International Journal of the Physical Sciences Vol. 7(2), pp. 166 - 170, 9 January, 2012
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPSX11.007
ISSN 1992-1950 ©2012 Academic Journals

Review

An overview of crumb rubber modified asphalt

Nuha S. Mashaan*, Asim Hassan Ali, Mohamed Rehan Karim and Mahrez Abdelaziz

Center for Transportation Research, Faculty of Engineering, University of Malaya, Kuala Lumpur 50603, Malaysia.

Accepted 19 September, 2011

Roadways are considered one of the most important elements of infrastructure and they play an essential role in our daily lives. In road pavement construction, the use of crumb rubber in the modification of bitumen binder is considered as a smart solution for sustainable development by reusing waste materials. It is believed that crumb rubber modifier (CRM) could be one of the alternative polymer materials in improving bitumen binder performance properties of hot mix asphalt. This study aims to present and discuss the findings from some of the studies, on the use of crumb rubber in asphalt pavement.

Key words: Rubberised bitumen, crumb rubber modifier, rheology, rutting, fatigue cracking.

INTRODUCTION

Over the years, road structures have deteriorated more rapidly due to increases in service traffic density, axle loading and low maintenance services. To minimise the damage of pavement surface and increase durability of flexible pavement, the conventional bitumen needs to be improved with regards to performance related properties, such as resistance to permanent deformation (rutting) and fatigue cracking. The modification of bituminous binder has been explored over the past years in order to improve road pavement performance properties.

There are many modification processes and additives that are currently used in bitumen modifications, such as styrene butadiene styrene (SBS), styrene-butadiene rubber (SBR), ethylene vinyl acetate (EVA) and crumb rubber modifier (CRM). The use of commercial polymers, such as SBS and SBR in road and pavement construction will increase the construction cost as they are highly expensive materials. However, with the use of alternative materials, such as CRM, will definitely be environmentally beneficial, and not only it can improve the bitumen binder properties and durability, but it also has a potential to be cost effective (Hamed, 2010).

In recent times, a serious problem that leads to environment pollution is the abundance and the increase of waste tyre disposal. Large amounts of rubbers are used as tyres for cars and trucks. Despite the long run in service, these tyres are not discarded. Although, the rubber as a polymer is a thermosetting material cross linked to processing and moulding, however, it cannot be softened or remoulded by re-heating unlike other types of thermoplastics polymer which can be softened and reshaped when heated. The major approach to solve this issue is the recycle and reuse of waste tyre rubber and the reclaim of rubber raw materials (Adhilkarri et al., 2000). In recent years, researches on applications of rubberised bitumen binders have reported many advantages. These advantages include improved bitumen resistance to rutting due to high viscosity, high softening point and better resilience, improved bitumen resistance to surface initiated cracks, the reduction of fatigue/ reflection cracking, the reduction of temperature susceptibility, improved durability as well as the reduction in road pavement maintenance costs (Liu et al., 2009).

HISTORY OF USING CRUMB RUBBER AS A MODIFIER IN BITUMINOUS PAVEMENT

The earliest experiments date back to the 1840s, which involved incorporating natural rubber into bitumen to increase its engineering performance properties. The process of bitumen modification involving natural and synthetic rubber was introduced as early as 1843 (Thompson, 1979). Then, in 1923, natural and synthetic rubber modifications in bitumen were further improved (Isacsson and Lu 1999; Yildrim, 2007). According to the study of Yildrim (2007), the development of rubber-bitumen

*Corresponding author. E-mail: asim@siswa.um.edu.my. Tel: +603-79675339. Fax: +603-79552182.

materials being used as joint sealers, patches and membranes began in the late 1930s. In 1950, the use of scrap tyre in asphalt pavement was reported (Hanson et al., 1994).

