

A SHORT REVIEW ON USING CRUMB RUBBER AS MODIFICATION OF BITUMEN BINDER

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Graphical abstract



Abstract

The increasing consumption of waste tire has generated many problems such as increasing landfill space, environmental pollution and causing health hazards. Parallel to this is the increasing of roads construction as a result of heavy traffic on roads. This study reviews to the use of crumb rubber (waste tires in powder form) in bitumen using the wet process. The study focuses on the crumb rubber as a replacement to the total weight of bitumen. The design or life span for all highways and urban roads is 10 – 20 years. Unfortunately, damages or distresses on pavements are still occurring before reaching the maximum period of the designed road serviceability. Among the major influencing factor that is contributing to this distress is the repeated heavy traffic loading on the road surfaces. Moreover, the use of waste crumb rubber in road construction as a pavement surface has a better skid resistance, fatigue crack resistance and increased rut resistance. The review includes physical tests that are used to determine the physical properties of bitumen and modified crumb rubber mix. The physical tests involve penetration test, softening point test and viscosity test. The second stage is rheological tests like rolling thin film oven test (RTFOT), pressure aging vessel (PAV) and dynamic shear rheometer (DSR) tests. The expectations from the study are to develop bitumen with waste crumb rubber that would minimize the costs of bitumen and providing better physical and rheological properties compared to the convention bitumen based on the tests that was conducted. Crumb rubber modifier as improved resistance to rutting due to high viscosity, Improved resistance to surface initiated, reduce fatigue/ reflection cracking, lower pavement maintenance costs, and saving in energy and natural resource.

Keywords: Crumb rubber; fatigue cracking resistance; potential rutting resistance

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1.0 INTRODUCTION

The modification of bitumen is prompted mainly by the limitation of the conventional refining practices used today in the production of bitumen from crude petroleum oil. Alteration by specialized refining practices, chemical reaction, and/or additives have been found to improve contribution of bitumen and the resistance of bitumen in various modes or pavement distress. In a recent survey of the State Highway Agencies in the United States of America

(USA), a total of 35 out of 47 agencies plan to increase the use of modified binders in road construction. Twelve of the agencies were expecting to use the same amount of modified bitumen and some agencies planned to reduce the usage of modified bitumen. Majority of the agencies have cited premature distresses such as rutting and fatigue cracking as the main reason for justifying the use of modified binders [1]. Several countries in Asia, Europe and Africa have been using recycle rubber or tires in various highways or roads applications. The usage of

crumb rubber not only conserves the road construction materials, but also minimizing the landfill space that will reduce environmental impact. Many researchers concluded that crumb rubber modified (CRM) binders could produce asphalt pavements with less traffic noise, less maintenance or corrective costs and improved resistance of rutting and fatigue cracking [2]. Paving products, focused on especially modified asphalt can be made with crumb rubber by several mixing or blending process including dry process and wet process. In dry process, the crumb rubber was blended with the aggregate before mixing with bitumen. As for wet process, 10 to 25% of the crumb rubber by weight will be used to properly mix with bitumen at 190 - 220°C for 1 to 2 hours. Based on previous research, CRM bitumen requires compaction at a higher temperature than conventional mixes [3]. At lower compaction temperatures, the use of CRM mix might result in several problems such as inadequate volumetric properties (i.e., high air voids), and poor short-term and long-term performances. Also, the increased viscosity with decreasing temperature can negatively affect the workability of asphalt mixture since CRM at higher temperature ensure sufficient binder viscosity for proper workability. The expectations from the study are to develop bitumen with waste crumb

rubber that would minimize the costs of bitumen and providing better physical and rheological properties compared to the convention bitumen based on the tests that was conducted.

2.0 BLENDING METHOD

In general there are two methods of blending waste crumb rubber with bitumen, which is the dry process and wet process. The wet process was first developed by Charles in 1981 which the modification was carried out at 5 to 25% by mass of fine crumb rubber at high temperature. The wet process includes the mixture or blending of crumb rubber with bitumen at high temperatures and produces a viscous fluid through rubber bitumen interaction [4]. Figure 1 illustrates the application of crumb rubber in the wet process to produce premix for paving works. The performance of CRM mixtures using the wet process has been evaluated by different researchers under both field condition and laboratory testing. In terms of mechanical performance such as fatigue, the crumb rubber blended with bitumen using the wet process presents a better resistance to fatigue compared to conventional mixtures [5].

