Improving Urban Infrastructure: Crumb Rubber Modified Asphalt

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Abstract: Roads are believed to be one of the most important elements in urban infrastructure and their role in our everyday life has increased over the years due to their crucial contribution to economic development and growth apart from bringing important social benefits. Modifying the asphalt used in road construction with recycled polymers such as crumb rubber leads to an improvement in its properties and reduces its cost. This paper aims to study the raw materials used in its production and the different methods to produce the crumb rubber modified asphalt (CRMA), physical and rheological properties of CRMA, an analysis of pavement distress, and advantages and benefits of its use. In the studies reviewed, it was found that CRMA improved every physical and rheological property as well as the fatigue and rutting resistance. Overall, the results indicate that the use of scrap tire rubber in asphalt not only helps recycle rubber waste, but also improves the engineering properties of this flexible pavement to get multiple benefits.

***Index Terms*— Crumb rubber, modified asphalt, sustainable paving, physical property, rheology.**

I. Introduction

ROADWAYS are enormously important to all countries. Without roadways, farmers are not able to get their produce to market, factories cannot transport goods to retailers, and people are incapable of getting from one point to another in an efficient manner. Countries or regions without adequate roadways cannot function. Over the years, there has been an increased need for new road structures due to an exponential growth of urban areas, together with maintenance of the old road infrastructure since it has deteriorated more rapidly because of an increase in service traffic density. To minimize the damage to pavement surface and increase the durability of flexible pavements or asphalt pavements, the conventional bitumen used in asphalt roads needs to be improved with regards to performance related properties, such as resistance to permanent deformation and fatigue cracking. The modification of bituminous binder has been explored over the past years in order to improve road pavement performance properties.

In today's world, the amount of rubbish accumulating everywhere is a fundamental concern. With hundreds of millions of car tires discarded, it has been found that they could be crushed to get crumb rubber, which can be used to replace a part of the fine aggregate, the sand, of the asphalt mixture. This is why, by addressing this problem of the need of new road structures and maintenance of the old ones, the solutions to this problem must be designed for sustainability. In this way, the achievement of one of the challenges for engineering identified by the American National Academy of Engineering (NAE): Restore and Improve Urban Infrastructure will be carried out.

In recent studies, civil engineers have found that using recycled crumb rubber as an asphalt modifier can improve every physical and rheological property of the flexible pavements. Also, large amounts of rubber will be recycled.

The aim of this paper is to study the general features of crumb rubber as an asphalt modifier. This will be done in order to present the benefits of using crumb rubber as a replacement of part of the fine aggregate to get better properties.

In order to achieve this, first of all, an analysis of the raw materials used and the dry and wet processes involved in the preparation of asphalt modified with crumb rubber obtained from recycled car tires will be conducted. Second, the physical and rheological characteristics of crumb rubber modified asphalt (CRMA) will be presented. Third, the study of the enhancement of the rutting and fatigue resistance, also known as pavement distress, will be discussed. Finally, advantages and benefits of its use will be presented.

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II. RAW MATERIALS AND METHODS OF PREPARATION

Crumb rubber modified asphalt needs different kinds of raw materials and processes to be developed. The raw materials used are bitumen or asphalt, which work as binders; coarse aggregate, which is a component made of rock quarried from ground deposits; fine aggregate; filler; and crumb rubber obtained from recycled car tires, which will be used as a replacement of part of the fine aggregate. These raw materials are utilized to obtain the CRMA by means of wet and dry processes.

A. Raw materials

Crumb rubber is an elastomer capable of deforming significantly when subjected to stress and recovering its initial shape as soon as stress ceases thanks to its elastic recovery. It can be added as a modifier to bituminous mixtures to enhance the properties of asphaltic concrete.

In order to get the best characteristics of asphalt modified with crumb rubber, the crumb rubber should comply with certain specifications mentioned in the NTE INEN 2680:2013 norm [1]:

- Recycled rubber must contain at least 0,75% of moisture by weight with a free flow.
- Specific rubber gravity must be 1,15 ± 0,05.
- The recycled rubber from tires must not contain non-ferrum metal visible particles and must not have more than 0,01% of weight in ferrous metal particles.

According to Vialidad Nacional Argentina [2], the percentage of crumb rubber included in the asphalt as a replacement for the fine aggregate to have the best effectiveness should not be less than 15%.

Regarding the bituminous material, which acts as a binder for the stony aggregates and the crumb rubber, traditional bituminous binders can be used to prepare the mixture. Also, other modifiers can be added to the bitumen to enhance other properties such as the molecular weight or the softening point for instance.