In 1960, Charlie Mac Donald working as head material engineer in Phoenix, Arizona, used ground tyre rubber as an additive in bitumen binder modification. He found that after completing the mixing of crumb rubber with the conventional bitumen and allowing it to blend for mix duration of 45 to 60 min, there were new material properties produced, which resulted in swelling in the size of the rubber particles at higher temperatures allowing for higher concentrations of liquid bitumen contents in pavement mixes (Huffman, 1980). In the mid-1980s, the Europeans began the development of newer polymers and additives for use in bitumen binder modification (Brule, 1996). In recent years, the use of crumb rubber has gained interest in pavement modification and has shown that crumb tyre rubber can improve the bitumen performance properties (Brown et al., 1997).

CRUMB TYRE RUBBER GRINDING PROCESS

The crumb rubber is made by shredding scrap tyre, which is a particular material free of fibre and steel. The rubber particle is graded and found in many sizes and shapes. The crumb rubber is described or measured by the mesh screen or sieve size through which it passes during the production process. To produce crumb rubber, generally, it is important to reduce the size of the tyres. There are two techniques to produce crumb rubber: ambient grinding and the cryogenic process (Becker et al., 2001). The ambient grinding process can be divided into two methods: granulation and cracker mills. The ambient describes the temperature when the waste tyres rubber as its size is reduced. The material is loaded inside the crack mill or granulator at ambient temperature. The cryogenic grinding is a cleaner, slightly faster operation resulting in production of fine mesh size. The high cost of this process is a disadvantage due to the added cost of liquid nitrogen.

PERFORMANCE OF CRUMB TYRE RUBBER IN BITUMINOUS MATERIALS

There are two rather different methods in usage of tyre rubber in bitumen binders. Firstly, crumb rubber in the bitumen is dissolved as binder modifier. Second, is by substituting a portion of fine aggregates with ground rubber that does not completely react with bitumen (Huang et al., 2007).

Numerous factors can influence the modification effects which consist of base bitumen constituents, blending time and temperature, the percentage of rubber, the gradation of crumb rubber, the type of mixing (wet or dry) and the grinding process method (Huang et al., 2007; Airey et al., 2003; Jeong et al., 2010). It observed that during the bitumen-rubber blending, due to higher stiffness and tensile strength at elevated temperatures, the mixture had decreased rutting capability (Palit et al., 2004). The design method for conventional bitumen mixture can be used for bitumen-rubber mixture as the mix stability being the primary factor. Also, standard paving machinery can be used for placement of bitumen-rubber mixture. However, a pneumatic tyre roller is not suitable as asphalt rubber will stick onto the roller tyres (Huang et al., 2007). Rubber pavement association found that using tyre rubber in open-graded mixture binder could decrease tyre noise by approximately 50%. In addition, in spray applications, rubber particles of multiple sizes had a better sound absorbing. Moreover, another advantage of using asphalt rubber is to increase the life-span of the pavement. However, recommendations were made to assess the cost effectiveness of asphalt rubber (Huang et al., 2007).

PHYSICAL AND RHEOLOGICAL PROPERTIES OF RUBBERISED BITUMEN

Penetration properties

The penetration is a measure of hardness or softness of bitumen binder which shows an effect by adding crumb rubber to bitumen binder; it decreases as rubber content is increased. The penetration shows lower values as rubber content increases at different mix conditions of rubberised bitumen binder, indicating that the binder becomes stiff and more viscous (Mashaan et al., 2011a). Mahrez (1999) investigated the properties of rubberised bitumen prepared by physical blending of bitumen 80/100 penetration grade with different crumb rubber content and various aging phases. The results of penetration values decreased over the aging as well as before aging by increasing the rubber content in the mix. Also, the modified binders have lower penetration values than unmodified binders.

Elastic recovery properties

The elastic recovery or elasticity describes the ability of a bitumen binder to elongate when the tension is applied and to recover its original shape when the tension is released. The degree of elastic recovery was used as an indicator of permanent deformation in pavement materials (Yildirim, 2007).