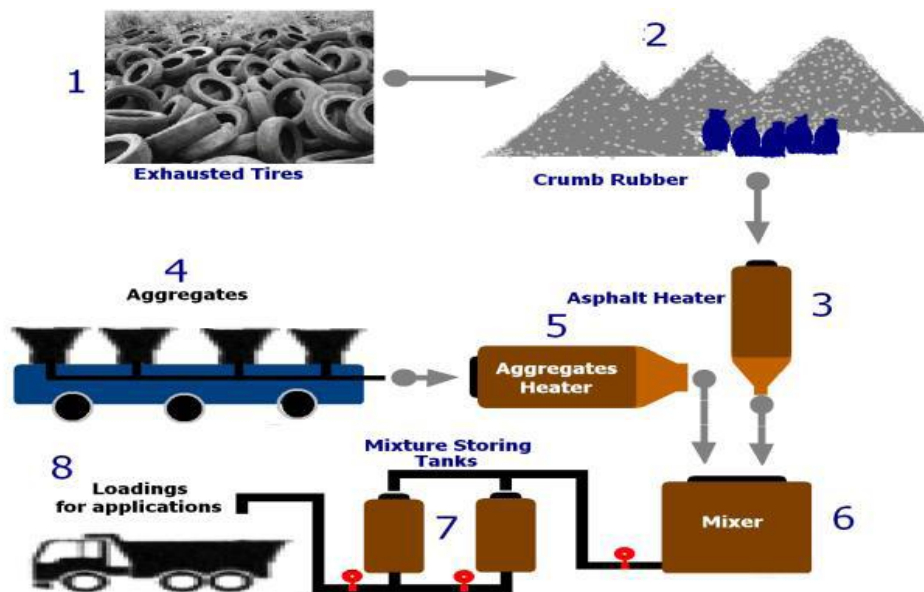


Figure 1 Application of crumb rubber in wet process for asphalt modification (google image)

3.0 REVIEW ON THE CRUMB RUBBER FOR BITUMEN MODIFICATION

In North Africa, especially in Sudan asphalt rubber binders have been used for crack sealers, chip seals, joint, and in hot paving mixes as thin overlays. The field performance of crumb rubber modifier (CRM) mixes have been positive effect but short comings due to poor performance based on the studies

conducted on this field of crumb rubber modified mixes may be attributed in part to poor mix design practices and poor construction practices. In addition, the properties of CRM mixes have been found to differ with the rubber type and gradation, asphalt type and concentration, rubber concentration, cure time and reaction temperature and time [6]. Another important aim of using crumb rubber as a bitumen modifier is to avoid

environmental issue resulting from scrap tyre disposal. Many researchers have reported the improvement of properties of asphalt concrete mixtures when crumb rubber was used. Most of those studies were based on standard traditional tests like resilient modulus, Marshall Stability and indirect tensile strength [7].

According to Ibrahim et al. (2009) Malaysia production of scrap tyres are currently being disposed in an environmentally friendly manner. A conventional bitumen 80-100 penetration grade is commonly used in Malaysia and it is subjected to the hot weather and high traffic load. The application of using crumb rubber as bitumen modification considered as a sustainable technology which transforms an unwanted residue into a new bituminous mixture highly resistant to fatigue and rutting[8].

In recent years, the researches and applications of rubberised bitumen binders in United States have reported many benefits of using crumb rubber modifier as improved resistance to rutting due to high viscosity, improved resistance to surface initiated, reduce fatigue/ reflection cracking, lower pavement maintenance costs, and saving in energy and natural resource [9].

Another study by Katman et al. (2005a, 2005b) on using crumb rubber in porous asphalt showed that the mixing procedure and mixing type also affect the performance of the rubberized porous asphalt. From an environment and economic standing point, the use of ground tyre rubber as bitumen – modifying agent may contribute to improving the quality of road pavement and solving a waste disposal problem[10].

4.0 PENETRATION TEST

The penetration of bitumen reduces when the amount of crumb rubber increased, typically when replacement was done for more than 20% of the total weight of bitumen [9]. The crumb rubber modified bitumen showed increasing stiffness with lower penetration value [11]. The increase in crumb rubber content has changed the structure of a bitumen, causing reduction in penetration and stiffness of rubberized bitumen [9]. Figure 2 illustrates the penetration test apparatus used to perform bitumen penetration.