According to [3, Fig. 1], the main mechanical characteristics required for the bituminous binders used in the production of CRMA should be the following ones:

Parameter	Value	Unit	Standard
Penetration to 25 °C	32	dmm	UNI EN 1426
Softening point	79	°C	UNI EN 1427
Dynamic viscosity 80 °C	352	Pa s	UNI EN 13072-2
Dynamic viscosity 160 °C	0.35	Pa s	UNI EN 13072-2

Fig. 1. Mechanical characteristics required for bituminous binder used in a CRMA mixture. [3]

The values of these mechanical characteristics are standardized by the European Committee for Standardization (CEN). Nevertheless, its values are among the ranges used all over the world.

The amount of bituminous binder used goes from 3.5% to 7% in weight of the entire mixture, it depends on the aggregate's gradation, while the other 93% to 96,5% of the mixture is composed by the aggregates, including the crumb rubber.

As regards the aggregates used in the mixture, they are:

- Coarse aggregate, which is usually crushed rocks, generally, crushed limestone.
- Fine aggregate, where different types of sand can be used.
- Filler, where cement dust or limestone powder are generally used.

The following table presents an approximation of the dosage of the mixture:

Component	Particle size [mm]	Percentage [%]
Coarse aggregate	4 – 8	62,5
Fine aggregate	0,063 – 4	27,5
Filler	0 - 0,063	5
Bituminous binder	-	5

Fig. 2. Asphalt mixture dosage.

The main requirement for the aggregates is to have a dense particle size distribution or gradation, which refers to an aggregate that is composed approximately of equal amounts of various sizes of aggregate.

The gradation is determined by a sieve analysis or a gradation test, which consists in allowing the aggregates to pass through a series of sieves of progressively smaller mesh size and weighing the amount of material that is stopped by each sieve as a fraction of the whole mass. The results of this analysis are presented in a graph of percent passing versus the sieve size.

B. Methods

Crumb rubber modified asphalts can be obtained by means of two methods [4]: by dry process or by wet process.

Asphalt-rubber mixture by dry process.

In the dry process, the crumb rubber is mixed with the stony aggregates before adding them to the asphaltic concrete. The crumb rubber is regarded as another aggregate, or as a substitution for a part of the fine aggregate. In this process, the rubber moves from being an elastic aggregate, to a modifier of the binder in the asphaltic mixture. This interaction process is called rubber digestion [5].

Asphalt-rubber mixture by wet process.

In the wet process, the asphalt is pre-mixed with the rubber at a high temperature (175-210 °C). The rubber must be incorporated as a very fine rubber powder. For the mixture of the asphalt and the rubber, a blending tank for asphalts with a velocity of around 2000 r.p.m. is used. The blending time is 4 hours.

It can be stated that the dry method is simpler and less expensive since it does not require any special equipment.

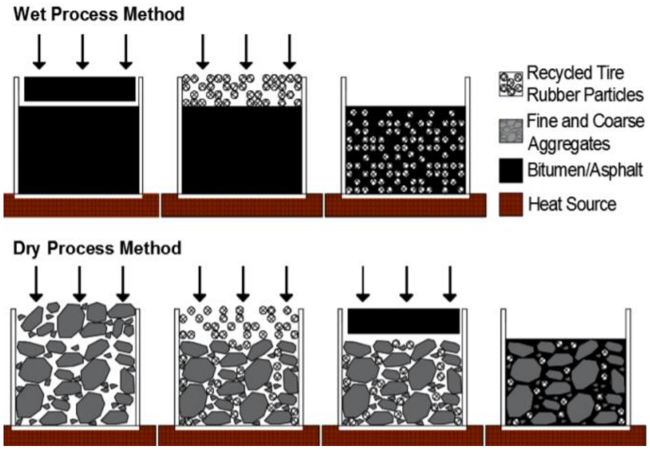

Fig. 3. Wet and dry process methods of asphalt-rubber mixture production [6].

III. Physical and Rheological properties of CRMA

Physical properties are those which can be observed or measured without changing the chemical nature of the analyzed substance, in this case, CRMA. Examples of this type of property are penetration, viscosity, or softening point. On the other hand, rheological properties are the material properties that determine the specific way in which materials deform or flow in response to applied forces or stresses. Elastic recovery and ductility are clear examples of this kind of property.

A. Elastic Recovery

Elastic recovery or elasticity describes the ability of a bitumen binder to elongate when tension is applied and to recover its original shape when the tension is released. The degree of elastic recovery is used as an indicator of permanent deformation in pavement materials [7].

