percent of rubber, 52.5 tons of tires are used in a lane-mile, which are about 7600 tires. This substitution for rubber with aggregates leads to a saving of approximately $140, 000 per lane-mile.

DISCUSSION

The tire waste is an environmental problem around the world. Using rubber both as fine or coarse rubber at the percentages mentioned suggested in this study leads to better laboratory performance. The fine rubber, though slightly more expensive than coarse rubber stiffens the binder and improves its shear resistance. Since rubber particles are softer and more porous than aggregates, the coarse rubber particles when substituted for aggregates need to be evaluated more carefully, to ensure durability performance.

CONCLUSIONS AND RECOMMENDATIONS

The conclusions based on this study are:

1. The laboratory rutting performance of the mixture improves appreciably with addition of fine rubber up to 15 % of total weight of binder.
2. The coarse rubber particles improve laboratory high temperature performance of the mixture up to 3.5 percent.
3. The amount of coarse rubber particles should be evaluated if the gradation and source aggregates are significantly different from that use din the study

4. The study needs to be evaluated with field sections.

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