Figure 2 Penetration test setup

5.0 SOFTENING POINT TEST

The softening point is defined as the temperature at which the asphalt reaches the degree of softening when an asphalt sample can no longer support the weight of a 3.5g steel ball. The softening point test determines the actual temperature which the bitumen is needed to heat up to for mixing purposes. As the crumb rubber content increased, it showed strong effects of increasing softening point depending on the amount of crumb rubber content that was added to bitumen [12]. Figure 3 is the apparatus used in the testing of bitumen softening point.

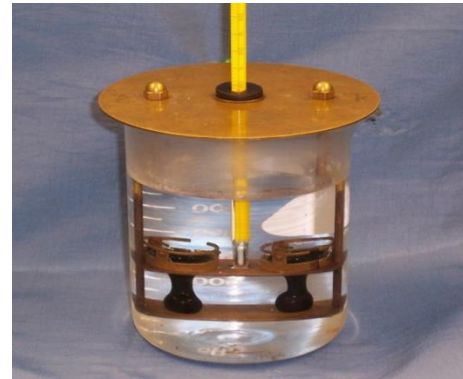


Figure 3 Softening Point test setup

6.0 VISCOSITY

The Rotational Viscometer (RV) is physical test of bitumen used to determine the behaviour of bitumen s at a given temperature. The viscosity value will be used to determine the range of temperature suitable for mixing and compaction works for a given asphalt mix. According to the study previously conducted, it shows that the increasing of crumb rubber content increased rotational viscosity [13]. The performance of pavement surface over base layer is also improved as a result of interaction with crumb rubber [14]. The apparatus used in testing a bitumen's viscosity is presented in Figure 4.



Figure 4 Rotational Viscometer used to determine the viscosity of bitumen

7.0 DYNAMIC SHEAR RHEOMETER

This test is used to characterise both viscous and elastic behaviour by measuring complex shear modulus (G^*) and phase angle (δ) of an bitumen at different temperature intervals. G^* is a measure of the total resistance of material deformation when exposed reported stress pulses of shear stress. A study conducted on the short term aging as rheological properties from different percentage of crumb rubber content in bitumen s, showed that after short term aging, the viscosity and shear modulus $|G^*|$ of bitumen increased more than conventional asphalt binder [14]. The dynamic shear rheometer is as shown in Figure 5.



Figure 5 Dynamic Shear Rheometer (DSR)

7.1 Rutting Resistance

The rutting resistance was evaluated by complex shear modulus ($G^*/\sin\delta$) phase angle value of rolling thin film oven test (RTFOT) aged bitumen, the higher ($G^*/\sin\delta$) indicated less liable of permanent deformation at high pavement temperatures [14]. Wheel path of heavy trucks, often due to the change in material properties, generally occurs at slow lane. It is a result of excessive compressive strain at the top of pavement layer which is considered fail if it exhibit a rut depth of 20mm. Other possible causes of rutting include improper design mix or manufacture process (insufficient amount of aggregate particles) and insufficient compaction of hot mix asphalt (HMA) layers during construction.

7.2 Fatigue Cracking

Fatigue cracking of flexible pavements occur from the result of heavy traffic loading is horizontal build up tensile strain at the bottom of the hot mix asphalt (HMA) layer. The failure criterion relates the allowable number of heavy load repetitions and the tensile strain. The cracking initiates at the bottom of the Hot Mix Asphalt (HMA) where the tensile strain is highest under the wheel load. The cracks propagate initially as one or more longitudinal parallel cracks.

Fatigue cracking is generally considered to be more of a structural problem than just a material problem. It is usually caused by a number of pavement factors that have to occur simultaneously. Obviously, repeated heavy loads must be present. Resulting in soft, high deflection pavement and poor subgrade drainage is the principal cause of fatigue cracking [15]. The Fatigue cracking encountered on pavement is as shown in Figure 6.