As seen in [8], CRMA's elastic recovery increases as the rubber particle size decreases. Modified bitumen binders with crumb rubber show an enhancement on the elastic recovery.

B. Ductility

Ductility is a distinct strength of bitumen, allowing it to undergo notable deformation or elongation. This property is defined by the degree to which a material can sustain plastic deformation under tensile stress before failure. Ductility test on bitumen measures the distance in centimeters to which a test sample of this bitumen elongates before breaking.

According to [7] and [9], the finer the size of the particles of rubber are, the higher the ductility elongation will be. Also, toughness increases as the content of rubber increases.

C. Penetration

Penetration is a measure of softness of bitumen binder which is expressed as the distance in tenths of a millimeter that a standard needle penetrates vertically into a specimen of the material under specified conditions of temperature, load, and duration of loading. An effect is shown by adding crumb rubber to bitumen binder; penetration decreases as rubber content is increased. Penetration shows lower values as rubber content increases at different mix conditions of rubberized bitumen binder, indicating that the binder becomes stiff and more viscous [9].

The conclusion is that modified asphalts with crumb rubber have lower penetration values than unmodified asphalts, which is what it is expected to get when modifying asphalts, since as a consequence of lower penetration values, a denser asphalt with higher consistency is obtained.

D. Viscosity and softening points

Bitumen is a viscoelastic material without sharply defined melting points; it gradually becomes softer and less viscous as the temperature rises.

The viscosity refers to the fluid property of the bitumen, and it is a measure of flow-resistance. At the application of temperature, viscosity greatly influences the potential of the resulting paving mixes, giving them a better workability.

The softening point is the temperature at which a material softens beyond some arbitrary softness. It is a measure of thermal susceptibility, which rises as density increases and, as mentioned before, penetration decreases. Bitumen's softening point is determined by ring and ball apparatus specified by ASTM D36 / D36M - 14(2020) "Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus)" norm [10]. Viscosity is strongly related to the softening point; a higher softening point means lower viscosity.

The use of crumb rubber in bitumen modification leads to an increase in the softening point and viscosity as rubber crumb content increases [9]. This is ideal, because as the softening point is the temperature that asphalts need to reach a determined fluency, much higher environmental temperatures when this asphalt is encountered in service, placed in the road, are needed to make it softer.

IV. Rutting and Fatigue Resistance

Properly designed and maintained asphalt pavements can provide many years of satisfactory service. However, asphalt pavements can be damaged by certain conditions, more commonly by repeated loads of heavy traffic.

Pavement distress is surface damage which occurs on the surface of the top asphaltic layer, where rutting and fatigue cracking are the two of the most common distress forms. Using crumb rubber as a bituminous binder modifier enhances the resistance to the emergence of these pavement distress forms.

A. Rutting

Rutting is defined as a surface depression in the wheelpath as a result of insufficient compaction of asphalt layers during construction, improper mix design or manufacture, and high traffic loads [11, Fig. 4]. Rutting in bitumen pavement develops as load applications increase. The rutting appears as longitudinal depressions in the wheel paths with small elevations on the sides. These are caused by a combination of traffic loads and shear deformation. Ruts are particularly evident after heavy rain when they are filled with water.

Rutting is a primary measure of the performance of pavement in several pavement design methods. Rutting failures are a consequence of heavy truckloads with high tire pressures and high pavement temperatures.

The improvement in physical and rheological properties as a consequence of using crumb rubber as an asphalt modifier leads to a higher resistance to rutting of flexible pavements. With a higher softening point and penetration values, a tougher and denser asphalt at environmental temperatures is got, much more reluctant to experiment shear deformations which give rise to ruts.

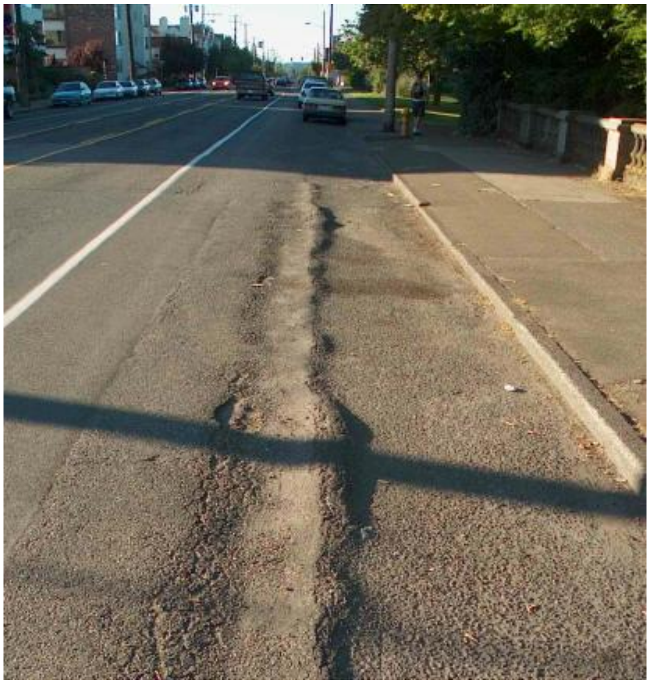

Fig. 4. Example of rutting in a flexible pavement [11].