According to the study of Jensen and Abdelrahman (2006), the elastic recovery property is very important in both fatigue and rutting resistance selection and evaluation. The elastic recovery is a property that indicates the quality of polymer components in bitumen binders. Oliver

(1981) concluded from his study, that the elastic recovery of rubberised bitumen binders leads to an increase as the rubber particle size decreases. Modified bitumen binders showed a significant enhancement on the elastic recovery, and, in contrast, the ductility decreased with respect to unmodified binders (Mashaan et al., 2011a, b).

Ductility properties

The ductility is a distinct strength of bitumen, allowing it to undergo notable deformation or elongation. The ductility is defined as the distance in centimetre, to which a standard sample or briquette of the material will be elongated without breaking.

The studies of Mashaan et al. (2011a, b) concluded that finer rubber particles resulted in higher ductility elongation and also, that toughness would increase as rubber content increases. A combined effect of both time and temperature was noted with minimum elastic recovery value improved at maximum time and maximum temperature of two hours and 240°C, respectively (Jensen and Abdelrahman, 2006). The bitumen-rubber modification resulted in a better rutting resistance and higher ductility. However, the modified binder was susceptible to decomposition and oxygen absorption. There were problems of low compatibility, because of the high molecular weight. Furthermore, the recycled tyre rubber decreases reflective cracking, which in turn increases durability. In using waste tyre rubber, there are however, several practical and experimental issues, such as it requires an elevated composite of temperatures and extended digestion time during the mixing process for it to be diffused in the bitumen (Yildrim, 2007).

Viscosity and softening point properties

The viscosity refers to the fluid property of the bitumen, and it is a gauge of flow-resistance. At the application temperature, viscosity greatly influences the potential of the resulting paving mixes. During compaction or mixing, the low or high viscosity has been observed to result in lower stability values. The softening point refers to the temperature at which the bitumen attains a particular degree of softening. The use of crumb rubber in bitumen modification leads to an increase in the softening point and viscosity as rubber crumb content increases (Mahrez, 1999; Mashaan et al., 2011a). Mahrez and Rehan (2003) claimed that there is a consistent relationship between viscosity and softening point at different aging phases of rubberised bitumen binder.

Also, it is reported that the higher crumb rubber content leads to higher viscosity and softening point. The viscosity is a continuously increasing non linear function of rubber content and the relative increase is a factor related to the application of temperature (Bahia and Davies, 1995).

BITUMEN - RUBBER BLENDS INTERACTION AND ABSORPTION

Modified bitumen using crumb rubber showed an improvement in the performance of pavements over the base binders as a result of the interaction of crumb rubber with base binders. Due to this interaction, there are noticeable changes in the viscosity, physical and rheological properties of the rubberised bitumen binder (Airey et al., 2003; Bahia and Davies, 1995), leading to high resistance of rutting of pavements (Huang et al., 2007).

From the aforementioned review of literature, the primary mechanism of the interaction is swelling of the rubber particles caused by the absorption of light fractions into these particles and stiffening of the residual binder phase (Abedlrahman and Carpenter, 1999; Airey et al., 2003). The rubber particles are constricted in their movement into the binder matrix to move about due to the swelling process which limits the free space between the rubber particles. Compared to the coarser particles, the finer particles swell easily thus, developing higher binder modification (Abedlrahman and Carpenter, 1999). The swelling capacity of rubber particle is linked to the penetration grade of the binder, crude source and the nature of the crumb rubber modifier (Airey et al., 2003). According to the study of Shen et al. (2009), the factors which affect the digestion process of the bitumen and rubbers blends are rubber content, rubber size, binder viscosity and blending conditions.

Rubber content

According to a study conducted by Lee et al. (2008), the higher crumb rubber content produced increased viscosity at 135°C and improved the rutting properties. It was also observed that the increased crumb rubber amount (fine crumb rubber) produced rubberised bitumen with higher viscosity and lower resilience. However, optimum crumb rubber content still needs to be determined for each crumb rubber size and asphalt binder. It is believed that a physicochemical interaction that occurs between the asphalt and the crumb rubber alters the effective size and physical properties of the rubber particle, thus influencing pavement performance (Huang et al., 2007).