Figure 6 Fatigue cracking encountered on pavement

8.0 CASE STUDIES

8.1 California

The California Department of Transportation (CalTrans) used waste tyres in the form of CRM in asphalt pavement as a component of chip seals in 1970 and rubberized asphalt concrete (RAC) in 1980 [16]. At the early phase of CalTrans initiatives, the performance of AR mixes varied from poor to excellent. But, in recent years, better specification and practices have yielded more consistent and perfect performance of AR mixes. CalTrans use open graded rubberized asphalt cement (RAC-O), which is reported to provide good surface frictional characteristics and also Gap-graded rubberized asphalt concrete (RAC-G) is widely used as a structural layer in the pavement.

8.2 Louisiana

The Louisiana Department of Transportation and Development (LADOTD) carried out a research [17] on AR concrete (ARC) pavement, wherein they presented a comparative study of both laboratory and field to evaluate the performance of various CRM HMA pavements. These studies constructed eight various CRM asphalt sections on five various state highway projects. They also constructed traditional asphalt mix sections for comparison. Three form of CRM powders (16-mesh CRM, a Rouse-80 powder, and Neste Wright) were used to prepare AR through the wet process. A few laboratory tests: Marshal Stability and flow, Indirect Tensile Strength

(ITS) Resilient Modulus (MR) and Strain, etc. were performed to evaluate the mixture properties of CRM and traditional mixes.

The following observations were made: (i) Gap graded CRM mixtures showed least Marshall Stabilities and Flows than dense graded CRM mixtures; (ii) CRM mixes generally show lower ITS and MR values than the traditional mixes; (iii) the wet processed CRM mixes generally showed higher structure capacities (iv) ARC pavement sections lower IRI and rut depth than traditional AC pavements; and (v) ARC pavements showed less fatigue cracks than the control AC pavement section.

8.3 Arizona

The technique for acquired rubber from waste rubber was first introduced by Charles H. McDonald in 1966 in Arizona [18]. This researcher demonstrated that asphalt mixed with rubber in the heating process improves binder flexibility. The Arizona Department of Transportation (ADOT) has carried out a series of research for developing asphalt rubber (AR) for the purpose of pavement maintenance.

ADOT has used CRM HMA as an overlaying material of asphalt pavements. After 30 years of monitoring AR pavements, ADOT has finalized the followings: (i) AR pavement extend better roadway condition in comparison to Portland cement concrete pavement and also improves the attractiveness of pavement surface; (ii) AR decrease the amount of reflective cracking; (iii) AR supply the desired rutting (below 0.25 inches) and smoothness (below 93 inches per mile), (iv) AR overlay appears to be able to decrease maintenance cost by \$666 per lane mile per year; and (v) AR pavement appear to be very effective in noise reduction properties.

8.4 ARKANSAS

The Arkansas State Highway and Transportation Department (AHTD) and the Mac Black Well National Rural Transportation Research Center (MBTC) conducted a combination of laboratory and field demonstration overlay projects to develop an understanding the condition of asphalt concrete mixes modified with CRM [19].

These laboratory test results discover that the blending of crumb rubber broadened the applicability of high service temperature of asphalt mixes from 64 to 800c with 10 to 15% and the minimum service temperature from -22 to -340c with 15% .suchconcluding were a clear significant of the potential advatages of CRM in terms of thermal cracking,increased resistance, and rutting of new pavement. AHTD also investigated resilient properties ,ruttingresistance,indirect tensile strength and fatigue properties of the CRM mixes.

However, a little improvement in rutting was obtained from marshall AR mixes. resilient modulus analysis showed that the CRMcombination in a small percentage (1%) improved the resilientpropetiesof

both AR mixes. however, higher amount of CRM modification results in lesser improvement compared

to traditional mixes. The CRM modified mises was showed no significant improvements of tensile strength properties were reported due to CRMcombination into asphalt mixes either by wet or dry process.

Gradation of CRM has a great effect on mixing time during CRM and asphalt cementblending. A coarser CRM gradation demand longer mixing time of CRM and asphalt cement compared with finer gradation (Douglas, 1996). It is also desirable that aggregate gradation should beeither open graded or gap-graded if a coarser grade CRM is used.