B. Fatigue

Fatigue is one of most important distress forms in asphalt pavement structure which appears as a result of repeated loads of heavy traffic services which occur at intermediate and low temperatures. As the number and magnitude of loads becomes too high, longitudinal cracks begin to form (usually in the wheelpaths). After repeated loading, these longitudinal cracks connect, forming many-sided sharp-angled pieces that develop into a pattern resembling the back of an alligator or crocodile. This is why fatigue cracking is also known as alligator cracking [12, Fig. 5].

According to recent studies of the effect of physical and rheological properties of crumb rubber on fatigue cracking [13], the use of crumb rubber as a modifier of the bitumen binder seems to increase the fatigue cracking resistance.

The improved performance of CRMA when compared with conventional bitumen pavements has resulted from improved physical and rheological properties of the rubberized bitumen, as it happens with rutting resistance. One of the most important properties which influences the increase in fatigue cracking resistance is elastic recovery and ductility, which allows the top layer of asphalt to deformate under repeated traffic loads, and always recover to its original shape, without suffering plastic deformations which result in fatigue cracks.

Fig. 5. Example of fatigue cracking in a flexible pavement [12].

V. ADVANTAGES AND BENEFITS

A. Resistance to plastic deformation

The mixture of crumb rubber with the bituminous binder, creates an elastically deformable conglomerate, but at the same time, it is highly resistant to permanent deformation which would not allow rutting and fatigue cracking appear so frequently as it happens with conventional asphalt pavements.

B. Safety

There is a decrease in the number of accidents since CRMA has a homogeneous and elastic surface. The homogeneous surface is a consequence of having a dense gradation of the aggregates, which reduces the empty spaces in the asphalt mixture, allowing a higher adherence of the car tires to the asphaltic layer, a controlled behavior of the roadway user's vehicle while driving, and better visibility in the rain since rutting is reduced.

C. Sustainability

Each year, automobiles produce one hundred thirty thousand tons of waste tires in Argentina alone [14]. Using crumb rubber as an asphalt modifier is one of the best options to give old car tires a new life and usage. All tires not used all over the world can be used to create better and safer roadways.

CRMA roadways require less maintenance and eliminate the additional CO2 emissions produced by conventional processes of application and repairing of the asphalt layer.

D. Lower Costs

There is a reduction in the amounts of fine aggregate used since crumb rubber is obtained from recycled car tires and replaces part of the fine aggregate. As well as this, there is a decrease in maintenance exigencies, because the enhancement of rutting and fatigue cracking resistance leads to lower damage to the superficial asphaltic layer, resulting in significant savings. Also, CRMA generates savings to drivers since there is a decrease in the wear of the vehicle as well as the expenses associated with the accidents due to the advantages regarding the safety issues previously mentioned.

This point is a fundamental concern in countries like Argentina, where there is poor urban infrastructure since the construction of new roadways, for instance, is not directly proportional to the population growth. In addition, there is a lack or basically there is no maintenance of the already constructed urban infrastructure.

E. Durability

By having improvements in rutting and fatigue cracking resistance, better durability is shown by minimizing the distress caused in flexible pavements.

VI. Conclusion

This paper presented an analysis of the application of recycled crumb rubber as an asphalt modifier in flexible pavements.

The use of recycled crumb rubber in an asphalt mixture leads to an improvement in elastic recovery, ductility, penetration, viscosity, and softening points. In addition, rutting and fatigue resistance is improved, together with the durability. Hence, roadways users can be guaranteed safer roads due to the smoother surfaces of the roads. Also, states have the possibility of building more cost-effective and better roadways by using CRMA.

Moreover, the use of crumb rubber as a modifier would help reduce pollution by recycling enormous amounts of waste tires.

The conclusion obtained in this work allows us to affirm that the modification of asphalt using crumb rubber from recycled car tires through the dry or wet method represents a valuable opportunity to recycle large amounts of car tires and to obtain pavements with better properties than conventional ones.

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