Becker et al. (2001) claimed that blend properties will be influenced by the amount of crumb rubber added to the bitumen. Higher amounts indicated significant changes in the blend properties. As rubber content generally increases, it leads to increased viscosity, increased resilience, increased softening point and decreases penetration at 25°C.

Rubber particle size

The study of Souza and Weissman (1994) using a binder with 15% rubber content (size of 0.2, 0.4 and 0.6 mm) in dense-graded bitumen.

The mixture showed improved performance in dynamic stability, 48 h residual stability, flexural strength and strain value. Asphalt containing 0.2 and 0.4 mm size rubber indicated the best laboratory results (Souza and Weissman, 1994). The particles size disruption of crumb rubber influenced the physical properties of bitumen-rubber blend. In general, small difference in the particles size has no significant effects on blend properties. However, the crumb rubber size can certainly make a big difference. According to a study of Shen et al. (2009), the particle size effects of CRM on high temperature properties of rubberised bitumen binders was an influential factor on visco-elastic properties. The coarser rubber produced a modified binder with high shear modules and an increased content of the crumb rubber decreased the creep stiffness which in turn showed significant thermal cracking resistance.

Blending conditions

In general, bitumen binder and ground tyre rubber are mixed together and blended at elevated temperatures for differing periods of time prior to using them as a paving binder. These two factors work together to evaluate the performance properties of rubberised bitumen binder through blending process of bitumen-rubber interaction. This variation in mixing time and temperature that results due to the normal activities are related to bitumen paving construction. Nevertheless, the consistency of rubberised bitumen rubber can be affected by the time and temperature used to combine the components and thus, must be cautiously used for it optimum potential to be achieved. Xiao et al. (2006) studied the effects of reaction time on the permanent changes of crumb rubber after mixing with bitumen.

The size reduction of rubber particle increased with the blend duration and with decreasing crumb rubber size. Lee et al. (2006) reported that a longer reaction time was ineffective in increasing the high temperature viscosity of the control binder. In a joined experiment, Mashaan et al. (2011b) also found that the blending time has an insignificant effect in the case of 30 and 60 min on rheological properties of rubberised asphalt. Paulo and Jorge (2008) investigated the effect of blending conditions (time and temperature) on penetration, softening point and resilience modulus. The results showed that there was no significant effect for three blending time (45, 60 and 90 min) on modified binder properties, although, there was a tendency for blending time effect to become constant between 60 and 90 min.

PAVEMENT DISTRESS

Rutting performance

Rutting defined as longitudinal depression in wheel paths as a result of continued densification by traffic load. According to Sousa and Weissman (1994) study, rutting in bitumen pavement develops as load applications increases. The rutting seems as longitudinal depressions in the wheel paths with small upheavals on the sides. These are due to a combination of densification and shear deformation.

The rutting is a primary measure of the performance of pavement in several pavement design methods. The rutting can occur as a result of problematic sub grade, unbound base course. Rutting failures are consequence of heavy truckloads with high tyre pressures and high pavement temperatures. Hence, the considerable selection of bitumen binder and aggregate combination will boost in providing optimum performing asphalt pavements (Sousa and Weissman, 1994). Brown and Cross (1992) reported that permanent deformation in bituminous mixture is caused by consolidation and/or lateral movement of the mixture under traffic. Shear failure (lateral movement) of the bituminous mixture courses generally occurs in the top 100 mm of the pavement surface. However, it can run deeper if proper materials are not used. Moreover, it was evident that rutting is caused mainly by deformation flow rather than volume change.

Tayfur et al. (2007) claimed that after the initial densification, the permanent deformation of the bituminous mixture happens due to shear loads which take place close to the pavement surface which in fact is the contact area between the tyre and the pavement. These efforts increase without the volume variations in the bituminous mixture. They are the primary mechanisms in the development of rutting during the life span of the pavement design.