9.0 Preparation of Mixes

9.1 Mixing and Compaction Temperatures

The temperatures to which the asphalt cement is to be heatedto produce kinematic viscosities of $170 \pm 20 \times 10^{-6}$ and $280 \pm 30 \times 10^{-6} \text{ m}^2/\text{s}$ are normally chosen as the mixing andcompaction temperatures respectively ~Asphalt Institut [20].Viscosity was measuredusingBrookefield rotational dial viscometer ~LV model!. TheLV-2 spindle was used. Rotational speeds of 6 and 12 rotational per minute (rpm) wereused in the measurement of viscosity. Figure 7 indicates that mixing. Mixing temperature can be taken as the temperature that produces a uniform and sufficient coating of the coarse aggregates and is to be estimated on the basis of experience [20].Therefore, after preparing a number of trial mixtures, a mixing temperature of 180°C and a compaction temperature of 165°C were selected.

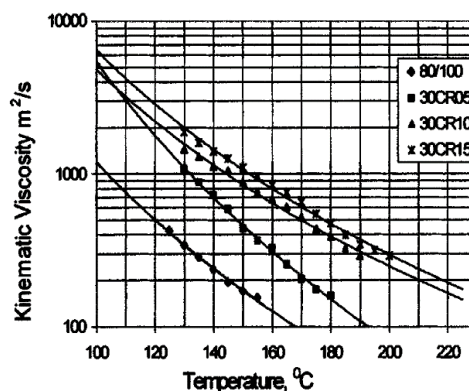


Figure 7 Viscosity–temperature relationship for various binders

9.2 Preparation of Crumb Rubber Modified Binder

The specifications developed earlier [21] were used blending crumb rubber with bitumen. In this

procedure, 80/100 penetration grade asphalt is heated to a temperature of 160°C before incorporate the crumb rubber by using wet process. The blend is mixed at low speed for about 5 min. The mixture is heated to 175°C and agitated vigorously for about 40 min using a mechanical stirrer operated at 2,000 rpm. Blending temperature is maintained between 175 and 180°C. Three different types prepared by with various concentration of crumb rubber by weight of asphalt binder in the blend and physical properties of materials used are given in Table 1. Basic characteristic of modified binders and 80-100 asphalt cement are given in Table 2. In the notation used to identify modified binders, concentration crumb rubber is used as suffix. "30" used as prefix indicates that the CR used in the blend was sieved through ASTM 30 sieve. Penetration, softening point, and ductility tests were conducted as per Bureau of Indian [22]. Elastic recovery test was conducted following the guidelines given by Indian Roads Congress [23]. Penetration of the modified binder at 4°C was found to be much more than that of the base asphalt cement, whereas at 25°C, base binder had higher penetration value. The binder, therefore, is expected to maintain flexibility at decrease the temperatures without being soft at higher temperatures. Penetration reduce with increase in rubber concentration while softening point increased. The various in the softening point and penetration values of 30CR10 and 30CR15 binders are not very significant. However, penetration ratio and elastic recovery values of 30CR10 are better than those obtained for other concentrations.

Table 1 Physical Properties of Materials Used

Material	Parameter measured	Value
Asphalt (80/100)	Penetration (25°C, 5 s, 100 g)	90
—	Softening point (ring and ball)	45.5°C
—	Ductility (27°C, 50 mm/min.)	100+ cm
—	Specific gravity (27°C)	1.026
—	Flash point (Cleveland open cup)	336°C
Coarse aggregate	Specific gravity	2.720
—	Water absorption	0.65%
—	Los Angeles abrasion value	19%
Fine aggregate	Specific gravity	2.634
Crumb rubber	Specific gravity	1.029
Cement	Specific gravity	3.130

Table 2 Binder Properties

Parameter measured	Property of binder			
	80/100	30CR5	30CR10	30CR15
Penetration				
at 25°C	90	58	54	53
at 4°C	14	19	20	18
Penetration ratio (%)	16	33	37	34
Softening point (°C) ^b	45.5	54	56.5	58
Ductility (cm) (Bureau of Indian Standards 1978d)	100+	45	42	45
Specific gravity ^c	1.026	1.029	1.032	1.037
Elastic recovery (%) ^d	31.2	66.4	78.0	71.5

9.3 Compaction Method

A modified Marshall compaction step [24] with indents provided on the face of the Marshall hammer, was used. This procedure ensures kneading and shearing of the mix during compaction. The resulting aggregate orientation and compaction levels are expected to be similar to the compaction normally attained in the field.