Fatigue cracking

Fatigue is one of most important distresses in asphalt pavement structure due to repeated load of heavy traffic services which occur at intermediate and low temperatures. Aflaki and Memarzadeh (2011) used different shear methods at low and intermediate temperature to study the effect of rheological properties of crumb rubber on fatigue cracking. The results showed that the high shear blending has more effect on improvement at low temperatures than the low shear blend. The use of crumb rubber modified with bitumen binder seems to enhance the fatigue resistance, as illustrated in a number of studies (Raad and Saboundjian, 1998; Soleymani et al., 2004; McGennis, 1995). The improved performance of bitumen rubber pavements when compared with conventional bitumen pavements has partly resulted from improved rheological properties of the rubberised bitumen binder.

CONCLUSION

This review study presented the application of crumb rubber modifier in the asphalt modification of flexible pavement. From the results of previous studies, it aspires to consider crumb rubber modifier in hot mix asphalt to improve resistance to rutting and produce pavements with better durability by minimising the distresses caused in hot mix asphalt pavement. Hence, road users would be ensured of safer and smoother roads. Furthermore, the use of crumb rubber modifier as an additive in bitumen modified binder would reduce pollution problems and protect our environment as well.

REFERENCES

Abdelrahman MA, Carpenter SH (1999). Mechanism of interaction of asphalt cement with crumb rubber modifier. Transportation Research Record: J. Transport. Res. Board, 1661: 106-113.

Adhikari B, De D, Maiti S (2000). Reclamation and recycling of waste rubber. Progress in Polymer Science, 25: 909- 948.

Aflaki S, Memarzadeh M (2011). Using two-way ANOVA and hypothesis test in evaluating crumb rubber modification (CRM) agitation effects on rheological properties of bitumen. Construction and Building Materials, 25: 2094-2106.

Airey GD, Rahman MM, Collop AC (2003). Absorption of bitumen into crumb rubber using the basket drainage method. Int. J. Pavement Eng., 4(2): 105-119.

Bahia HU, Davies R (1995). Factors controlling the effect of crumb rubber on critical properties of asphalt binders. J. Assoc. Asphalt Paving. Technol., 64: 130-162.

Becker Y, Mendez MP, Rodriguez Y (2001). Polymer modified asphalt. Vision Tecnologica, 9(1): 39-50.

Brown DR, Jared D, Jones C, Watson D (1997). Georgia's experience with crumb rubber in hot – mix asphalt. Transportation Research Record: J. Transport. Res. Board, 1583: 45-51.

Brown DR, Cross SA (1992). A National Study of Rutting in Asphalt Pavement. J. Assoc. Asphalt. Paving. Technol., 61: 535-583.

Brule B (1996). Polymer-modified asphalt contents used in the road construction industry: Basic principles. Transportation Research Record: J. Transport. Res. Board, 1535: 48-53.

Hamed FK (2010). *Evaluation* of fatigue resistance for modified asphalt concrete mixture based on dissipate energy concept. Ph.D. Thesis, Technische University Darmstadt, Germany.

Hanson DI, Foo KY, Brown ER, Denson R (1994). Evaluation and characterization of a rubber-modified hot mix asphalt pavement. Transportation Research Record: J. Transport. Res. Board, 1436: 98-107.

Huang Y, Bird RN, Heidrich O (2007). A review of the use of recycled solid waste materials in asphalt pavements. Resources, Conservation and Recycling, 52: 58-73.

Huffman JE (1980). Sahuaro Concept of Asphalt-Rubber Binders. Presentation at the First Asphalt Rubber User Producer Workshop, Arizona.

Isacsson U, Lu X (1999). Characterization of bitumens modified with SEBS, EVA and EBA polymers. J.Mater. Sci., 34(15): 3737-3745.

Jensen W, Abdelrahman M (2006). Crumb rubber in performance-graded asphalt binder. Final Report SPR-01.Nebraska Department of Roads University of Nebraska-Lincoln, 05: 585.

Jeong KD, Lee SJ, Amirkhanian, SN, Kim KW (2010). Interaction effect of crumb rubber modified asphalt binder. Construction and Building Materials, 24: 824-831.

Lee SJ, Akisetty CK, Amirkhanian SN (2008). The effect of crumb rubber modifier (CRM) on the performance properties of rubberized binder in HMA pavements. Construction and Building Material, 22: 1368-1376.

Lee SJ, Amirkhanian SN, Shatanawi K (2006). Effect of reaction time on physical and chemical properties of rubber-modified binders. International Rubber Conference. Compendium of Papers CDRom, Lyon, France.

Liu S, Cao W, Fang J, Shang S (2009). Variance analysis and performance evaluation of different crumb rubber modified (CRM) asphalt. Construct. Build. Mater., 23: 2701-2708.

McGennis RB (1995). Evaluation of physical properties of fine crumb rubber – modified asphalt binder. Transportation Research Record: J. Transport. Res. Board, 1488: 62-71.

Mahrez A (1999). Properties of rubberised bitumen binder and its effect on the bituminous mix. M.Sc. Dissertation, Faculty of Engineering, University of Malaya, Malaysia.

Mahrez A, Rehan M (2003). Rheological evaluation of aging properties of crumb rubber-modified bitumen. Journal of the Eastern Asia Society for Transportation Studied, 5: 820-833.

Mashaan NS, Ali AH, Karim MR, Mahrez A (2011a). Effect of crumb rubber concentration on the physical and rheological properties of rubberised bitumen binders. Int. J. Phys. Sci., 6(4): 684-690.

Mashaan NS, Ali AH, Karim MR, Mahrez A (2011b). Effect of blending time and crumb rubber content on properties of crumb rubber modified asphalt binder. Int. J. Phys. Sci., 6(9): 2189-2193.

Oliver J (1981). Modification of paving asphalts by digestion with scrape rubber. J. Transport. Res. Board, 821: 37-44.

Palit SK, Sudhakar RK, Pandey BB (2004). Laboratory evaluation of crumb rubber modified asphalt mixes. J. Mater. Civil Eng., 16(1): 45-53.

Paul AP, Jorge CP (2008). Laboratory optimization of continuous blend asphalt rubber. Proceedings of 3rd European Pavement and Asset Management EPAM 3. Coimbra.

Raad L, Saboundjian S (1998). Fatigue behavior of rubber – modified pavements. Transportation Research Record. J. Transport. Res. Board, 1639: 73-82.

Shen J, Amirkhanian SN, Xiao F, Tang B (2009). Influence of surface area and size of crumb rubber on high temperature properties of crumb rubber and modified binders. J. Construct. Build. Mater., 23: 304-310.

Soleymani HR, Zhai H, Bahia H (2004). Role of modified binders in rheology and damage resistance behavior of asphalt mixture. Transportation Research Record: Transport. Res. Board, 1875: 70-79.

Sousa JB, Weissman SL (1994). Modeling permanent deformation of asphalt-aggregate mixes. J. Assoc. Asphalt. Paving. Technol., 63: 224-257.

Tayfur S, Ozen H, Aksoy A (2007). Investigation of rutting performance of asphalt mixtures containing polymer modifiers. Construct. Build. Mater., 21: 328–337.

Thompson DC, Hoiberg AJ (Eds) (1979). Bituminous Materials: Asphalt Tars and Pitches. New York: Krieger Publishing Co.

Xiao F, Ameirkhanian SN, Putman BJ (2006). Laboratory investigation of dimensional changes of crumb rubber reacting with asphalt binder. Asphalt Rubber 2006 Conference, Palms spring, California.

Yildrim Y (2007). Polymer modified asphalt binder. J. Build. Construct. Mater., 21: 66-72.