9.4 Aggregate Gradation

Aggregate gradation recommended for asphalt concrete by Ministry of Surface Transport [25] Superpave gradation [25] and a gap gradation [25] were adopted for preparation of Marshall specimens with traditional and modified binders. The gradation curves are shown in Figure 8. Ministry of Surface Transport gradation is widely used in India for asphalt concrete. Based on the evaluation conducted on the effect of aggregate gradation on the characteristic of asphalt mixes [26] recommended a gap gradation for improved performance of asphalt concrete. The beneficial influence of using Superpave gradation on the performance of asphalt mixes is widely knowledge. These three gradations were selected to investigate their influences on the performance of crumb rubber modified mixes.

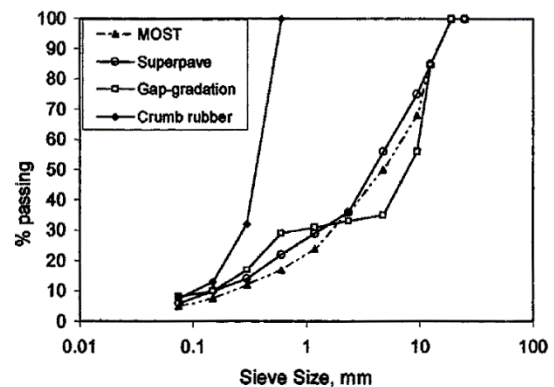


Figure 8 Gradations of aggregates and crumb rubber

9.5 Marshall Tests

Marshall tests were conducted on normal and modified mixes containing MOST aggregate gradation. The results are presented in Table 3. The stability values obtained for various crumb rubber (CR) concentrations are almost similar to those observed for mixtures containing normal binder. The 30CR10 binder yielded the highest Marshall stability value. Flow values increased marginally with CR content. Air voids content showed reducing trend with increasing CR concentration. Marshall results of various mixes donot give a clear indication of the relative performance.

Table 3 Marshall Characteristics at Optimum Binder Contents

Binder in the mix	Optimum binder content (%)	Marshall stability (kN)	Flow value (mm)	Bulk density (kg/m ³)	Air voids (%)	Retained stability (%)
80/100	5.35	11.74	3.09	2,420	2.69	63
30CR5	5.45	10.55	2.94	2,360	5.38	91
30CR10	5.56	12.70	3.80	2,410	3.48	95
30CR15	5.66	10.40	4.09	2,400	3.31	90

9.6 Stripping

The adhesion characteristic of normal and modified binders with aggregates were studied using static immersion test [27] and boiling test [28] Results are presented in Table 4. As can be seen from the table, mixes containing normal binder without modification showed 12% stripping in static immersion tests while the stripping was negligible for mixes prepared with modified binders. In boiling tests, modified mixes displayed 30– 50% lower stripping compared to normal mixes.

Table 4 Results of Moisture Susceptibility Tests

Binder used	Stripping test		Tensile strength ratio test		
	Percent stripping		Indirect tensile strength at 30°C (MPa)		Tensile strength ratio (%)
	Static immersion test	Boiling test	Unconditioned	Conditioned	
				at 60°C for 24 h	
80/100	12	44	0.539	0.426	72.7
30CR05	03	30	0.664	0.561	84.5
30CR10	00	25	0.745	0.711	95.5
30CR15	00	23	0.587	0.479	81.6

9.7 Aging Caharacteristics of Mixes

Field and laboratory and studies conducted in the past [29,30,31,32,33,34,35,36] showed that crumb rubber modified binders are less severely influence by oxidative aging compared to normal binders. Better retention of viscosity was observed in the case of rubber modified binders. Thin film oven test (TFOT) and Rolling thin film oven test (RTFOT) for short term aging were conducted on various types of binders to evaluate the impact of aging on modified binders developed in the present investigation. Retained penetration of the modified binders using crumb rubber ranged from 73.1 to 88.9% compared to a value of 65.5% observed for normal binder. Indian Roads Congress guidelines on modified binders [23] recommend a minimum value of 65%. The increment in the softening point of the binders after the thin film oven test (TFOT) test was in the range of 1–2°C, whereas for a normal binder the increase was 4°C. Indian Roads Congress specifies that the increase in softeningpoint of modified binders after TFOT should be less than 5°C.

10.0 RECOMMENDATION

It is recommended to conduct various studies to evaluate the performance of modification of bitumen with various different percentage of crumb rubber powder and investigate the optimum percent of crumb rubber replacement in bitumen content, so that it can be a resource in highway industry as well in using waste material to consume the resource.

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